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รายงานวิจัยฉบับสมบูรณ์

โครงการเทคโนโลยีการอบแห้ง

เล่มที่ 2

โดย สมชาติ โสภณรณฤทธิ์ และคณะ

กันยายน 2546

สัญญาเลขที่ RTA/12/2543

รายงานวิจัยฉบับสมบูรณ์

โครงการเทคโนโลยีการอบแห้ง

เล่มที่ 2

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สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

Solar and Wind Energy in Thailand

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Abstract

Application of renewable energy such as solar and wind should be promoted according to emission free of greenhouse gas. Advanced developing country like Thailand may have to limit the amount of greenhouse gas emission in the very near future.

Yearly average solar radiation in Thailand is approximately 17 MJ/m^2-day of which 50% is diffuse radiation with small variation of solar radiation during each season. Potential application of solar energy are water heating, water distillation, drying, direct energy conversion via photovoltaics aiming at the application on lighting, battery charging, water pumping, telecommunication, etc.

Solar water heating has been commercialized for more than 25 years, mostly used in houses and isolated hotels and resorts. Drying and distillation have not been used widely due to high investment cost.

Electricity generation by photovoltaics is approximately five times compared to conventional thermal power plant. Therefore, the application is limited to isolated area. Up to present, there are about 6 MW of photovoltaics installed in Thailand, mostly for lighting, battery charging, water pumping and telecommunication. In the future, supplemented electricity generation via photovoltaic system may be widely accepted if cost is significantly reduced.

Average wind velocity is relatively low in Thailand. Therefore, it is not much interested in generating electricity by windmill with the present technology, except in some areas where wind velocity is high enough. However, windmill is appropriate for water pumping and its application is extensive in some areas of rice cultivation and salt production in Thailand.

Introduction

According to greenhouse gas problem, solar and wind, some forms of renewable energy, are gaining interest and potential for the development of society and economic. Thailand is situated near the equator with hot and humid climate. Yearly average solar radiation is approximately 17 MJ/m^2-day of which 50% is diffuse radiation with low variation of solar radiation during each season. Due to high fraction of diffuse radiation, concentrating solar collector is not very appropriate. Wind energy has no great potential in Thailand due to low wind speed, 6-11 km/h including calm period and 9-15 km/h excluding calm period. There are some areas such as coastal and mountain areas that may have higher wind speed. (NRCT, 1997 a)

Utilization of solar energy may be divided into two forms as follows:

1. Thermal application

Potential for thermal applications of solar energy are such as water heating at low (<100°C) and medium (100-300°C) temperatures, drying, distillation, generation of electricity or mechanical work, refrigeration, etc. (NRCT, 1997b).

2. Direct conversion of solar radiation into electricity by photovoltaics

At present, production capacity of photovoltaics all over the world is higher than 100 MW per year (NRCT, 1997c). Mostly is produced in the forms of single crystal and polycrystal of silicon. Some are in amorphous form. There are extensive works of research and development on multi-junction, thin-film and other semiconductor materials for improving efficiency.

Utilization of wind energy can be divided into three forms: 1) for water pumping with low head (<2m) and medium head, 2) for electricity generation and 3) for air ventilation via the top of the roof of building (NRCT, 1997d).

Utilization of solar and wind energy with some applications is now widely practiced in some countries. Examples are as follows:

- Solar water heating for domestic use, large building such as hotel and hospital.
- Solar drying of agricultural products.
- Solar water distillation for isolated areas.
- Photovoltaics for telecommunication and isolated villages.
- Windmill for electricity generation in windy areas.

Status of Solar and Wind Energy in Thailand

1. Database

Database for solar and wind energy available in Thailand is relatively good. Solar map was produced three times, in 1976, 1984 and 1999. However, this information is mostly limited to global solar radiation. For wind energy, wind map was produced in 1984 using data during the years 1966-1972. Presentation includes wind speed including and excluding calm periods.

2. Solar thermal processes

Solar water heater is relatively popular in some countries such as Australia, China, Greece, Israel, etc. Though it has been commercializing in Thailand for more than 25 years, the number of utilization is still limited. This is due to high initial cost and low quality of fabrication and services of some companies. Application of solar water heating in industry has not been accepted yet due to high initial cost compared to conventional fuel used in industry.

There have been several projects of research, development and demonstration on drying of agricultural products for small and medium scale industries as well as for agricultural group. With the financial support for the first investment, solar dryers especially for drying fruit and vegetable with high value added are now limited acceptance. However, true commercialization of solar dryer has not yet existed in Thailand.

The research and development works on water distillation, steam generation, refrigeration, water pumping and natural air ventilation in building have been available, but these technologies have not yet been accepted or commercialized.

3. Photovoltaics

Electricity generation by photovoltaics is approximately five times compared to conventional thermal power plant. Therefore, the application is limited to isolated area. Up to present, there are about 6 MW of photovoltaics installed in Thailand of which 85% belong to government agency, 1% belong to university and 14% belong to private sector. Most of the applications are for lighting, battery charging, water pumping and telecommunication.

There are three factories in collaboration with foreign companies that fabricate photovoltaics in Thailand. The factories import most of the parts and just fabricate locally. Total production capacity is 3 MW per year.

In Thailand, there are research and development works on production of single crystal and polycrystal of silicon as well as on the application of solar cell for lighting, battery charging, water pumping and telecommunication.

In the future, supplemented electricity generation via photovoltaic system may be well accepted if cost is significantly reduced, perhaps in the time frame of 25 years.

4. Wind energy

Application of windmill for water pumping is extensive in some areas of rice cultivation and salt production in Thailand. Elevation head is normally less than 2 m. Some application for water pumping with medium head is in limited practice. Several units of windmill connected to grid for generating electricity were installed by Electricity Generation Authority of Thailand. Total capacity is 192 kW. (DEDP, 1998) Application of windmill for air ventilation from shed and building is relatively popular.

Average wind velocity is relatively low in Thailand. Therefore, it is not much interested in generating electricity by windmill with the present technology, except in some areas where wind velocity is high enough.

5. Electricity generation by renewable energy

In 1998, total production capacity of electricity generation system is 14300.9 MW while installed capacity is 18423.4 MW. The productiòn capacity is 4.2% less compared to that of the year 1997. Total production of electrical energy in 1998 is 90068.9 million kW/h which is 3.4% less compared to the year 1997. It is noticed that the installed capacity from power plants of geothermal, solar and wind energy is 1.1 MW and produced electrical energy of 1.8 million kW.h in 1998.

Recommendation for Research, Development and Demonstration

1. Policy recommendation

- To support research, development and demonstration on solar and wind energy with close collaboration with private sector, aiming at producing prototype and processes that have good potential for commercialization or for upgrading quality of life.
- To support establishing standard for solar equipment and solar energy test center.
- To promote government agency, private sector and people to understand the benefit of using renewable energy, based on the concept of sustainable development of society and economic, reduction of environmental pollution and greenhouse gas from using fossil fuel, and saving of foreign currency from importing fossil fuel.

2. Suggested projects on research, development and demonstration

Projects on research, development and demonstration of solar and wind energy should be in close collaboration with private sector if possible. Examples of recommended projects are as follows:

- To support research and development on photovoltaics such as silicon extraction and production of materials for photovoltaic industry. Care should be given to the pollution from production processes.
- To support research and development on photovoltaic system such as battery, AC/DC converter.
- To support research, development and demonstration on the utilization of photovoltaic system such as battery charging and lighting in isolated villages; and electricity generation by photovoltaics with grid connected roof top (limited numbers).
- To support establishing standard test center for solar equipment based on the concept of consortium from several agencies.
- To support development of solar water heater in order to upgrade product quality of local company.
- To support development and demonstration on solar drying of agricultural products with high value added.
- To support establishing standard for solar equipment.
- To support policy research on renewable energy.
- To promote educating people to understand benefit from using renewable energy.

3. Possible collaboration with GMS countries

Several recommended projects as mentioned above could be in collaboration with GMS countries. In addition, some projects below could be effectively proceeded in a short time.

- Higher education for master's and doctoral degrees in the fields of energy and environment related to energy issue. Examples of academic institutes that have international programs and may be interested in collaboration with GMS countries are as follows:

    1. Joint Graduate School on Energy and Environment, King Mongkut's University of Technology Thonburi.
    2. Sirindhorn International Institute of Technology.
    3. Solar Energy Research and Training Center, Naresuan University.

- Extension on solar map for GMS countries.

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Continuous Drying of Paddy in Two-Dimensional Spouted Bed

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[Key Words] Dehydration, Grain, Spouting

Abstract
An industrial–scale prototype of spouted bed paddy dryer with a capacity of around 3500 kg/h was constructed and tested. The prototype was shown to be a desirable feature of spouted bed as well as capability of continuous drying and offering consistent results through the testing period. At early phase of experiments, feed rate and energy consumption were undesirable. To overcome these problems, a high pressure blower was used. Experimental results showed that the prototype performed well on moisture reduction and milling quality. However, in the experiments, difficulties were experienced in achieving high moisture reduction while high feed rates were maintained. This is due to the insufficient residence time that increased with the increase in drying chamber length. The high temperatures up to 130-160°C were applied to dry paddy from various initial moisture contents to the range of 14-25% dry basis without significant quality changing. Thermal energy consumption, which in range of 3.1-3.8 MJ/kg water, is comparable with commercial dryers. The effect on milling quality while paddy moisture is further reduced to 16-18% dry basis should be studied.

1. Introduction

The combination of two distinct hydrodynamic categories, a pneumatic transport in the spout which allows intensive heating and moisture evaporation and a falling bed in the downcomer which processes tempering of particles, is the main feature of the spouted bed. To overcome the limitations of conventional cylindrical-conical spouted bed, Mujumdar (1984) proposed the two-dimensional spouted bed which the scaling – up can be achieved.

Kalwar *et al.* (1991), Kalwar and Raghavan (1993 a and b) studied drying of grains in two – dimensional spouted bed with draft plates using soybean, wheat, corn and shelled corn. It was found that thin layer drying of grains yielded to Page's equation was in very well agreement with observation data, and two constant parameters of equation correlated with bed geometry and operating parameters. The circulation of particles strongly depended on the entrance height, spout width and slant angle. It was also illustrated that the drying rate was significantly influenced by grain circulation rate.

The effect of bed height on drying rate was also reported by Tulasidas *et al.* (1993). The results indicated that the MR and the apparent diffusion coefficient increased with the decrease in bed height. A linear equation was also found to be suitable to describe the drying kinetic of paddy and two parameters of this equation were related to hold-up and drying temperature as reported by Wetchacama *et al.* (1999). The milling of paddy in terms of head rice yield and drying characteristics were investigated by Nguyen *et al.* (1998 a and b). A triangular spouted bed was proposed in their experiments. The result of head rice yield was satisfactory as long as the moisture content was above 17.6% dry basis regardless of using high temperature up to 160°C. Thermal energy consumption in a rice mill which used diesel oil as fuel to heat drying air was reported by Meeso *et al.* (1993) and was found to be 2.56 and 5.82 MJ/kg water evaporated for first and second stages of drying, respectively.

Although extensive research has already been done on the spouted bed technique, the past effort has focussed on laboratory scale spouted bed dryer with particular emphasis on batch drying of agricultural food product. However, none of these works is introduced to the grain drying industry. In order to serve the commercial rice mill which continuous paddy drying is favorable, there is a need to enhance the capacity of spouted bed dryer.

The objectives of this research are therefore to design and construct an industrial–scale prototype of continuous spouted bed paddy dryer, and then test in a rice mill.

2. Materials and Methods

Drying studies were conducted in an industrial-scale prototype of spouted bed paddy dryer with a capacity of 3500 kg/h as shown in Figs. 1 and 2. The dryer consists of a vertical rectangular chamber 0.6 m in width, 1.45 m in height and 2.1 m in length. Front and both side walls of the drying chamber were made of glass to visualize the grain flow patterns. The slanting base plates were inclined at 60 degrees. The air entrance width is 0.04 m. The draft plates with 0.62 m in height are centrally installed to accommodate a spout width of 0.06 m at early phase of experiments and 0.82 m in height for final phase of experiments. The entrance height was held at 0.10 m, 0.125 m and 0.15 m, respectively. The air was heated by a diesel oil burner. Paddy was continuously fed into the hopper by an elevator before being automatically fed to the drying chamber. With sufficient air velocity, the paddy traveled upward and forward through the draft channel before raining back onto the downcomers. The hot air leaving the chamber was discharged into a cyclone and some portion of it was recirculated to the combustion chamber. The air recirculation ratio was in the range of 60-70%. Air and paddy temperatures were measured by K-type thermocouples connected to a data logger with an accuracy ±1°C and a thermometer, respectively. The pressure across the bed and air velocity were determined by a U-tube manometer and a hot air anemometer with and an accuracy ±4%, respectively. The samples were taken for measuring moisture content, head rice yield and whiteness at ten minute intervals for periods of 90 minutes. Moisture contents were determined by a hot air oven at temperature of 103°C for 72 hours. Head rice yield was determined according to the method of the Rice Research Institute and the whiteness was measured by Kett meter.

3. Results and Discussion

3.1 Paddy Motion in Spout and Bed Shape

The proper air distribution at the entrance allowed uniform flow of paddy through 2.1 m length of the drying chamber. At early phase of experiments, the spouting was observed intermittent occurrence. It took 1-2 seconds after sending the paddy through the draft plate in order to build up pressure before starting the next pass. This could be attributed to the improper fan performance, and resulted in low bed pressure drop (1225 Pa) and low inlet air velocity (10 m/s). To overcome this drawback, an existing blower was replaced with a high pressure blower at final phase of experiments.

