VISCOSITY AND TEXTURE ANALYSES

Due to the rice samples from the experiment no.2 were infected by fungi so the amount of rice samples were not enough to all of the quality testing so the TABLE 1 only illustrated the chemical, physical and physico-chemical properties of rice in the experiment no.1

From the quality parameters, they indicated that rice after drying was changed in physical properties in terms of hardness, stickiness and cohesiveness and also was changed in physico-chemical properties in terms of viscosity. The value of rice hardness, stickiness and cohesiveness after drying were higher than control rice as shown in TABLE 1. The increasing changes of the hardness, stickiness and cohesiveness after drying were supported and correlated to RVA testing in terms of peak viscosity increasing (158.38 RVU of control rice and 249.29 RVU of after drying) and final viscosity increasing (340 RVU of control rice and 387 RVU of after drying rice). These were because rice after drying was tightly packed with polygonal granules and spherical shaped protein bodies and these results were the same phenomena as previous work. [Imprasit and Noomhorm, (1999)]. However, the comparison chemical properties between control rice and dried rice showed that it was not significant different in pH and the amylose content.

Table 1. Quality parameters of Suphanburi-1 rice variety dried on in-store drying

Drying type	Amylose (%)	pH	Hardness (kg)	Stickiness (kg)	Cohesiveness (kg-s)	Peak viscosity (RVU)	Final viscosity (RVU)	Relative Head rice yield
Control rice EXP-1	26.1	9.64	16.66±4.25	-0567±0.03	-0.037±0.005	158.38	340.75	1
After drying EXP-1	28.6	9.34	23.87±5.28	-1.015±0.15	-0.681±0.12	249.29	387.00	0.92

CONCLUSIONS

1. The deep bed paddy drying using ambient air temperature has no a significant effect on the average yellowing of rice kernel.
2. The modified Grain Drying Simulation (GDS) program including the yellowing kinetics can suitably be described the drying kinetics and rice whiteness in the deep bed drying.
3. The simulation including the respiration effect shows the more accurate moisture predictions than that excluding the respiration effect and the energy from the effect is an impartial contribution to reduce the moisture content of grain. So, the in-store drying technique is low energy consumption process.
4. The in-store drying technique using ambient air ventilation is slightly affected the physical qualities physico-chemical qualities of rice.

ACKNOWLEDGEMENT

The authors wish to express their sincere thank to the Thailand Research Fund (TRF). The authors also thank to the Japanese International Research Center for Agricultural Sciences (JIRCAS) for financial support and the Institute of Food Research and Product Development(IFPRD) at Kasetsart University, Thailand for testing of rice qualities.

REFERENCES

Agrawal, Y.C. and Singh, R.P., (1977) "Thin-Layer Drying Studies on Short-Grain Rough Rice". ASAE Paper No.77-3531, ASAE, St.Joseph, MI.

Bakker-Arkema , F.W., Bickert, W.G. and Morey, R.V., (1967) "Simultaneous Heat and Mass Transfer during the Process of Deep Bed Drying of Grain (translated)". Landtechnische Forschung, 17(6), 175-180.

Brooker, D.B., Bakker-Arkema, F.W. and Hall, C.W., (1974) "Drying Cereal Grain". AVI Publishing.

Chung, D.S., Kanuyoso, B., Erickson , L. and Lee, C.H., (1985) "Grain aeration and in-store drying in U.S.A.". ACIAR Proc. No.15, Preserving grain quality by aeration and in-store drying. Australian Center for International Agricultural Research, Canberra.

Gras, P.W. and Bason, M.L., (1989) "Biochemical Effects of Storage Atmospheres on Grain and Grain Quality". ACIAR Proceeding No.25, Fumigation and Controlled Atmosphere Storage of Grain, 83-91.

Gras, P.W., Banks, H.J., Bason, M.L. and Arriola, L.P., (1989) "A Qualitative Study of the Influences of Temperature, Water Activity and Storage Atmosphere on the Yellowing of Milled Rice". J. of Cereal Science, 9, 77-89.