3.2 Drying Efficiency and Milling Quality

The fifteen experiments were carried out. The results of some experiments of early and final phases were summarized as in Tables 1. To observe how the dryer performed in terms of moisture content reduction, milling quality and energy usage, feed rate of paddy and the inlet air temperature had been varied from one experiment to another.

3.2.1 Moisture Content

Cycle time strongly effects the moisture distribution throughout the paddy in the downcomer and number of turns of paddy flowing through the draft channel. This allows for consequent partial tempering in the downcomer and heating and moisture removal in the draft channel. However, it was impractical to record cycle time in these experiments. Thus for studying the drying kinetics, it was convenient to define the mean residence time in the dryer (t_m) by the equation:

(1)

Due to insufficient of airflow rate during the early phase of experiments, paddy feed rates were limited to not exceeding 1000 kg/h. The results showed that the prototype performed well on the reduction of paddy moisture. The paddy was dried from the range of 20.0-30.3% dry basis to 14.4-21.5% dry basis, and the mean residence time lied between 9-17 minutes as shown in Table 1. At the final phase of experiment, the prototype achieved to handle maximum capacity of around 3500 kg/h after replacing an existing blower. However, the results as shown in Table 1 illustrated that the main difficulty arised was obtaining high moisture reduction while feed rate over 3000 kg/h was required. Since the mean residence time was relatively short, i.e. in range of 5-6 minutes, while beds were deeper, grains were less frequently drawn through the draft channel. The paddy was dried from the range of 21.7-29.4% dry basis to 17.1-25.0% dry basis during final phase. The final moisture content appeared to be consistent through an operating period.

The question of how to reach high moisture reduction, i.e. 30% dry basis down to the range of 16-18% dry basis, is therefore of considerable practical interest. To achieve a desirable moisture reduction, drying chamber should be extended somewhat that allows sufficient residence time. If cycle time is long enough to redistribute moisture in the grain, the drying kinetics could account the moisture relaxation during tempering in downcomer. This effect was in according with what was studied in lab-scale two dimensional spouted bed dryer reported by Wetchacama *et al.* (1999). This allowed for consequent linear decrease in moisture content versus drying time. Therefore, under similar bed configurations and operating conditions of temperature and airflow of lab-scale spouted bed dryer against the prototype, it is reasonable to estimate the drying chamber length corresponding to a desirable moisture reduction by extrapolation the result of experiments. For example in test no. 13, the mean residence time as well as drying chamber should be increased about 3 times to dry 3160 kg/h of paddy from 29.4% dry basis to the range of 16-18% dry basis.

3.2.2 Milling Quality

As seen in Tables 1, it was clear that the drying process did not affect the quality in terms of head rice yield and whiteness. There was no significant reduction in head rice yield while the paddy was dried continually from various initial moisture contents until the moisture content reduced to around 14-25% dry basis regardless of using high inlet air temperature up to 144-160°C. This was simply explained that the moisture was somewhat redistributed throughout the grain kernel during partial tempering process in the downcomer, and resulted in less stress occurring between the inner part and outer surface when passing through the spout channel. A satisfactory whiteness result could be influenced by a very short period in the spout region. Result of test no. 5 indicated that it is able to dry paddy from around 30% dry basis to around 21% dry basis without quality changing. A similar trend could be expected for high feed rate, i.e. more than 3000 kg/h, if the cycle time is slightly deviated and residence time is sufficient.

3.2.3 Energy Consumption

Table 1 also lists the energy consumption. Thermal energy consumption of early phase was relatively high, i.e. in range of 5.6-7.7 MJ/kg water, thus arised from poor paddy circulation. However, after using a high pressure blower, the thermal energy efficiency was much improved. It reached to 3.1-3.8 MJ/kg water while paddy was fed in range of 3100-3500 kg/h. It is probably due to shorter cycle time thus the contribution of the residence time between draft plates where intense heat and mass transfer occur in the total circulation time is relatively higher. Energy consumption of the prototype was comparable with commercial dryers operated in rice mills as reported by Meeso *et al.* (1999).

4. Conclusions

The prototype achieves to complete the main feature of spouted bed. It is able to continuously dry of around 3500 kg/h, and the results of moisture reduction and milling quality appear to be consistent throughout the testing periods. With assisting of tempering process in downcomer, the drying kinetics in the spout performed well, and resulted in satisfactory moisture reduction. However, with limitation of an exiting drying chamber length, high percentage of moisture reduction with high paddy feed rate could not achieve unless extending the drying chamber. No significant changes in head rice yield and whiteness were observed during the experiments. The energy consumption is efficient compared to those of commercial dryers.

5. Recommendations

The experiment should be further conducted to study paddy quality when paddy of high moisture content, i.e. 30% dry basis, is continually dried to 16-18% dry basis by extending the length of drying chamber.

6. Acknowledgments

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Table 1 Summary of some experimental results of early and final phases.

Description	Test no.							
	Early phase			Final phase				
	2[a]	3[a]	5[a]	11[b]	12[b]	13[b]	14[b]	15[c]
Feed rate (kg/h)	1000	900	664	2370	2400	3160	3280	3550
Hold-up (kg)	210	135	190	240	210	335	290	310
Residence time (minutes)	12.6	9.0	17.2	6.0	5.3	6.4	5.3	5.2
Average inlet air temp. (°C)	144	144	146	152	159	154	156	160
Exit grain temp.(°C)	71	69	72	71	68	67	67	68
Average moisture content								
BFD (% dry basis)	20.0	23.2	30.3	22.1	25.0	29.4	28.2	22.8
AFD (% dry basis)	14.4	17.8	21.3	17.1	19.7	25.0	23.3	19.0
Head rice yield								
BFD (%)	34.2	45.6	48.2	49.0	49.6	50.1	54.3	41.2
AFD (%)	33.4	42.7	48.0	47.4	48.4	52.4	55.0	40.8
Whiteness								
BFD	47.6	50.2	45.9	47.6	47.6	47.8	46.4	46.7
AFD	47.5	51.1	46.7	46.8	46.7	47.5	46.3	45.9
Drying rate (kg water/h)	49	41	49	101	106	111	130	101
Energy consumption (MJ/kg water evaporated)								
Heat	6.7	7.0	5.6	4.4	5.2	3.5	3.8	3.1
Electricity	0.76	0.91	0.74	0.50	0.50	0.46	0.40	0.46

AFD = after drying   a) entrance height 10 cm
BFD = before drying   b) entrance height 12.5 cm
Temp. = temperature   c) entrance height 15 cm

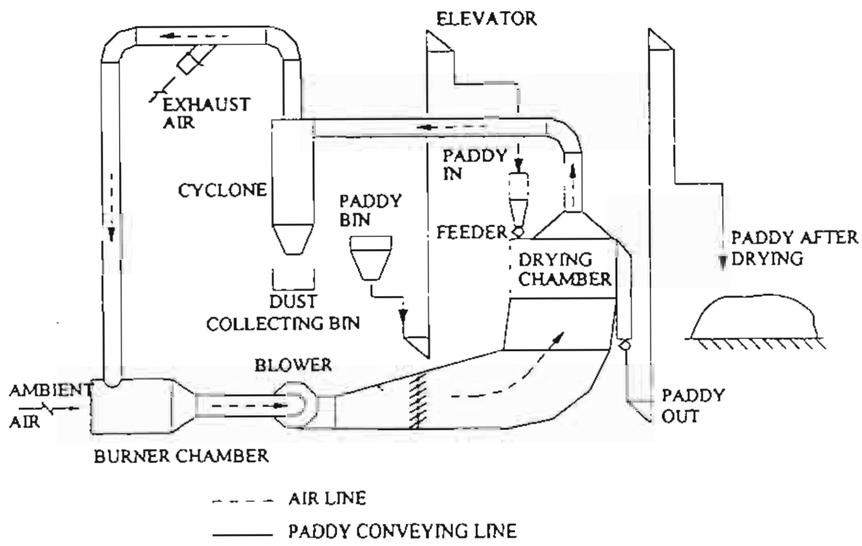

Figure 1 Schematic diagram of continuous spouted bed dryer.

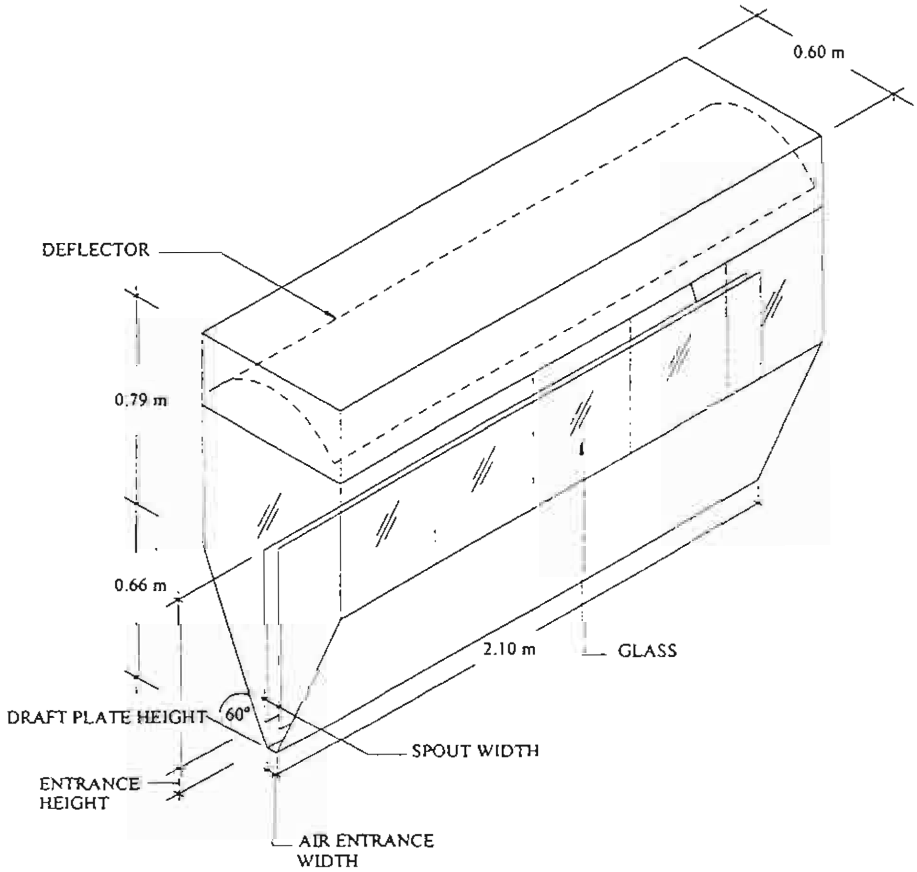

Figure 2 Dimensions of the drying chamber of continuous spouted bed dryer.

Diffusion Models of Paddy Drying by Fluidization Technique

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Keywords and phrases: diffusion coefficient, fluidized bed, grain, modeling

Abstract
The objective of this research was to develop diffusion models of paddy drying by fluidization technique that consider the grain shape as a finite cylinder. The fluidized bed paddy drying normally operates with the drying air temperature over 130°C. Therefore, the diffusion models reported in this paper are valid for the temperature higher than those previously reported in the literatures. Effective diffusion coefficient using four different models in form of Arrhenius equation was studied. The parameters in the diffusion models were evaluated by regression analysis from the 286 experimental thin layer drying data. The result showed that the Arrhenius type equation could predict the effective diffusion coefficient of paddy drying by fluidization technique. The model that had the greatest accuracy was the one of which the Arrhenius factor was replaced as a function of moisture content in form of exponential relation of 2nd order polynomial.

1. Introduction

At present, paddy drying by fluidization technique is widely used in several countries. The advantages of this technique are as follows: rapid drying, small size dryer and uniform final moisture content. If the product quality in terms of head rice yield and whiteness is to be maintained, the fluidized bed dryer could not reduce grain moisture content down to safe storage level at 16.3% dry basis by a single drying pass. Several researchers [Steffe et al. (1978), Zhang and Litchfield (1991) and Soponronnarit et al. (1999)] suggested to temper the grain between each drying pass for improving drying performance and product quality.

Tempering times used in commercial rice drying vary widely. It is worth to know tempering time for different drying techniques and different drying conditions. Steffe and Singh (1980) simulated the multi-pass drying of rough rice that determined the effect of drying variables on tempering time and the effect of tempering on the following drying pass. The results showed that the drying air temperature was the main parameter, which affected tempering time. For the temperature between 35-55°C, tempering was 95% complete in less than 2 hours and fully complete in less than 5 hours. Sopornronnarit et al. (1999) introduced tempering and ambient air ventilation as the processes after fluidized-bed paddy drying. The maximum rate of moisture reduction during ambient air ventilation was obtained when tempering time was 15 minutes or longer. In addition, the quality in terms of head rice yield was improved as compared to that without tempering.

In the past, Soponronnarit and Prachayawarakorn (1994) and Soponronnarit et al. (1996) simulated the fluidized bed drying by using empirical drying kinetics equations as a part of drying model. The model predicted the average moisture contents of paddy fairly well. In the simulation of drying system that includes tempering between each drying pass, the moisture profile in the grain kernel at the end of each drying pass must be known. However, the moisture profile cannot be predicted with the empirical drying equation. It can be determined by using the theoretical drying equation of which the diffusion coefficient is included. The differential equation with boundary and initial conditions for a paddy considered as a finite cylinder can be written as follows:

$$\frac{\partial M}{\partial t} = D\left[\frac{\partial^2 M}{\partial r^2} + \left(\frac{1}{r}\right)\frac{\partial M}{\partial r} + \frac{\partial^2 M}{\partial z^2}\right] \tag{1}$$

$t = 0,\ 0 \le r \le r_o$ $\quad M = M_{in}$ and $-\ell \le z \le +\ell$ $\quad M = M_{in}$

$t > 0,\ r = r_o$ $\quad M = M_{eq}$ and $z = \pm\ell$ $\quad M = M_{eq}$

$t > 0,\ r = 0$ $\quad \dfrac{\partial M}{\partial r} = 0$

The analytical solution is expressed by the following equation:

$$\overline{MR} = \left(\frac{32}{\pi^2}\right)\sum_{n=1}^{\infty}\frac{1}{\lambda_n^2}\exp\left(\frac{-\lambda_n^2 Dt}{r^2}\right)\sum_{m=0}^{\infty}\frac{1}{(2m+1)^2}\exp\left(\frac{-(2m+1)^2\pi^2 Dt}{4\ell^2}\right) \tag{2}$$

where $$D = D'\exp\left(\frac{-E_a}{RT_{abs}}\right) \tag{3}$$

D' is Arrhenius factor and E_a is activated energy. D' may depend on drying air temperature and moisture content. For examples, Tong and Lund (1989) proposed the Arrhenius factor as a second degree polynomial function of moisture content. Brooker et al.(1992) proposed the Arrhenius factor as a function of moisture content and temperature.

The aim of this research was to develop diffusion models for paddy drying by fluidization technique at high temperature range ever reported in the literatures. The effective diffusion coefficients were determined by regression analysis from experimental data to the analytical solution of the diffusion equation.

2. Materials and Methods

2.1 Experimental Procedure

The experimental batch fluidized bed dryer comprises of a cylinder shaped drying chamber with dimension of 20 cm in diameter and 140 cm in height, a 12 kW electrical heater and a backward-curved-blade centrifugal fan driven by a 1.5 kW motor. Air temperature was controlled by a PID controller with an accuracy of $\pm 1^{o}C$. Air flow rate could be regulated by a mechanical variable speed unit.

Dry paddy was rewet, mixed and kept in a cold storage at the temperature of 3-5^{o}C for 5-7 days. Before starting the experiment, the paddy was kept in ambient air until grain temperature was close to ambient temperature. During the experiment, final moisture content and grain temperature were collected from 289 drying conditions. Paddy with three levels of moisture content (22.1, 24.6 and 29.2% dry basis) was dried at the drying air temperatures of 110, 120, 130, 140, 150, 160 and 170^{o}C with drying time of 0, 0.5, 1, 1.5, 2, 3, 5, 7.5 and 10 minutes. All drying conditions were performed at constant bed air velocity (2.2 m/s) and bed thickness (1.5 cm). Grain temperature, drying air temperature and ambient conditions were measured by type K thermocouple connected to a data logger with an accuracy of $\pm 1^{o}C$. The moisture contents of paddy were determined by using an air oven at temperature of 103^{o}C for 72 hours.

2.2 Development of moisture diffusion models

In this study, four different models as shown below were applied to estimate the effective diffusion coefficients.

Model 1 $$D = a\exp(\frac{-b}{T_{abs}}) \quad (4)$$

Model 2 $$D = (aM^2 + bM + c)\exp(\frac{-d}{T_{abs}}) \quad (5)$$

Model 3 $$D = a\exp(bM^2 + cM)\exp(\frac{-d}{T_{abs}}) \quad (6)$$

Model 4 $$D = a\exp(bM + cMT_{abs})\exp(\frac{-d}{T_{abs}}) \quad (7)$$

All selected models are based on the Arrhenius type equation. Model 1 has the effective diffusion coefficients that depends on drying air temperature only. In Models 2 and 3, the Arrhenius factors were modified as a 2nd order polynomial relation and exponential relation of 2nd order polynomial, respectively. In Model 4, the Arrhenius factor is a function of both the moisture content and drying air temperature. The constant values in each model were determined by regression analysis from the 286 experimental data to the substitution of diffusion models [Eqns(4)-(7)] into the analytical solution of thin layer drying equation [Eqn (2)].

3. Results and Diuscussion

Figure 1 shows the results of paddy dried in the fluidized bed dryer. Moisture content of the paddy rapidly decreased during the first 3 minutes. On the other hand, paddy temperature rapidly increased. Experiments with different initial moisture content also show similar results.

Table 1 shows the calculation of constant values in various models by using regression analysis. The first model has the lowest activated energy 3,434.8 kJ/mol and the fourth one has the highest activated energy of 4,268.0 kJ/mol. By comparing mean residual square value (MRS), the results show that Model 3 has highest accuracy. Figure 2 shows the predicted moisture ratio of various models by comparing with the experimental values. It was found that all models have great accuracy in every range of moisture ratio. However, Model 3 has the best accuracy due to lowest MRS and Model 2 is the second best. Figure 3 shows the comparison of simulation and experimental drying curves. It can be seen that the moisture ratios calculated by using Models 3 and 2 agree very well with the experimental values. The predicted values obtained from Models 1 and 4 are a little bit lower than the experimental values at the later drying period.

Figure 4 shows the calculation of effective diffusion coefficients from different models. It was found that the effective diffusion coefficient of Model 4 is positively correlated with the moisture content. The effective diffusion coefficients of Models 2 and 3 increase with the moisture content in the first period and then the effective diffusion coefficients decrease. During the early period of drying, the effective diffusion coefficient increases due to the rapidly increases of grain temperature until it reaches a peak, and then the decrease of effective moisture content is due to the decrease of moisture gradient between the grain and the surroundings. The moisture diffusion coefficient calculated from Model 1 does not vary with the moisture content and is in range of that obtained from other models.

Diffusion coefficient increases with temperature. Tempering paddy at high temperature requires shorter time as compared to the case of low temperature. Consequently, the capacity of the tempering bin can be significantly reduced. It is recommended to study further in detail.

4. Conclusion

From the experimental result, it can be concluded as follows:

1. The Arrhenius type equation is able to predict the moisture diffusion coefficient for high temperature paddy drying by fluidization technique.
2. The Arrhenius factor expressed as a function of moisture content in form of exponential relation of 2^{nd} order polynomial is the most accurate.

5. Nomenclatures

a, b, c, d	Constant
D	Effective diffusion coefficient, mm^2/minute
D'	Arrhenius factor
E_a	Activated energy, kJ/mol
ℓ	Height of the cylinder, mm
M	Moisture content, % dry-basis
MR	Moisture ratio, decimal
R	Universal gas constant, kJ/mol-K
r	Radius of the cylinder, mm
T	Temperature, K
t	Drying time, minute
z	Height of the cylinder, mm
λ_n	Root of the Bessel function of the first kind of order zero

Subscripts

abs	Absolute
eq	Equilibrium
in	Initial
o	Outside

6. Acknowledgment

The authors would like to express their sincere thanks to the Thailand Research Fund for financial support.

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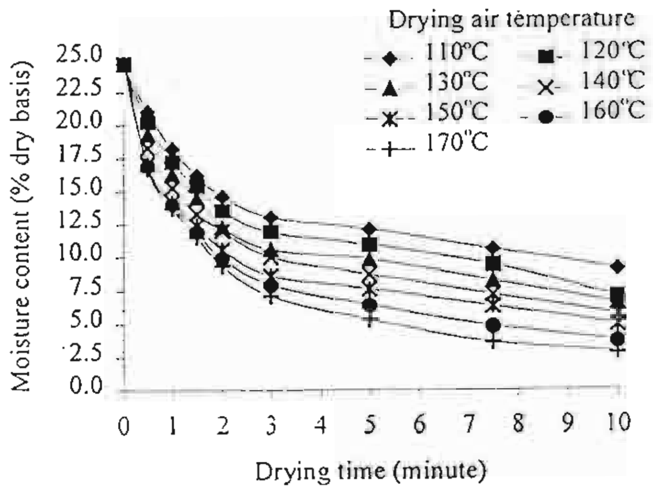
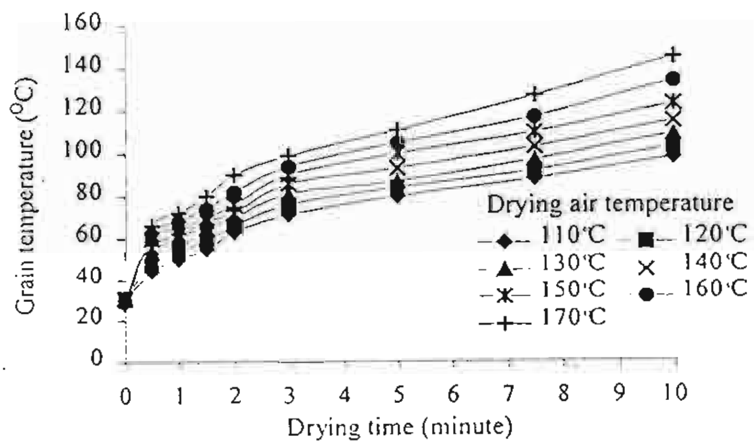
Table 1 Diffusion models of paddy drying by fluidization technique.

Model	Diffusion coefficient equation	MRS*
1	$D = 121.76 \exp(-3433.8/T_{abs})$	0.001758
2	$D = (97.958+1987.2M-7203.3M^2) \exp(-3681.6/T_{abs})$	0.001438
3	$D = 119.75 \exp(10.815M-39.161M^2) \exp(-3705.9/T_{abs})$	0.001396
4	$D = 755.10 \exp(16.356M-0.035742MT_{abs}) \exp(-4268.0/T_{abs})$	0.001528

*MRS = Mean residual square = $\dfrac{\sum_{i=1}^{N}(MR_{predicted,i} - MR_{observed,i})^2}{N}$



a) Evolution of moisture content



b) Evolution of grain temperature

Figure 1 Evolution of paddy moisture content and grain temperature at different drying air temperatures. (Initial moisture content of 24.6% dry basis)

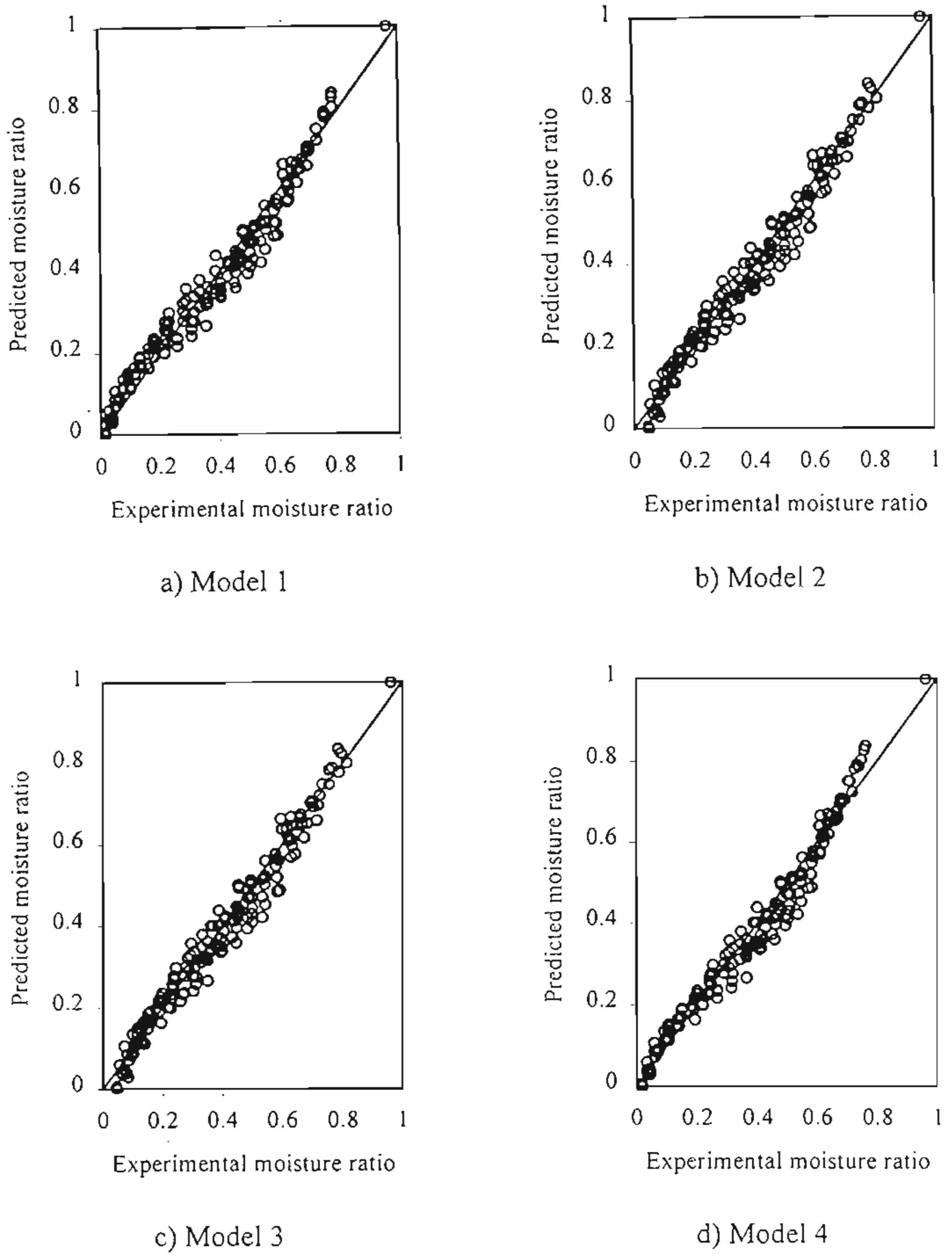


Figure 2 Comparison between predicted values and experimental values of moisture ratio using various models.