Hukill, W.V., (1947) "Basic principles in drying corn and grain sorghum". Agricultural Engineering,. 28 (8), 335-338, 340.

Imprasit, C. and Noomhorm, N., (2001) "Effect of Drying Air Temperature and Grain Temperature of Different Types of Dryer and Operation on Rice Quality". Drying Technology, 19(2), 389-404.

Quitco, R.T., (1982) "Studies of Fungal Infection and Heating of Paddy". Proc.GASGA Seminar on Paddy Deterioration in the Humid Tropics, Baquio, 1981, Philippines, 52-56, GTZ, Eschborn.

Seib, P.a., Pfost, H.B., Sukaboi, A., Rao, V.S. and Burroughs, R., (1980). "Spoilage of rough rice as measured by carbon dioxide evolution". Proc. of the 3rd Annual Workshop on Grain Post-Harvest Technology, 29-30 Jan., K.Lumpur, Malaysia.

Soponronnarit, S., (1988) "Energy Model of Grain Drying System". ASEAN J. on Sci. and Tech. for Dev., 5(2), 43-68.

Soponronnarit, S. and Chinsakolthanakorn, S., (1986) "Energy Consumption Patterns in Drying Paddy by Various Drying Strategies". Proc. Of the Regional Seminar on Alternative Energy, Chiang Mai, Thailand, 27-29 Oct.

Soponronnarit, S., (1987a) "Strategies for Drying Paddy under Tropical Climates". Paper presented at the Consultative Workshop on Grain Drying and Rice Milling in ASEAN, Hyatt Central Plaza Hotel, Bangkok, 24-27 Nov.

Soponronnarit, S., (1987b) "Drying in Bulk Storage of High Moisture Grains in the Kingdom of Thailand". Final report submitted to Australian Centre for International Agricultural Research, Canberra.

Soponronnarit, S., (1988) "Energy Model of Grain Drying System". ASEAN J. on Science and Technology for development, 5(2), 43-68.

Soponronnarit, S. and Chinsakolthanakorn, S., (1990) "Effect of Heat and Water from Respiration on Drying Rate and Energy Consumption". ASEAN Journal for Science and Technology for Development, 7, 65-83.

Soponronnarit, S. and Nathakaranakule, A., (1990) "Field Experience of In-store Drying of Paddy under Tropical Climates". Proc. 13th ASEAN Seminar on Grain Postharvest Tech., Brunei Darussalam, 4-7 Sep., 183-196.

Soponronnarit, S. and Preechakul, P., (1990) "Experiments on In-Store and Batch Drying of Paddy: Quality of Product". Kasetsart University Science Journal, 24 367-388 (in Thai).

Soponronnarit, S., Srisubati, N. and Yoovidhya, T., (1998) "Effect of Temperature and Relative Humidity on Yellowing Rate of Paddy". J.Stored Prod. Res., 34(4), 323-330.

Thompson, T.L., Peart, R.M. and Foster, G.H., (1968) "Mathematical Simulation of Corn Drying-a New Model". Transaction of ASAE, 11(4), 582-586.

DRYING 2002

DRYING 2002

Editors: C.W. Cao Y.K. Pan
X.D. Liu Y.X. Qu

Series editors: A S Mujumdar

IDS 2002
BEIJING CHINA

Volume ABC

Drying' 2002-Proceedings of the 13th International Drying Symposium (IDS' 2002)
Beijing, China, 27-30 August' 2002, vol. B, pp. 1246

COMPARATIVE STUDY OF HEATING PROCESSES FOR SOYBEAN

S. Wiriyaumpaiwong, S. Soponronnarit and S. Prachayawarakorn

School of Energy and Materials
King Mongkut's University of Technology Thonburi
Suksawat 48 Rd., Bangkok 10140, Thailand

ABSTRACT

Soybean must be processed through heat treatment in order to eliminate the anti-nutritional factors before used as animal feed. The presence of anti-nutritional factors such as trypsin inhibitors, hemagglutinins, saponins, and allergenic factors in raw soybean affect detrimentally animal performance. There are several processing methods to reduce the levels of these anti-nutritional factors and to improve the utilization of soybeans such as cooking, infrared roasting, hot air roasting and extrusion etc.