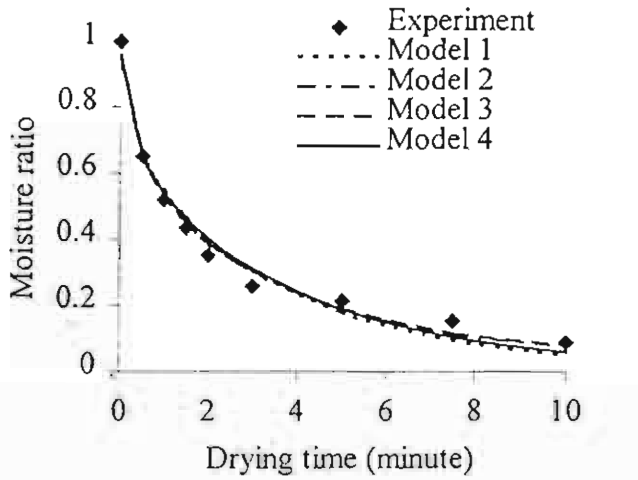


Figure 3 Evolution of moisture ratio using various models with experimental data at drying air temperature of 150^{O}C and initial moisture content of 24.6% dry basis.

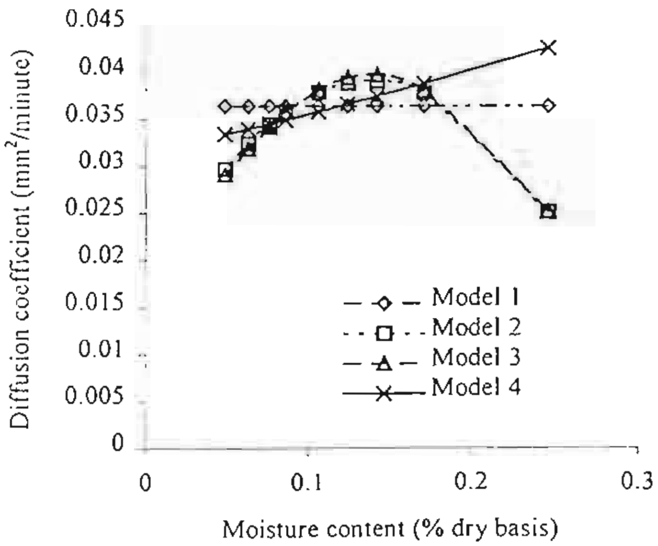


Figure 4 Diffusion coefficient calculated by various models at drying air temperature of 150^{O}C and initial moisture content of 24.6% dry basis.

Heat Pump Fruit Dryer for Small-Scale Industry

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Abstract

In this paper, the design, construction and performance evaluation of a closed-loop operation of heat pump dryer for small-scale industry was conducted. The dryer chamber, with designed capacity of 100 kg of fruit per batch, can accommodate a mobile cabinet with 12 tiers. According to the drying load, a heat pump having 1.3 kW compressor and using R-22 refrigerant was installed with the dryer. To determine the performance of heat pump dryer, pineapples banana, bean sprout and cabbage were dried at maximum controlled temperature of 55^{O}C with the air flow rate of 0.54 m^3/s, of which bypass air ratio was fixed at 78%. It was found that the maximum loading capacity was 98 kg. The good performance of dryer was indicated when the drying load was approached to the full capacity. The maximum drying rate, SMER and COP_{hp} were 1.95 kg water evap./h, 1 kg water evap./kWh and 4.99, respectively. For the specific energy consumption, the minimum value was 3 62 MJ/kg According to the low operating temperature. the color of products was good. The drying unit cost estimation was also carried out.

Keywords : Dehydration, fruit, heat pump

Introduction

Variety of fruits is produced in Thailand Some of these fruits are consumed as fresh fruit, while the other are modified for increasing the value added and preservation such as dried, canned and frozen fruits etc. Drying is a popular method for modification and preservation because the process is relatively simple. Dried fruit is not only supplied for domestic market but also can be exported. From the statistical data of Department of Thai Agriculture Extensions [1], the value of exported dried fruit are continuously increased from 14,355 metric tons or 328.5 million baht in 1995 to 55,320 metric tons or 2,389 million baht in 1997. Drying is an energy intensive process. Product quality could be degraded during operation. Thus to increase the benefit of the dried fruit production, an energy efficient dryer with better product quality should be applied for fruit drying. Heat pump dryer is known as an energy efficient drying equipment by recovering the heat from the drying air. The application of heat pump dryer of some selected fruit products was studied by Chou et al.[2] and Prasertsan et al. [3]. In common, they summarized that heat pump dryer were economically feasible. Soponronnarit et al. [4] observed that the heat pump fruit dryer offered better product quality. The optimum temperature for food drying from which the good quality can be obtained is 60°C [5]. The maximum achievable drying air temperature of heat pump dryer without auxiliary heater depends on refrigerant type For the refrigerant R22 which is approximately 57°C [6]. There are several operation modes for the heat pump dryer such as drying with the fully or partially open loop modes, of which the performance is affected by the ambient condition [7]; and the closed-loop mode of which the performance is not affected by ambient condition. In this study, the heat pump fruit dryer for small-scale industry was designed and constructed as closed-loop operation in order to minimize the effect of ambient conditions, which is dependent on the location The dryer performance was tested by using pineapple and banana. Besides fruits drying, some vegetables -bean sprout and cabbage - were also tested. The drying unit cost estimation was also carried out.

Materials and Methods

Based on the average operated conditions of the research studies on heat pump fruit dryer for closed-loop operation [4,8], the heat pump fruit dryer with closed loop operation was designed and constructed for the capacity of 100 kg fruits per batch as shown in Figure 1. The dryer consists of a 85x115x75 cm^3 drying chamber, a mobile cabinet with 12 tries, a 1.3 kW rotary compressor, 3 7 kW evaporator, 4 6 kW internal condenser, 2.2 kW external condenser and 0.75 kW fan. The refrigerant used in this heat pump was R22. The maximum operating temperature of drying air was controlled at 55°C. When the drying air is higher than the controlled temperature, the solenoid valve is opened to bypass the refrigerant to external condenser. The excess heat supply to drying chamber, therefore, can be avoided. To balance between evaporator heat load and the amount of condensed moisture from the chamber outlet air, the bypass air ratio was set at 78% and the air flow rate of 0.54 m^3/s was fixed for all experiments.

The pressure and temperature of refrigerant, drying air temperature, weight of product, electricity consumption and drying time were measured for dryer performance evaluation. Figure 2 shows the position for pressure and temperature measurement of refrigerant and drying air. Two types of fruits and vegetables - fresh pineapple, banana, bean sprout and cabbage - were used for drying test. Each raw material was prepared as follows: (a) fresh pineapple was cut into small circular segment of 1 cm thickness, (b) cabbage was cut into small square pieces approximately 25 mm wide, (c) ripe banana fruit and bean sprout were dipped in sodium meta-bisulfite solution for anti-darkening effect. The color of product after drying was checked with R.H.S. color chart. For pineapple drying, loading capacity was varied from 44 to 90 kg. For banana fruit drying, the drying period was divided into two stages. The banana fruit was dried for 20 hours in the first stage, then it was tempered for 10 hours and followed by second stage drying unit it was dried.

Results and Discussion

Drying air distribution is well performed in the drying chamber. At the beginning of drying period, the small temperature difference between the inlet and outlet air of the tiers and between the top and bottom tray were 3°C - 8°C and 2 °C - 4 °C, respectively. These temperature differences decreased with operating time, and were nearly zeroed at the end of drying period The performance indicators of dryer were evaluated in terms of the specific moisture extraction rate (SMER) in unit of kg/kWh and the specific energy consumption (SEC). To investigate the energy efficiency of the heat pump, the coefficient of performance (COP_{hp}) was evaluated. All the results of each experiment were concluded in Table 1. It was found that the maximum loading capacity was 98 2 kg The good performance of dryer was indicated when the drying load was approached to full capacity. The maximum drying rate, SMER and COP_{hp} were 1.95 kg water evap./h, 1 kg water evap./kWh and 4.99, respectively. For the specific energy consumption, the minimum value was 3.62 MJ/kg water evap. Useful heat from the heat pump was 73-89%.

According to the low operating temperature, the change in product color drying was small, especially for dried banana. Based on the dryer investment cost of 64,800 baht with 5 year life time and average electricity cost of 3.16 baht/kWh, it was found that the total unit cost was ranging from 6.94 -9.33 baht/kg water evap. which comprised of 60.5-67.8% electricity cost, 32 % capital cost, and 6.1% maintenance cost

Conclusions

The heat pump fruit dryer for small-scale industry with closed-loop operation was designed and constructed. Fresh pineapple, ripe banana fruit, bean sprout, and cabbage were used as samples for dryer performance test The maximum product loading was nearly 100 kg At loading approached to full capacity, the dryer showed good performance. For the quality study, only product color after drying was checked and the change was found to be relatively small According to good distribution of drying air, the product quality was uniform. The total unit cost of drying was estimated, and the electricity cost is the main cost of operation. The useful heat obtained from heat pump was in the range of 73% to 89% of the total condenser heat load

Acknowledgement

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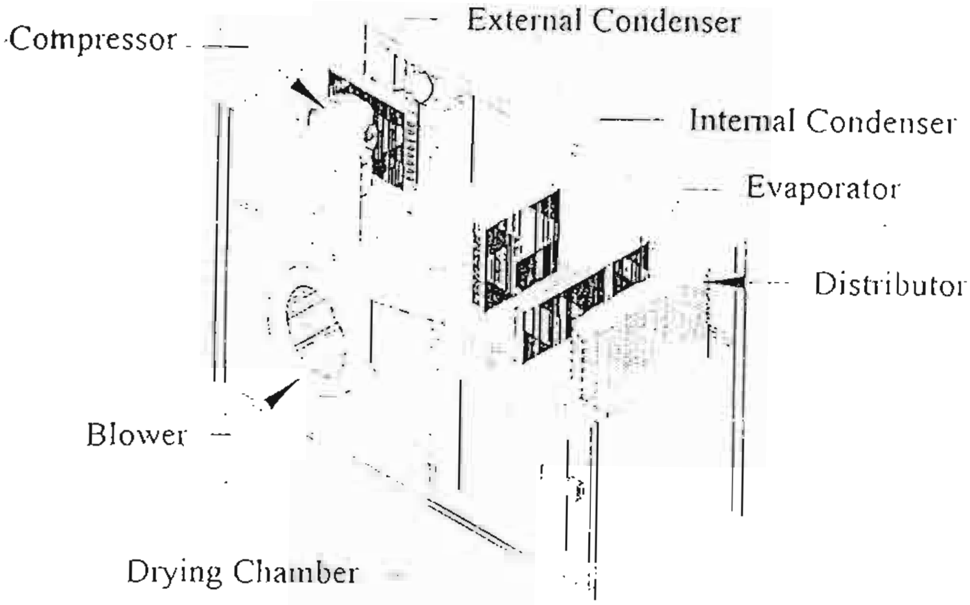

Figure 1 Heat pump fruit dryer.

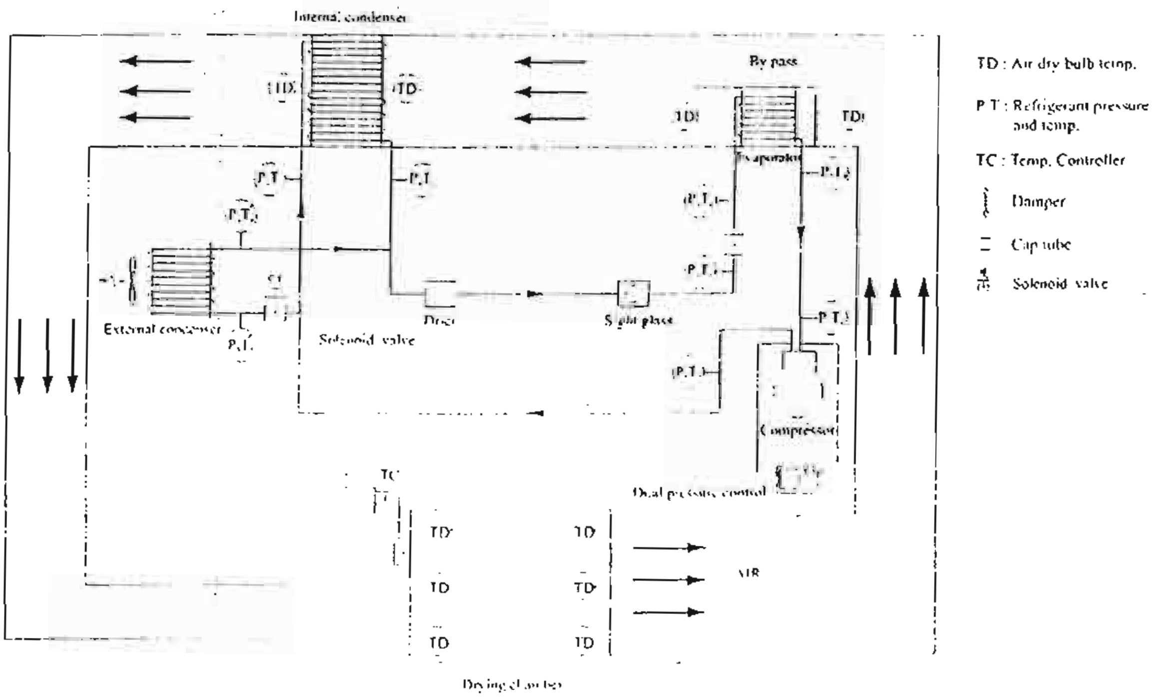

Figure 2 The locations for pressure and temperature measurements during performance test of heat pump dryer.

Table 1 Summary of experimental drying results.

Descriptions	Test Nos.								
	1	2	3	4	5	6	7	8	
								1st	2nd
Condition of product									
Product	pineapple	pineapple	pineapple	pineapple	pineapple	bean sprout	cabbage	Banana fruit	Banana fruit
Average moisture before drying (%d.b.)	694	767	675	722	640	1872	1590	287	186
Average moisture after drying (%d.b.)	18.6	19.0	17.3	18.4	18.5	16.8	17.6	133	57.8
Initial weight (kg)	44.4	66.0	72	78	90	24.6	21.32	98.2	59.5
Final weight (kg)	7.2	11.6	10.80	10.62	13.10	1.50	1.5	59.3	39.25
Moisture removed (kg)	37.20	54.40	61.20	67.38	76.90	23.10	19.82	38.9	20.25
Drying air conditions									
Average temperature (°C)	55	51	53	52	49	45	55	52	55
Evaporator by-pass air (%)	78	78	78	78	78	78	78	78	78
Air flow rate (kg/h)	1939	1939	1939	1939	1939	1939	1939	1939	1939
Average input work compressor(kW)	1.44	1.38	1.41	1.39	1.32	1.22	1.44	1.39	1.42
Energy consumption (kWh)	77.40	86.50	93	95.7	102.4	37.3	39.7	39.1	69
Drying time (h)	40	45	48	49	55	21	20	20	35
Performance of heat pump dryer									
Drying rate$_{avg}$ (kg water evap. / h)	0.93	1.21	1.28	1.38	1.40	1.10	0.99	1.95	0.58
MER $_{avg}$ (kg water cond. / h)	0.75	0.97	0.99	1.05	0.94	0.87	0.71	1.41	0.42
SMER$_{avg}$ (kg water evap / kWh)	0.481	0.629	0.658	0.704	0.751	0.619	0.499	0.995	0.293
SEC$_{avg}$ (MJ / kg water evap)	7.49	5.72	5.47	5.11	4.79	5.81	7.21	3.62	12.27
COP$_{hp}$	4.83	4.61	4.71	4.70	4.92	4.67	4.99	4.53	4.53
*$Q_{C,in}/Q_{C,overall}$	0.79	0.81	0.73	0.81	0.77	0.83	0.76	0.89	0.74

Note: * $Q_{C,in}/Q_{C,overall}$ means the ratio of internal condenser heat load to overall condenser heat load

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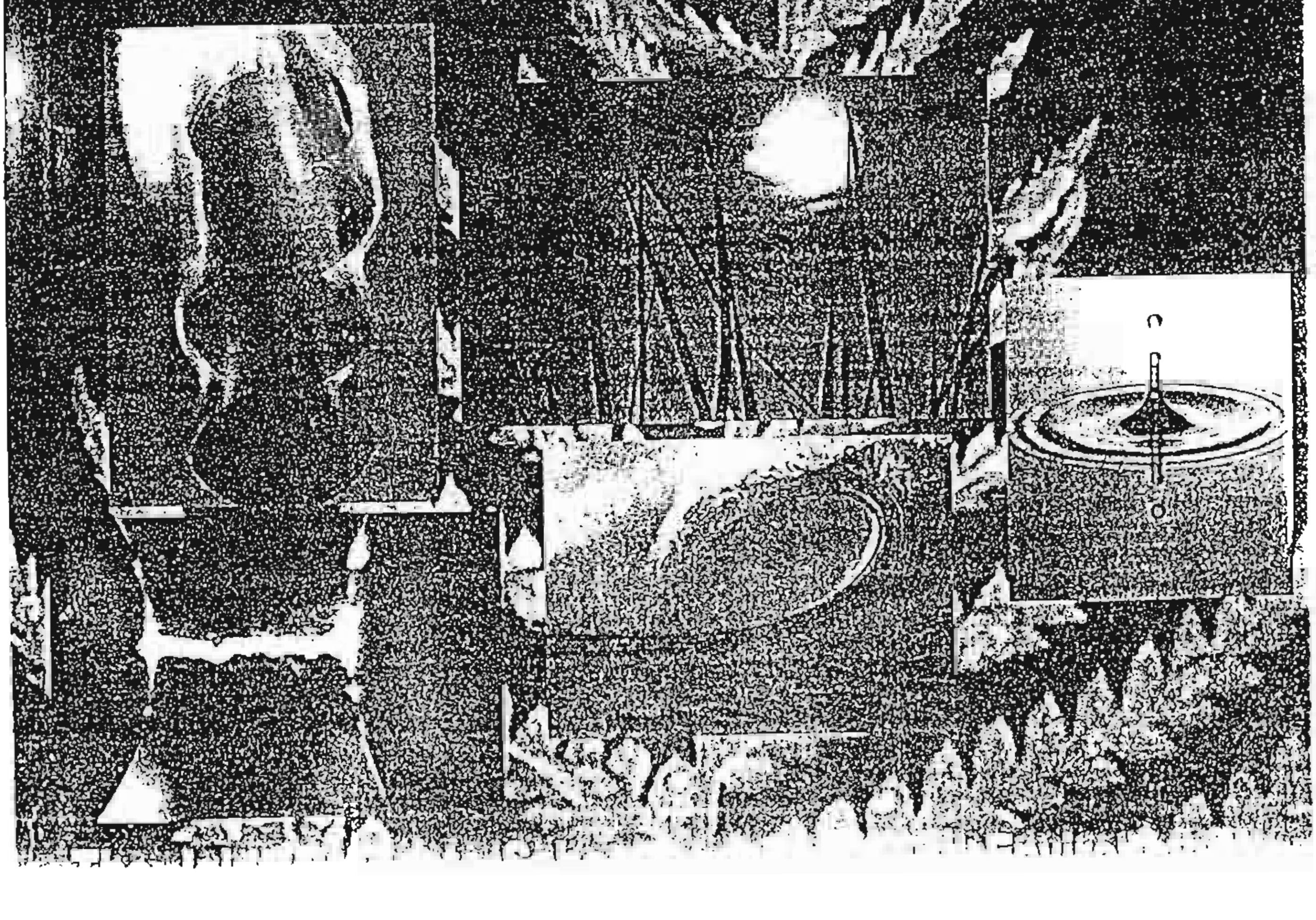

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DRYING KINETICS OF LONGAN FLESH

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ABSTRACT

The objectives of this research were to study the theoretical drying kinetic equation of longan flesh drying and to develop diffusion models. Effective diffusion coefficient was determined by regression analysis of the experimental data to the drying kinetic equation. Numerical method based on finite difference was applied for solving drying kinetic equation. Three alternative diffusion models were developed by modifying the Arrhenius factor and/or energy of activation as a function of product moisture content. The volume shrinkage of longan flesh during drying was also considered. Models 1 and 2 were established by modifying the Arrhenius factor as a second-degree polynomial and an exponential function of product moisture content. respectively. In Model 3. not only the Arrhenius factor but also the energy of activation was modified as a function of product moisture content. The effective diffusion coefficients obtained from each model were compared. It was found that Model 2 gave the maximum value of R^2 and the lowest value of mean residual square. Also. by comparing the moisture ratios calculated from each model with experimental results. it could be concluded that the drying kinetic curve calculated using Model 2 was recommended

Keywords: diffusion model. finite difference. modeling. shrinkage.longan

1. INTRODUCTION

The physical mechanism of drying in capillary porous products such as fruits and vegetables is quite complicated. It is generally agreed that the moisture within agricultural product moves in the form of liquid and/or vapor. Several theories have been proposed to describe drying behavior in the falling rate period. When external resistance to moisture is negligible. drying could be assumed that moisture transfer is controlled by diffusion only. The mass transfer mechanism is described by equation of diffusion based on Fick's second law.

In General. the effective diffusion coefficient is calculated by regression analysis of experimental data to the solution of Fick's diffusion equation. Usually. the effective diffusion coefficient is assumed to be constant in the entire drying period so that this solution can be solved analytically. However. the effect of moisture content on diffusion of fruits is big. Some researchers applied analytical solution for calculating the effective diffusion coefficient as a function of moisture content by assuming that it was constant over a short time interval (Azzouz *et al*..1998: McMinn and Magee. 1996: Raghavan *et al*.. 1995). In order to improve the accuracy of the effective diffusion coefficient. the effects of moisture content and shrinkage during drying should be considered. but the diffusion equation cannot be solved analytically. The numerical analysis solution is an alternative method for solving this equation.

The goal of this work was to study the drying kinetics of longan flesh drying with considering product shrinkage during drying. The effective diffusion coefficient was calculated by regression analysis of the experimental data to drying kinetic equation, which was developed based on Fick's second law, with a hollow sphere form. In this research, three alternative diffusion models were developed by modifying the parameters in the Arrhenius equation as a function of moisture content.

2. MATERIALS AND METHODS

2.1 Experimental Procedure

Longans of the variety E-dor of uniform size were selected and used in this study (average size 25 ± 2 mm in diameter). The initial moisture content of whole longan varied from 220 to 300% dry-basis. Whole longan was punched at the pole for taking the seed out. Next this longan was peeled and blanched. The blanching pre-treatment consisted in dipping the longan flesh in a 0.3% (w/w) aqueous potassium metabisulphite solution for 5 minutes at room temperature. The initial moisture content of the samples varied from 420 to 500% dry-basis

Volume change or shrinkage of longan flesh during drying was studied. It was assumed that the shrinkage was a linear function of moisture content only. The volume was determined by liquid displacement technique using toluene at room temperature. The external radius was measured by venire before and after drying. A total of 40 duplicate experiments were done under convective drying air of 60°C and air velocity of 1 m/s.

The drying experiments were performed in laboratory hot air dryer. Air passed through the products from the bottom toward the top, and there was no air recirculation. The experiments were carried out at various air temperatures of 45, 58, 69 and 82 °C and at constant air velocity of 1 m/s. The humidity ratios of drying air varied from 0.017 to 0.019 kg-water/kg-dry air. In each experiment, the weight of the product was recorded as a function of drying time. Before drying, internal and external diameter of the sample were measured by venire. Drying was continued till the final moisture content about 20% dry-basis. Each experiment was replicated thrice. The bone-dry moisture contents were determined by hot air oven at 103 °C for 72 hours.

2.2 Shrinkage Equation

The shrinkage kinetic equation was fitted to experimental data in order to express the change in size as a function of moisture content. It was expressed as a linear equation (Achariyaviriya *et al.*, 1999; Queiroz and Nebra, 1998) for correlating the shrinkage ratio (r/r_{in}) to the fraction of moisture content (M/M_{in}). It could be written as:

$$r/r_{in} = a + b(M/M_{in}) \quad \ldots(1)$$

2.3 Drying Kinetic Equation

The drying kinetic equation of longan flesh drying, which is useful for studying the behavior of the internal moisture transfer within the product, is developed. Mathematical model of drying kinetic uses Fick's second law of diffusion by which the effective diffusion coefficient depend on moisture content. Moreover, the effect of product shrinkage during drying is also considered. To obtained a solution, it is necessary to use numerical method with the assumptions that the sample is a hollow sphere shape and has a uniform initial moisture content.

In solving this problem, the hollow sphere is divided into N (N=20) spherical membranes of thickness Δr. The internal spherical surface of radius r_i, the external surface r_e and a spherical membrane of radius r are shown in Figure 1. A position within the solid is characterised by the radius of the sphere which pass through this position. Thus

$$r = r_i + j\Delta r \qquad \text{for} \qquad j = 1, 2, 3, \ldots, N-1 \qquad \text{and} \qquad r_i < r < r_e \qquad \ldots(2)$$

$$\Delta r = (r_e - r_i)/N \qquad \ldots(3)$$

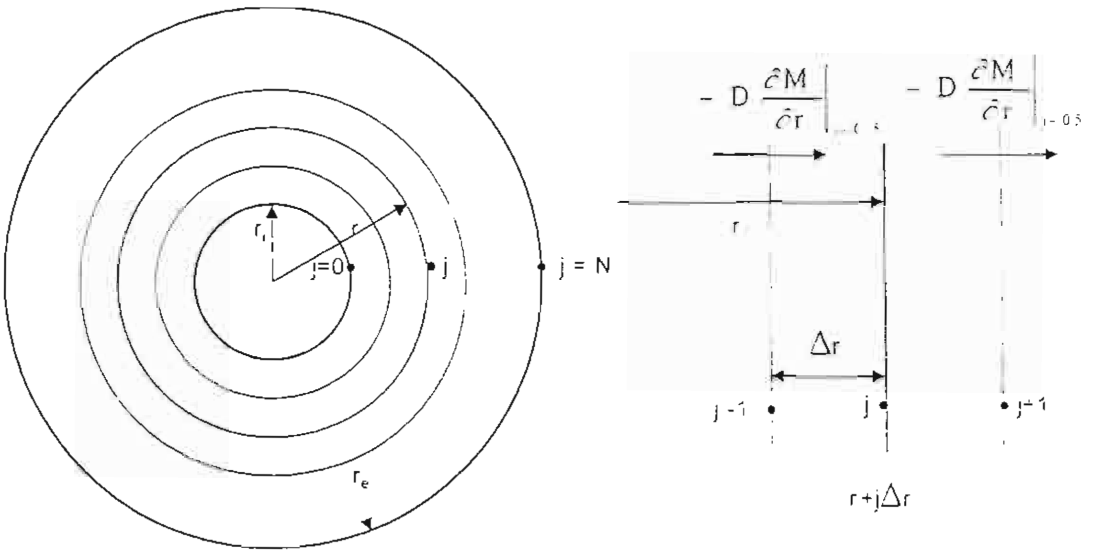

Fig. 1: Scheme for a solid hollow sphere, with integer j and for spherical membrane for radius r.