Keywords : Protein, Soybean, Urease

In this work, the performance of fluidized bed and wet extrusion process in the industrial scale has been evaluated. The fluidized bed dryer involves the cooking of soybean using heated dry air with an average temperature of 164.5°C. The soybean with an initial moisture content of 12% dry basis was dried to 1-2% dry basis with a feed rate of 2 tons/h for fluidized bed dryer. For the wet extrusion process, initial and final moisture contents are not significantly different with showing a value of 12% dry basis. The heat generated in the extruder barrel typically raises the temperature to 104-115°C at feed rate of 1 ton/h. The qualities of soybean in terms of urease activity and protein solubility in 0.2% KOH have also been considered along with the energy consumption in each process. The urease activity, a practical indicator, is an indirect test for level of trypsin inhibitors in animal feed industries. The urease activity and protein solubility, after cooking of soybean using extrusion process, vary in the range of 0.01-0.04 and 72.8-79.3%, respectively. In case of the fluidized bed dryer, urease activity and protein solubility were given the results as 0.21-0.27 and 72.6-77.6%, respectively. In additional to the qualities as mention above, the fluidized bed drying technique has a high potential for replacing the extrusion process since it could save the investment and energy cost around 88% and 72% when the system was operated by closed loop.

INTRODUCTION

Soybeans are well recognized as a valuable source of dietary protein for feeding both animals and human in many country of the world. Raw soybean, however, contains anti-nutritional factors, such as trypsin inhibitors, heamagglutinins, lectins and saponins, that depress the growth rate and efficiency of food utilization for animals (Liener, 1994). Proper processing of soybean treatment requires the control of moisture content, temperature and processing time to inactivate these factors (Wright, 1981). Adequate moisture during processing facilitates the destruction of the anti-nutritional factors in soybeans.

Although heat can destroy such anti-nutritional factors, the careful control of the heating conditions is required to prevent either under- or over-heating of soybeans (Liener and kakade, 1980). A method developed for treating soybeans is the extrusion, as a process in which the friction, produced by forcing the soybeans through die holes under pressure, creates the heat that eliminate the natural anti-nutritional factors (Waldroup, 1982). The advantages of extrusion process are to destruct the anti-nutritional factors and rupture the oil cells. Several workers have been concerned with heating conditions (Stephenson and Tollett, 1959; Renner and Hill, 1960) and the use of extrusion and infrared roasting to improve the performance of chick fed. It indicated that the extruded soybean serviced higher gain weight and growth of animal than the infrared roasted soybean (White et al., 1967; Faber and Zimmerman, 1973).

Large-scale commercial production of soybean meal in animal feed has been developed in Thailand. Recently, fluidized bed dryers have been commercialized in Thailand for soybean drying and soybean meal production. In most industrial fluidized bed dryer, heat is supplied externally to a product by air to provide energy for the moisture evaporation and the anti-nutritional factors inactivation. There are 80 units of fluidized bed dryer for paddy drying, with a few units being used for maize meal production and one unit being used for soybean drying and dietary meal production (Soponronnarit et al., 1998). A previous results of soybean tests showed that it could be 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. However, soybeans should not be dried below 23.5% from 33.3% dry-basis in order to avoid excessive grain cracking. The optimum conditions for heat treatment coincided at a temperature of 140°C, a bed depth of 18 cm, an air velocity of 2.9 m/s. These conditions resulted in 27% cracking and 1.7% breakage. In addition, Osella, Gordo, Gonzalez, Tosi and Ré (1997) studied the fluidized bed technique for treating soybeans with drying and inactivation of heat-labile inhibitors. As a result, soybean drying and inactivation can be potentially performed in a single step, with maintaining the nutritional value.

The aims of this work are to evaluate the performance of fluidized bed dryer and wet extrusion process in the industrial scale for eliminating the urease activity in soybeans and to explore the energy consumption of both processes.