The mass balance during the increment of time Δt (Δt = 0.001 h) is calculated by taking into account the diffusion of the moisture through the surface of radii $r_i + (j-0.5)\Delta r$ and $r_i + (j+0.5)\Delta r$ (see Figure 1). The new moisture at position j after time Δt is thus expressed in terms of the previous moisture at the same place and adjacent positions. The radius r and spherical membrane of thickness Δr are recalculated according to the new moisture. The drying kinetic equation can be written as:

$$MR_{j,t+\Delta t} = MR_{j,t} + \frac{\Delta t D}{(r_i + j\Delta r)^2}\left[\frac{\{r_i+(j+0.5)\Delta r\}^2}{\Delta r^2}(MR_{j+1,t} - MR_{j,t}) - \frac{\{r_i+(j-0.5)\Delta r\}^2}{\Delta r^2}(MR_{j,t} - MR_{j-1,t})\right]$$

...(4)

The following initial and boundary conditions are used:

$$MR_{j,0} = 1 \qquad \text{for } j = 0, 1, 2, \ldots, N \qquad \ldots(5)$$

$$MR_{0,t} = 0 \qquad \text{for } t > 0 \qquad \ldots(6)$$

$$MR_{N,t} = 0 \qquad \text{for } t > 0 \qquad \ldots(7)$$

Where MR is moisture ratio defined as $MR = (M - M_{eq}) / (M_{in} - M_{eq})$. M_{eq} is the equilibrium moisture content using the equation of Oswin(1946) whose parameters are evaluated by fitting of the experimental results to the Oswin equation. It is given by Equation (8).

$$M_{eq} = 0.2208\,[RH/(1-RH)]^{(0.7052-0.0010T)} \qquad ...(8)$$

2.4 Development of Diffusion Model

The effective diffusion coefficient was estimated by fitting of experimental data to drying kinetic equation using least square method. A Fortran computer program was written for solving the set of equations and calculating the moisture distribution inside the solid hollow sphere and average moisture content as well as the effective diffusion coefficient. To develop diffusion models, the parameters in diffusion model were evaluated by fitting the calculated data to each diffusion model. As is generally accepted, the variation of the effective diffusion coefficient with temperature is represented according to the Arrhenius equation. It is given by the following equation.

$$D = D_o \exp[-E_a/(RT_{abs})] \qquad ..(9)$$

However, the effect of product moisture content has not yet been formatted into an Arrhenius equation. In this study, diffusion models were developed by modifying the Arrhenius factor (D_o) and/or energy of activation (E_a) to depend on product moisture contents. The detailed models are as follows:

In Models 1 and 2, D_o is considered as a polynomial function of second order and exponential of polynomial function of second order of the moisture content, respectively. In model 3, D_o is considered as a polynomial function of second order and E_a is considered as a linear function of the moisture content.

3. RESULTS AND DISCUSSION

Of all experiments showed that there was no constant drying period so that the moisture transfer within longan flesh during drying was limited by diffusion only. The shrinkage ratio was correlated with the fraction of moisture content as Equation (1). It was found that the volume shrinkage of longan flesh after drying was about 85%. The values of a and b calculated by regression analysis were 0.49 and 0.51 for external radius, and 0.59 and 0.41 for internal radius, respectively.

Diffusion models of longan flesh drying developed here were shown in Table 1. The effect of product shrinkage during drying was considered for all models. In Table 1, it can be seen that Model 2 gives the maximum value coefficient of determination. (R^2=0.92) and the lowest value mean residual square, (MRS=0.0009).

Table 1 Diffusion Models of Longan Flesh Drying.

Model	Diffusion Model	*R^2	**MRS
Model 1	$D=(-0.5431M^2+3.245M-0.6592)*10^{-2}\exp[-28.76/RT_{abs}]$	0.87	0.0019
Model 2	$D=2.567*10^{-3}\exp(-0.4899M^2+2.634M+0.08618)\exp[-30.48/RT_{abs}]$	0.92	0.0009
Model 3	$D=(-0.2141M^2+1.468M-0.2986)*10^{-3}\exp[-(0.1237M+20.01)/RT_{abs}]$	0.85	0.0013

$$*R^2 = \sum_{i=1}^{n} [(MR_{pr})_i-(MR_{ex})_{av}]^2 / \sum_{i=1}^{n} [(MR_{ex})_i-(MR_{ex})_{av}]^2$$

$$**MRS = \sum_{i=1}^{n} [(MR_{pr})_i-(MR_{ex})_i]^2 / \text{the number of observations}(n)$$

The simulated moisture ratios were shown only for one drying condition, however, similar results were obtained for all drying condition tested. Figure 2 illustrates the comparison of moisture ratios with the experimental results at drying air temperature of 58 °C. It is found that the moisture ratios obtained from Models 1 and 3 are nearly the same as that from experimental results at the beginning and middle of drying but slightly higher towards the end of drying. The moisture ratios obtained from Models 2 are close to the experimental results in the entire period of drying.

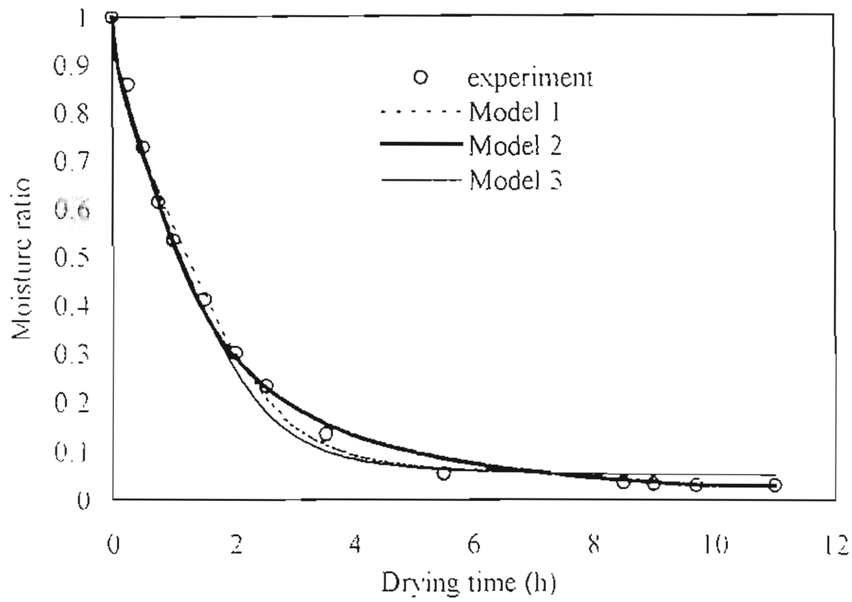

Fig. 2: The evolution of predicted and experimental moisture ratios of longan flesh during drying(drying air temperature 58°C)

Figure 3. Shows the effective diffusion coefficient of longan flesh drying as a function of moisture content at drying air temperature of 58°C. The effective diffusion coefficients obtained from Models 1 and 3 give similar results, such that in the early interval of drying, effective diffusion coefficient increases slightly with decreasing moisture content until the moisture reduces to 300% dry-basis and then it decreases with moisture content.

From Model 2, the effective diffusion coefficient is lower than Models 1 and 3 but it increases rapidly with decreasing moisture content until it reaches a peak (280% dry-basis) and then it decreases with moisture content. This characteristic is in good agreement with the other products which have been reported by several authors (Achariyaviriya *et al.*, 1999, Raghavan *et al.*, 1995).

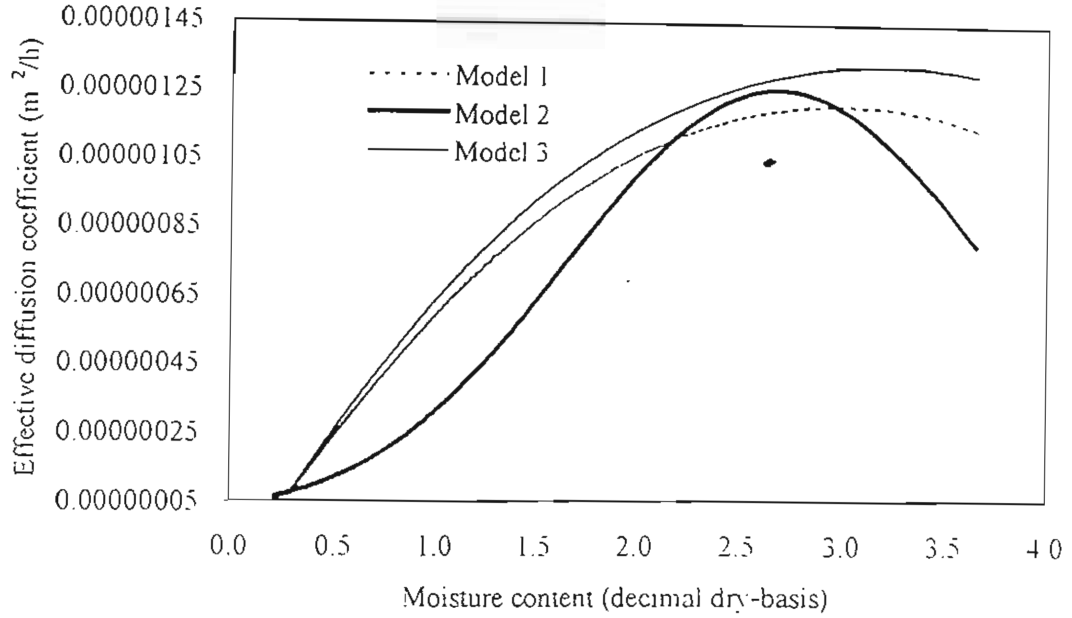

Fig. 3: Effective diffusion coefficient of longan flesh drying calculated by various models (drying air temperature 58°C)

4. CONCLUSIONS

The results of the investigation on the drying kinetics of longan flesh drying could be summarized as follows:

1. The simulated moisture ratios obtained from drying kinetic equation using diffusion model which was developed by modifying the Arrhenius factor as an exponential function of moisture content were able to have the best predictions.
2. The diffusion model developed by modifying energy of activation as a function of moisture content was unable to improve the predictions of the simulated results particularly towards the final period of drying
3. The percentage shrinkage of longan flesh after drying (20% moisture content) was more than 80% by volume.

ACKNOWLEDGEMENTS

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NOMENCLATURE

a, b	constant in Equation (1)	
D	effective diffusion coefficient	(m^2/h)
D_o	Arrhenius factor	(m^2/h)
E_a	energy of activation	(kJ/mole)
M	moisture content	(decimal dry-basis)
MR	moisture ratio	(decimal)

MR	average moisture ratio	(decimal)
MRS	mean residual square	(decimal)
R	universal gas constant	(kJ/mole-K)
r	radius	(m)
R^2	coefficient of determination	(decimal)
RH	relative humidity	(decimal)
T	temperature	(°C or K)
t	time	(h)

Subscripts

abs	absolute
av	average
e	external
eq	equilibrium
ex	experimental value
i	internal
in	initial
pr	predicted value

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HEAD RICE YIELD AFTER DRYING BY FLUIDIZATION TECHNIQUE AND TEMPERING

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Keywords: fluidized bed; grain; grain quality; rough rice

ABSTRACT

Process of paddy drying was performed by first removing its moisture content in a fluidised bed dryer and then tempering with subsequent ambient air ventilation. The variables of operating condition were inlet air temperature, tempering time. The quality of paddy in terms of head rice yield has been investigated. It shows that tempering treatment provides better the head rice yield than that with no tempering. To maintain high quality, the moist paddy should not be reduced lower than 22.5% dry basis in first stage, corresponding to lower grain temperature of 100°C, with the following tempering for 30 minutes. Under this condition, the relative head rice yield is higher than 100%. The change of relative head rice yield can be described adequately by the second order polynomial of tempering time with the coefficients formed as a linear relation of final moisture content and grain temperature after fluidized bed drying (tempering temperature).

INTRODUCTION

Paddy drying by fluidization technique has been widely accepted in several countries. The advantages of this technique are as follows: rapid drying, small size dryer and uniform final moisture content. Paddy drying by fluidisation has been studied and developed for several researchers. Soponronronnarit and Prachayawarakorn (1994) have contributed significantly to the research and development on fluidized bed paddy drying. The results showed that minimum fluidized bed velocity was 1.65 m/s. Drying air temperature and final moisture have the greatest effect on paddy quality. They suggested that the maximum drying air temperature had to be limited to 115°C and final moisture content of paddy not lower than 24-25% dry basis. Soponronnarit et al. (1996a) described the development of cross flow fluidized bed paddy dryer with a capacity of 200 kg/h. The dryer was designed to use recycled air for reducing energy consumption. Simulation results indicated that appropriate operating parameters should be as follows: air velocity, 2.3 m/s; bed thickness, 10 cm; fraction of air recycled, 0.8. With these conditions, energy consumption was close to the minimum, while drying capacity was near the maximum. Soponronnarit et al. (1995) designed a prototype of fluidized bed paddy dryer for commercialization. Soponronnarit et al. (1996b) developed a cross flow fluidized bed paddy dryer with high capacity for commercialization. This dryer had capacities of 5 tons/h and of 10 tons/h. Drying air temperature was 120-150°C. Since 1995, The dryer could be sold approximately 100 units in 8 countries.

Due to the commercial fluidized bed paddy dryer operating at high drying air temperature. If the product quality in terms of head rice yield and whiteness is to be maintained, the fluidized bed dryer cannot reduce moisture content down to safe storage level at 14% wet basis by a single pass. Several researchers [Steffe et al. (1978), Zhang and Litchfield (1991) and Soponronnarit et al. (1999)] suggested to temper the grain between each drying pass for improving drying performance and product quality. During the tempering period, the moisture profile in the kernel is equalized through moisture diffusion. This moisture equalization decreases the stresses caused by moisture gradient within the kernel, thus the head rice yield after the next pass of drying is increased when compare with process without tempering.