MATERIALS AND METHODS

PROCESSING

Fluidized bed technique

An industrial-scale fluidized bed dryer with a feed rate of 2 ton/h capacity as shown in Fig. 1 is consisted of a drying chamber with a dimension of 0.7 x 2.1 x 1.3 m, a diesel oil burner and a backward curved blade centrifugal fan driven by a 50 kW motor. The fluidized bed dryer involves the cooking of soybean using the heated air with an average temperature of 164.5°C. Grains were forced by heated air and moved forward to the dryer exit. A thermostat controlled the temperature of heated air with an accuracy of ± 1°C.

Extrusion

Figure 2 shows the schematic diagram of extruder with a pre-conditioner. Extrusion of soybeans was performed in a 95 kW insta-pro model 2500 Extruder with a 3.8 kW insta-pro model 2594 pre-conditioner. Pre-conditioner is an additional part for extruder in which steam is used to pre-heat the product before entering the extruder, thereby increasing the extruder capacity and reducing the wear. Steam jacket in the pre-conditioner was fed with low pressure steam (0.9 MPa). After that the heat generated in the extruder barrel typically raises the temperature to 104-115°C at feed rate of 1 ton/h and the product was held in the extruder with 2.9 min. of retention time.

Materials

Raw soybeans that used for producing the animal feed in this work were the dry soybeans, which were stored in the silo in order to prepare as a raw material for drying by fluidized bed dryer. The moisture content was approximately 12% dry-basis. For the raw material used in the extrusion process, it must be milled as a soya flour before entering the system. This was given the moisture content of 13-14% dry-basis. The moisture contents of samples were determined at a temperature of 103°C in an electrical oven for 72 hr.

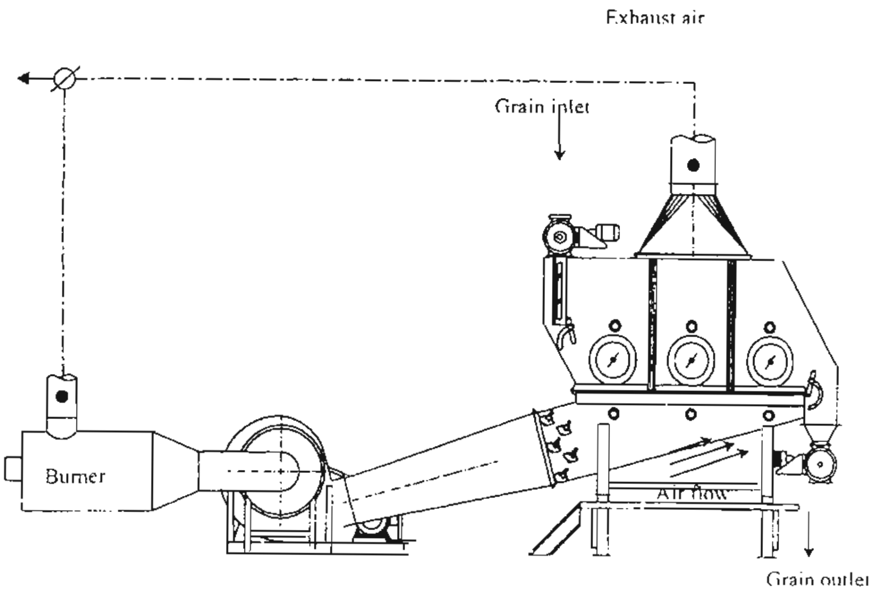


Figure 1 Schematic diagram of fluidized bed dryer

ANALYTICAL METHODS

Urease activity

The urease activity could be measured by detecting pH change, which was caused by the urease converting urea to ammonia. 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 analysed 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 indicated the dispersion of proteins in 0.2% KOH solution. The nitrogen in the supernatant was determined by the Kjeldahl method. According to American Soybean Association (Araba, 1990), 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 higher than 85%, soybean is insufficiently cooked. Protein solubility was calculated by

$$\text{Protein solubility} = \frac{\text{nitrogen of the supernatant in 0.2\% KOH solution}}{\text{crude protein}} \times 100 \quad (1)$$