Steffe et al. (1978) studied suitable tempering time of paddy between the first and the second pass of drying. The experiment results showed that moisture content of tempered paddy after drying in the second step was less than that without tempering. Quality of milled rice showed that tempered paddy yielded more head rice yield compared to paddy without tempering. Sopornronnarit et al. (1999) introduced tempering and ambient air ventilation as the processes after fluidized-bed paddy drying. It was found that the maximum rate of moisture reduction during ambient air ventilation was obtained when tempering time was 15 minutes or longer. In addition, the quality in terms of head rice yield was improved as compared to that without tempering.

Tempering period used in the commercial rice drying varies widely. It is important to know tempering time for different drying process and different

drying condition. For these reasons, the objective of this research was to study the effect of drying and tempering on the head rice yield and to develop the prediction equation of relative head rice yield for paddy drying by fluidization technique and tempering.

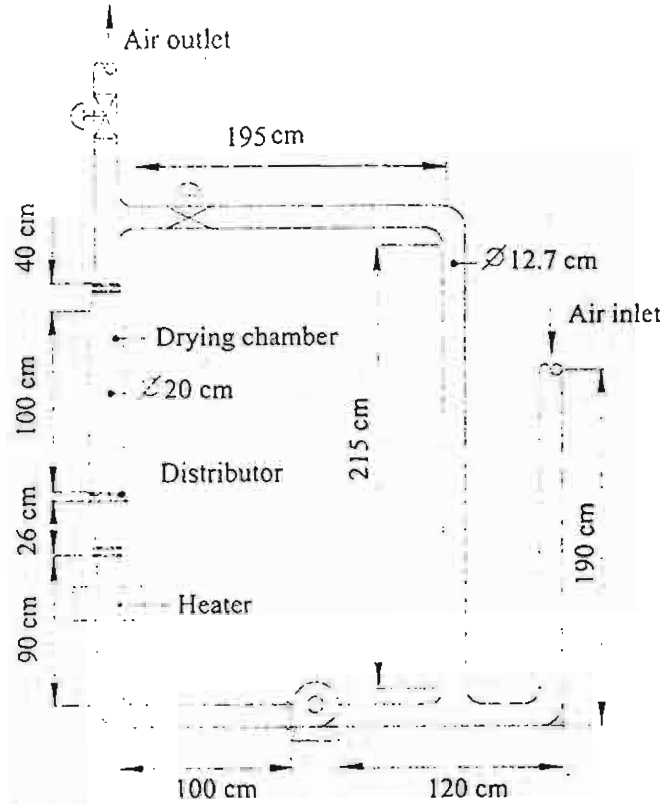

FIGURE 1 Diagram of Experimental Fluidized Bed Dryer.

MATERIALS AND METHODS

Paddy used in all experiment was rewet, mixed and kept in a cold storage at the temperature of 3-5°C for 5-7 days. Before the beginning of the experiment, the paddy was kept in ambient air until grain temperature was close to ambient temperature. To start the experiment, paddy was dried with a batch-type fluidized bed dryer as shown in Figure 1. This dryer comprises of a cylinder shaped drying chamber with dimension of 20 cm in diameter and 140 cm in height, a 12 kW electrical heater and a backward curved-blade centrifugal fan driven by a 1.5 kW motor. The drying air temperature was controlled by a PID controller with an accuracy of $\pm 1^{O}C$. A mechanical variable speed unit could regulate airflow rate. The conditions in this experiment were performed at constant bed air velocity (2.2 m/s) and bed thickness (10 cm). After drying paddy was put into a glass bottle with a diameter of 12 cm and a height of 10 cm, which could be closed completely and kept in an oven at temperature equal to the paddy temperature after drying. After the desired tempering time, it was ventilated immediately with a fixed low airflow rate of ambient air until moisture content was close to 16.5% dry basis. Finally, 300 g of paddy per each condition was kept in a complete seal plastic bag for 2 weeks before head rice yield test.

During the experiment, moisture content after fluidized bed drying, grain temperature and head rice yield were collected from 240 drying conditions. Paddy with three levels of moisture content (35, 30 and 25% dry basis) was dried at the drying air temperatures of 110, 130, 150 and $170^{O}C$ with drying time of 1, 2, 3 and 4 minutes. Tempering time was 0, 15, 30 and 45 minutes. Grain temperature, drying air temperature and ambient air conditions were measured by K type thermocouple connected to a data logger with an accuracy of $\pm 1^{O}C$. The moisture contents of paddy were determined by an air oven at temperature of $103^{O}C$ for 72 hours. Head rice yield was determined by using the test method of the Ministry of Agriculture and Cooperatives. Relative head rice yield refers to the ratio of head rice yield obtained from the above mentioned process to head rice yield obtained from ambient air drying.

RESULTS AND DISCUSSION

Figure 2 shows the effects of final moisture contents and tempering temperatures or grain temperatures on the relative head rice yield at different initial moisture contents. The results represented in this figure were obtained by such a way that paddy dried firstly with the fluidised bed dryer was then cooled immediately with the ambient air temperature until the grain temperature reached to the ambient air temperature and the moisture content reduced to 16% dry basis. According to FigureE 2, it clearly indicates that the relative head yields of paddy having the initial moisture contents of 30% and 35% dry basis are relatively higher than 80% if its water content was removed to be not lower than 25% dry basis. The corresponding grain temperatures varied between 70°C and 90°C,

depending upon drying time, inlet air temperature and initial moisture content. The relatively reduced head rice yield at the early drying period is mainly caused by both of temperature and moisture gradients. However, when the final moisture content was

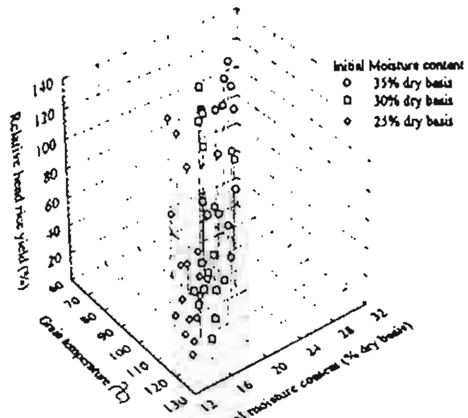

FIGURE 2 Effect of Final Moisture Content and Grain Temperature after Fluidized Bed Drying (tempering temperature) on Relative Head Rice Yield (without tempering).

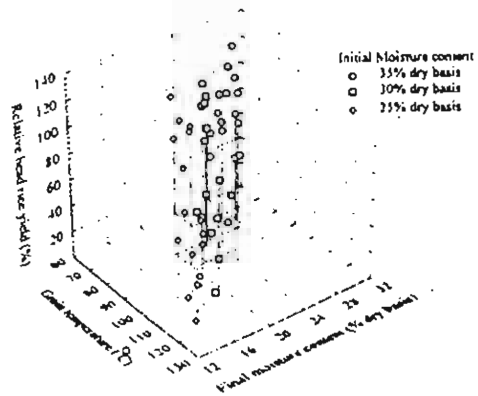

FIGURE 3 Effect of Final Moisture Content and Grain Temperature after Fluidized Bed Drying (tempering temperature) on Relative Head Rice Yield at Tempering Time of 15 minutes.

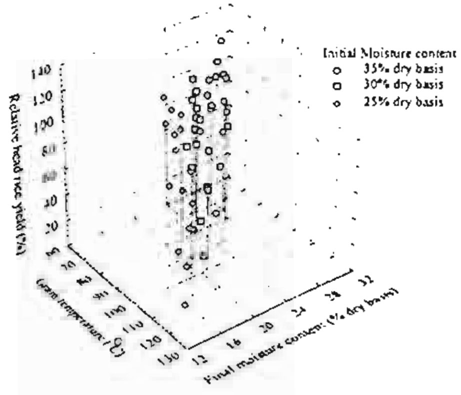

FIGURE 4 Effect of Final Moisture Content and Grain Temperature after Fluidized Bed Drying (tempering temperature) on Relative Head Rice Yield at Tempering Time of 30 minutes.

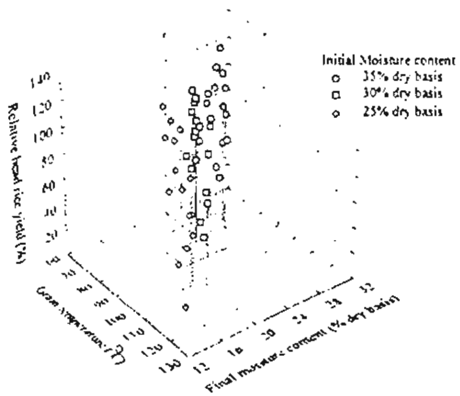

FIGURE 5 Effect of Final Moisture Content and Grain Temperature after Fluidized Bed Drying (tempering temperature) on Relative Head Rice Yield at Tempering Time of 45 minutes.

reduced to level lower than 25% dry basis, with the corresponding increase of grain temperature up 110°C, the head rice yield becomes significantly poorer and most of data represent the values lower than 40%. In this case, the only moisture gradient inside paddy plays the dominant contribution to the stress crack. This can be explained by the fact that the mobility of water in a range of relatively low moisture level is very slow from the inside to the outside. Accordingly, the surface of paddy becomes rather dry and the matter at the inside is still wet. Such phenomenon then induces the expansion and the contraction in the starch cells.

However, for initial moisture content of 25% dry basis as represented in Figure 2, it is shown that the head rice yield is very lower in amount although the degrees of moisture reduction and of grain temperature seem to be the same magnitude with the above cases. Reducing the quantity of moisture up to 5 points from the beginning during the first stage drying can result in the relative head yield lower than 40%, corresponding to final moisture content of 20% dry basis. These results clearly demonstrate that the rapid drying technique is not suitable for the range of low moisture content of paddy. This fact is drawn from the single stage drying.

To maintain the high relative head rice yield, the tempering technique was applied and the important requirement for this stage is to know the appropriate tempering time for a specific drying condition. Sufficient tempering time provide the equalisation of water concentration in every part of paddy. This equality improves the energy utilisation during subsequent drying stages. However, the second stage drying was not considered in this work. During tempering period, samples were kept in the oven at the temperature of grain after dried by fluidization technique. The tempering temperature used was higher than that being operated industrially for the conventional dryer. In Figure 3, the dried paddy was tempered for 15 minutes and the results are shown up the small improvement of relative head rice yield especially for the final moisture contents lower than 24% dry basis. When the additional tempering times were longer, it is found a greatly beneficial influence on the head rice yield as represented in Figure 4 for tempering time of 30 minutes. Most data, represented previously the lower relative head rice yields than 40% for initial moisture contents of 25% and 30% dry basis in Figure 2, now raise up to level moderately higher than 60% with fewer still showing the poor quality. The improved relative head rice yield, related closely with the length of tempering time, can be explained reasonably that during tempering at high temperature together with a sufficiently long time, the starch cells in the moist paddy are gelatinized. In addition, the water concentration inside the kernel is almost similar in everywhere. This result is also similar to works reported by Elbert et al. (2001) and Soponronnarit et al. (1999). For the case of tempering time 45 minutes as shown in Figure 5, the results show a similar trend to Figure 4. This indicates that 30-minute tempering time is long enough for maintaining the relative head rice yield.

According to the experimental results, it recommends that in drying paddy at high temperature with this technique, it should not be removed the water content lower than 22.5% dry basis in the single stage drying, corresponding to the grain temperatures lower than 100°C, with subsequent tempering for 30 minutes. Under this condition, it is certainly sure that the accomplished head rice yield is found.

Drying is a very simple process, just removing the water content from solids. However, whenever it has to consider the quality of final product, the management of drying process is a very task because this process involves with the coupled heat and mass transfers. Which are the main factor affecting the quality change. Unfortunately, the fundamental correlation to describe the change of product quality particularly paddy is really rare. The empirical equation is normally used although it can be used in an only limited range. The multiple linear regression approach was used to fit the experimental data with the proposed equation. Numerous forms of equation were tried and the results yielded the best correlation by considering the lowest value of sum of square error were chosen for predicting the relative head rice yield. A prediction equation of the relative head rice yield with their coefficients fitted a function of final moisture content and grain temperature after fluidized bed drying (tempering temperature) is given by the following equations:

$$RHY = A + B\,t + C\,t^2$$

where $A = -39.232 + 8.4227\,M - 0.34060\,T - 0.029105\,T\,M$

$B = 25.945 - 1.1878\,M - 0.24443\,T + 0.012202\,T\,M$

$C = -0.33610 + 0.015028\,M + 0.0032590\,T - 0.00015762\,T\,M$

t, M and T were tempering time in minutes, final moisture content in percent dry basis and tempering temperature in °C, respectively. This equation can be used only in the following ranges:

$$15.5 < M < 30.0$$
$$65 < T < 115$$
$$0 < t < 60$$

Figure 6 shows the comparison between the experimental data with the above equation. The equation can predict agreement with the experimental results particularly at the relative head rice yield higher than 80%. This high range is of great industrial interest. For the lower range, the prediction of this equation has a moderate error.

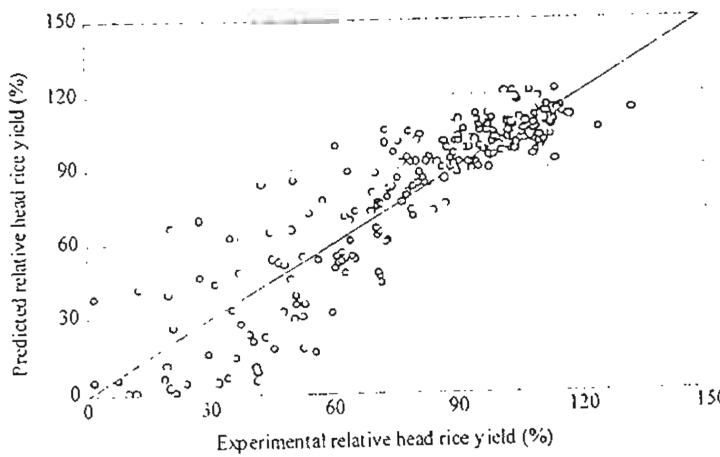

FIGURE 6 Comparison between Predicted Values and Experimental Values of Relative Head Rice Yield.

CONCLUSIONS

- Reducing high moisture level down to low value and the corresponding increase of grain temperature by a single stage drying severely affect the head rice yield
- Tempering treatment after drying stage can maintain the head rice yield. An increase in tempering time produces an increase of head rice yield. To obtain the high head rice yield, moisture content of paddy should not be reduced lower than 22.5% dry basis, corresponding to grain temperature 100°C, with subsequent tempering for 30 minutes.
- The second order polynomial equation of tempering time can predict adequately the relative head rice yield. The coefficients depend on the final moisture content and the grain temperature.

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SIMULATION OF A SOLAR TIMBER DRYER

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Key words: solar dryer, timber drying, simulation, ESP-r

ABSTRACT

Solar timber drying involves several complex interactive processes. The complexity arises from the intermittent energy flow from the sun, variable weather conditions, complex heat and mass flows between the dryer and environment, between dryer and timber, within timber and process control applied. This complex mechanism has made the performance appraisal and optimisation of solar dryer non trivial. This paper describes the simulation of the solar timber dryer using a generic energy simulation program for buildings namely Environmental Systems Performance (ESP-r, where 'r' stands for research). The energy and mass flows between the drying medium and timber were developed and linked to the main program to allow for the simulation of the drying system as a whole. Data collected from the solar dryer based at the Forest Research Institute Malaysia, was used to calibrate the model. The model enables the prediction of the solar drying of kapur for the whole year.

INTRODUCTION

Solar timber drying involves several complex interactive processes. The complexity arises from the intermittent energy flow from the sun, variable weather conditions, process control scheme applied, complex heat and mass flows between the dryer and environment, between dryer and timber, and within timber. These make the performance appraisal and optimisation of the solar dryer non trivial. With the advancement in computing power, computer simulation readily enables the influence of operating parameters and wood properties to be ascertain for both the design and performance of the drying system.

There are numerous reported simulation works done on solar timber drying. These range from physically simulating the dryer in a humidity chamber (Steinmann 1989), empirical modelling (Kyi 1983) to numerical simulation

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EFFECT OF TEMPERATURE ON SOYBEAN QUALITY USING SPOUTED BED TECHNIQUE

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Keywords: Grain, pH change, protein solubility

ABSTRACT

The effect of temperature on moisture reduction rate and soybean qualities using a two-dimensional spouted bed dryer has been studied. Air velocity was varied in a range of 15.86-20.50 m/s, with a fixed hold-up of 25 kgs. The soybean with initial moisture levels varying between 28 and 32% dry basis was dried to 12-17% dry basis using inlet air temperatures of 120-150°C. The experimental results indicate that higher temperatures and higher moisture contents provide faster moisture reduction rate. The qualities of soybean have also been considered in terms of stress cracking, breakage, urease activity and protein solubility in 0.2% KOH. It is shown that the percentages of cracking and breakage depend on temperature, final moisture content and degree of collision of kernel with deflector. The percentages of stress crack and breakage lie in the range of 50-60% and of 3-24%, respectively. The urease activity and protein solubility are accepted with slightly changing in the protein quality.

INTRODUCTION

Soybean (Glycine max (L.) Merrill) is classified as an oilseed legume which contains both of heat-labile anti-nutritional factors, i.e. trypsin inhibitor, heamagglutinin, and heat-stable anti-nutritional factor, i.e. saponin. These factors directly affect the growth of various species of animals (Liener, 1988). The trypsin inhibitor (TI) is the one to be of practical interest in considering the quality of soybean because it increases the secretory activity of pancreas, causing the pancreatic hypertrophy and the growth depression. When soybean is treated by sufficiently high heat processing, the trypsin inhibitor and the other anti-nutritional factors are inactive, but their nutritional components are improved (White et al. 1967; Faber and Zimmerman, 1973; Qin et al. 1996).

White et al. (1967) reported growth response of chick fed. In their works, soybean used as a protein supplement was prepared by several methods such as autoclaving, extrusion and infrared roasting. It indicated that gain weight and feed to gain ratio depended on the preparation methods. The extruded soybean serviced higher gain weight and feed to gain ratio than the roasted and autoclaved soybeans. Faber and Zimmerman (1973) studied the growth response of baby pigs and the results showed the similar trend as reported by White et al. (1967).

In addition to the process of heat treatments as mentioned above, fluidization technique has recently been applied. (Soponronnarit et al. 2001). It was found to be able to reduce the level of urease activity, which is an indirect measure of trypsin inhibitor, using 120°C being the minimum required to reduce the urease activity to an acceptable level. The protein level was insignificantly reduced in a temperature range of 110-140°C. For the physical qualities, the degree of cracking and breakage were found to be higher with increase of drying temperature.

However, the conventional fluidized bed usually provides the poor quality of fluidization (bubbling and slugging) for such coarse particles, resulting in low heat and mass transfer between solid and gas phases (Gishler, 1983). Thus spouted bed technique was developed in order to improve the quality. Several researchers have used this technique for drying cereal grains (Mathur and Eptein, 1974; Viswanathan et al. 1986; Massarani, 1987; Pasos et al. 1987 & 1989). This technique has the following advantages: simple design and construction, regular cyclic movement of solids, easily handling and lower pressure drop.

The use of two-dimensional spouted bed as a heat processing to reduce anti-nutrition factors in the soybean has been less attended. Therefore, this work studies the drying rate of soybean in a two-dimensional spouted bed and the effect of temperature on the soybean qualities such as percentages of cracking and breakage, urease activity and protein solubility.

MATERIALS AND METHOD

Drying Rate

A batch two-dimensional spouted bed dryer as shown in Figure 1 was used for drying and heat treatment. The system consisted of a spouted bed dryer with a width of 60 cm, a height of 200 cm, a 12 kW electric heater, an on-off temperature controller and a backward-curved blade centrifugal fan (2.2 kW motor). Geometry of dryer was the inlet cross sectional area of 0.04×0.15 cm^2, the spout width of 8 cm and the entrance height of 12 cm.

Temperatures were recorded by Chromel-Alumel (Type K) thermocouples connected to a data logger with an accuracy of ± 1°C. Pressure drop across bed and air velocity were respectively measured by a U-tube manometer and a hot wire anemometer.

Soybeans were rewetted to obtain the desired moisture content and then placed at temperature controlled room between 8 and 10°C for 5 or 7 days to ensure uniform moisture content of kernels. The experimental conditions were set up as follows: initial moisture contents of 28-32% dry basis, a fixed hold up of 25 kgs, temperatures of 120-150°C and a fixed air velocity of 20.5 m/s. Sample taken at every five minutes for periods of 5-30 minutes were collected in an electric oven for 72 hrs at temperature of 103°C to determine the moisture content.

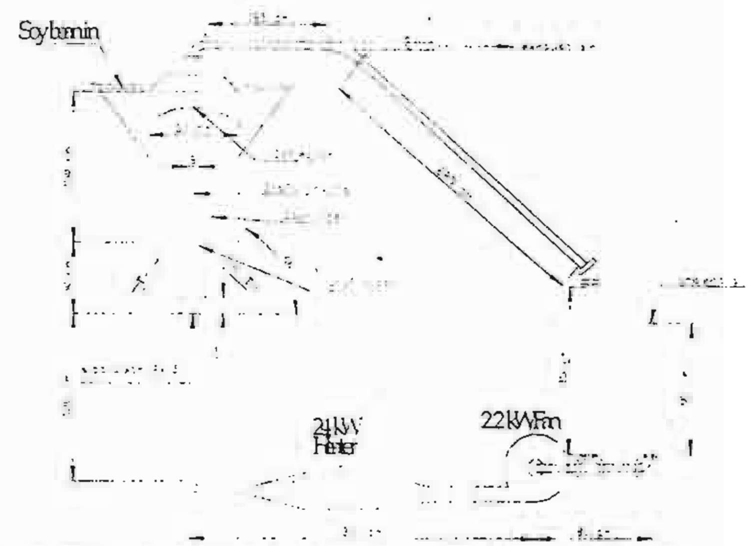

FIGURE 1 Schematic Diagram of a two-dimensional spouted bed dryer

Quality

Percentages of cracking and breakage

Cracking and breakage were considered by visually sorting out the cracked and broken kernels with fluorescent from 200 gram sample. The percentages of cracking and breakage were expressed by the following equations:

$$\text{Percentage of cracking} = \frac{\text{weight of cracked kernel}}{\text{weight of sample}} \times 100 \quad (1)$$

$$\text{Percentage of breakage} = \frac{\text{weight of broken kernel}}{\text{weight of sample}} \times 100 \quad (2)$$

Urease activity

The urease activity could be measured by detecting pH change, which is caused by the urease converting urea to ammonia. This method is an indirect test for level of trypsin inhibitor. A properly cooked soybean will give a urease activity of 0.30 rise in ΔpH. The measurement method was followed by the AACC procedure (1944).

Crude protein

Nitrogen content of soybean was estimated by Kjeldahl method (AOAC, 1980) using a nitrogen analyzer (Model VAPODEST12) and crude protein content was calculated by %N x 6.25.

Protein solubility

Protein solubility indicates the dispersion of proteins in 0.2% KOH solution. The nitrogen in the supernatant is determined by the Kjeldahl method. According to Cheong (1997), protein solubility should be in a normal range between 70 and 85%. If its value is lower than 70%, it means the overcooked soybean, but if it is higher 85%, soybean is insufficiently cooked. Protein solubility was calculated by

$$\text{Protein solubility} = \frac{\text{nitrogen of the supernatant in 0.2\% KOH solution}}{\text{crude protein}} \times 100 \quad (3)$$

RESULTS AND DISCUSSIONS

Effect of Temperatures on Drying Rate

A set of drying curves of soybeans at different inlet air temperatures is given in Figure 2. It is clearly illustrated that moisture content is decreased rapidly at the beginning of drying period and then reduces slowly at the end of drying period. In all cases, drying rates of soybean are increased with inlet air temperature and drying of soybean is in the falling rate period. During this period, moisture movement is controlled by internal diffusion.

Effect of Temperatures on Cracking and Breakage

The cracking and breakage of soybean caused by drying at high temperatures is formed in V-shape. These results are similar to those reported by Overhults et al. (1973) and Soponronnarit et al. (2001).

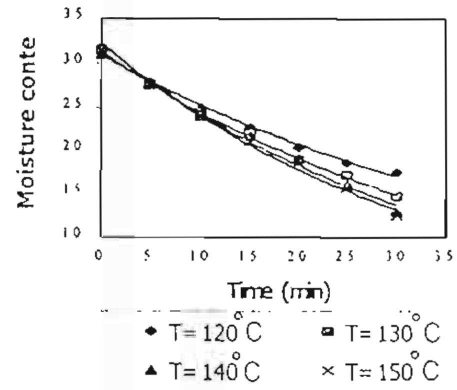

FIGURE 2 Effect of temperatures on reduction of moisture content

The percentages of cracking and breakage shown in Figures 3 and 4, respectively, were obtained by the following conditions: inlet air temperatures of 120-150°C, a deflector height of 138 cm from the entry of air inlet and a fixed air velocity of 20.5 m/s. They reveal that percentages of cracking and breakage depend strongly on the final moisture content and the inlet air temperatures; they increase with decrease of final moisture contents and increase of inlet air temperatures. Such defects are caused by the slow movement of water from the inside to the outside. Hence, soybean becomes brittle at the surface and tends to be cracked. Furthermore, the surface temperature of soybean rapidly increases as drying proceeds.

As illustrated in Figure 4, the percentage of breakage of final product lies in a range of 6-24% higher than an acceptable level (3%). The cause of such result is due to the effect of strong collision of kernels with the deflector, besides the drying effect. The effect of the deflector will be discussed in the next section.

Effects of Air Velocity and Deflector Height on Cracking and Breakage

Figures 5 and 6 show the increased percentages of cracking and breakage at the different air velocities and a deflector height of 142 cm. It is found that the percentages of cracking are insignificantly changed with increase of air velocity, but the percentages of breakage are substantially higher. When compared to

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OSMOSIS-PUFFING AS AN ALTERNATIVE FOR THE FRUIT DEHYDRATION PROCESS

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Keywords: CO_2; electrolyte; freeze drying; sugar; drying; bulk specific volume

ABSTRACT

In the osmosis drying the fruits were soaked in an osmotic media. The process was continued by puffing the product with CO_2 gas and then dried using a fluidized bed dryer which resulted in a product that resembles the volume and shape of a fresh product. The use of electrolyte solution such as KCl and NaCl sifnificantly increase the rate of water loss. The negative effect of KCl and NaCl is suppressed by the taste of the fruit itself or by combining the electrolyte solution with sugar. The product treated with the solution of KCl and NaCl had a lower bulk specific volume of puff product compared to that treated without the use of KCl and NaCl. The higher the concentration of sugar and KCl, the lower the bulk specific volume of puff product.

INTRODUCTION

Dehydration is one of the oldest and most effective ways of preserving food, especially for developing countries. Dehydration not only preserves food by lowering its water activity but it may also kill or prevent the growth of toxic microorganisms. Dehydrated products have an advantage over fresh products because of their increased shelf life, reduced refrigeration cost, and lower transportation cost.

The general drying processes, using solar energy, hot air, and other artificial heat source, do not yield a prime quality product. The quality of hot air dried product, especially flavor, aroma, and nutrition value, is degraded due to a