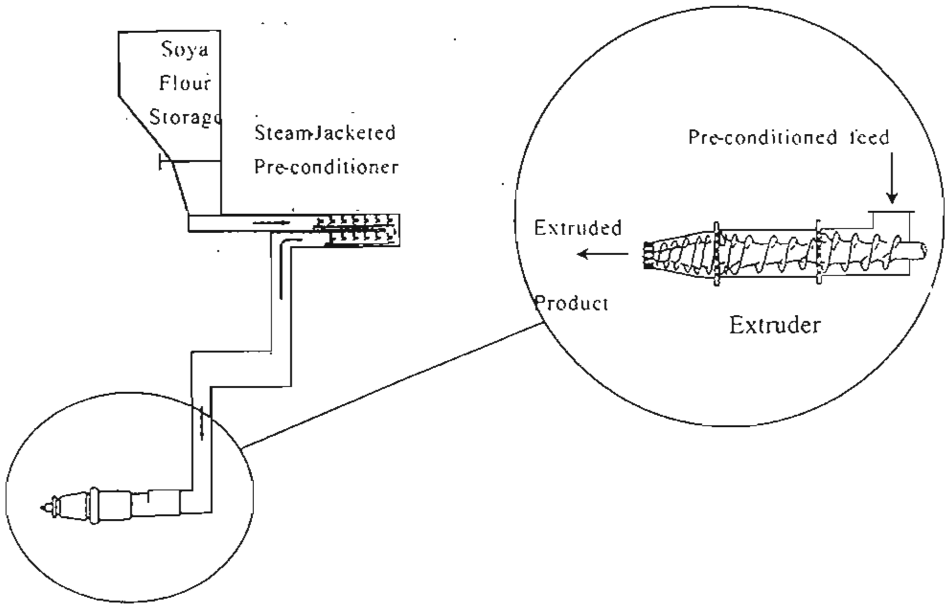


Figure 2 Schematic diagram of extruder with a pre-conditioner.

RESULTS AND DISCUSSIONS

MOISTURE DISTRIBUTION

Figures 3 shows the moisture content of soybean entering and exiting from the extruder (Fig.3a) and fluidized bed dryer (Fig.3b) during the operation. It was found that inlet moisture content of soybean was nearly constant during the experiments. For the extrusion process, the outlet moisture content of soybeans was slightly different from the inlet, 1-2% for the moisture reduction. Whilst the moisture content was rapidly reduced from 12% to 1% dry-basis for using the fluidized bed dryer as shown in figure 3b.

SOYBEAN QUALITY

Table 1 shows the full-fat soy flour analysis after the extrusion process. Temperatures of soy flour reach 88-94°C and 104-115°C at the pre-conditioner and the extruder exist, respectively. From this table, it indicates that the temperature of 104-115°C is enough for reducing the urease activity to be lower than the acceptable limit. The urease activity is very low (0.01-0.04) when compared to the AACC standard limit (0.30 ΔpH). For the full-fat soybean kernels dried by the fluidized bed dryer, the urease activity varies in a narrow range of 0.21-0.26, which is significantly higher than those obtained from the extrusion. The larger amount of urease activity is probably due to the lower grain temperature obtained from the dryer. However, this range is still accepted for using as a raw material for the animal feed industry.

For the change of protein solubility, it correlates inversely with temperature; lower protein solubility associated with higher temperature. As represented in Table 1, 2, the percentage of protein solubility after passing such processes varies in a range of 72.6-79.3%. According to these values, it indicates that the soybean is suitably cooked.

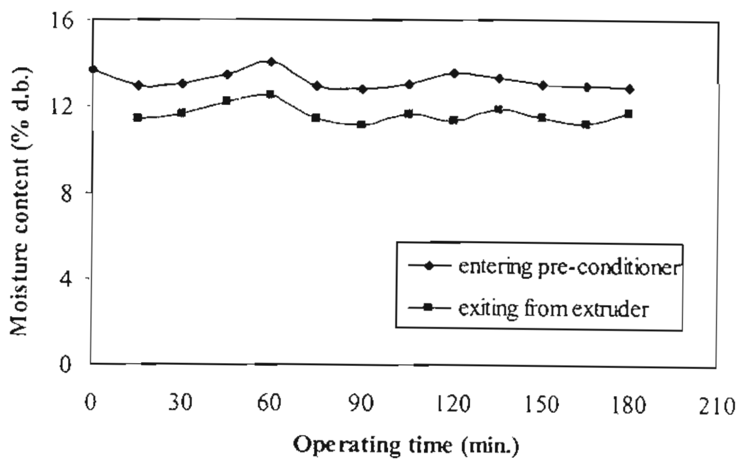


Figure 3 Moisture content of soybean entering pre-conditioner and exiting from extruder *vs.* operating time

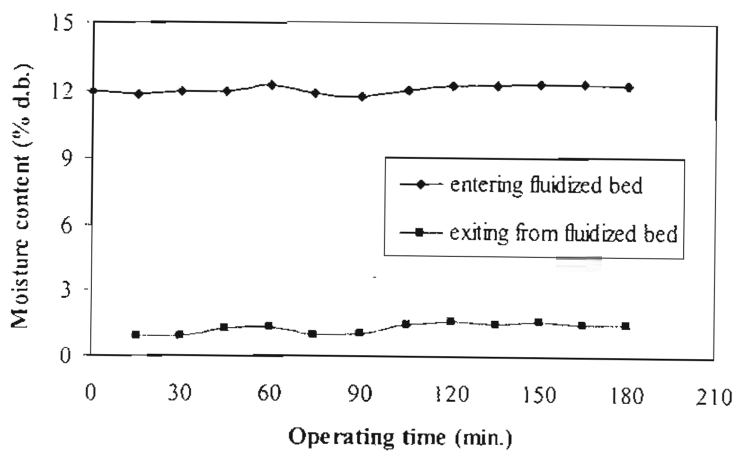


Figure 4 Moisture content of soybean entering and exiting fromfluidized bed vs. operating time

ENERGY CONSUMPTION

Table 3 shows the energy consumption of industrial-scale extruder and fluidized bed dryer. From this table, it indicates that the thermal and electrical energy consumption are respectively 625 and 928 MJ/ton of product for the extrusion process and 911 and 204 MJ/ton of product for the fluidized bed dryer. The electrical energy consumption was calculated by multiplying a factor of 2.6. These results show that the soybeans treated with the fluidized bed dryer can be saved the energy around 28%, comparing to the extrusion process.

Table 1 Full-fat soy flour analysis after extrusion process

Time (min.)	Temperature (°C)		Moisture Content (%d.b.)		Urease Activity (pH Change)	Protein Solubility (%)
	Pre-cond.	Exit	inlet	outlet		
15	89	105	12.9	11.4		
30	88	104	13.0	11.6	0.04	79.3
45	91	108	13.4	12.1		
60	92	111	14.1	12.5	0.04	76.4
75	92	110	12.9	11.3		
90	92	111	12.7	11.1	0.03	75.0
105	94	113	12.9	11.6		
120	93	115	13.5	11.3	0.03	72.8
135	93	114	13.3	11.8		
150	92	112	12.9	11.4	0.01	75.6
165	92	113	12.9	11.2		
180	92	112	12.8	11.7	0.01	76.2

Table 2 Full-fat soybean analysis after fluidized bed heating process

Time (min.)	Temperature (°C)		Moisture Content (%d.b.)		Urease Activity (pH Change)	Protein Solubility (%)
	inlet Air	drying room	inlet	outlet		
15	161	140	11.8	0.8		
30	160	143	11.9	0.9	0.25	77.6
45	162	144	11.9	1.2		
60	155	145	12.3	1.3	0.21	74.4
75	160	145	11.9	1.0		
90	167	147	11.8	1.0	0.26	74.4
105	166	147	12.1	1.4		
120	171	152	12.3	1.6	0.27	75.6
135	174	156	12.3	1.5		
150	178	159	12.4	1.6	0.24	72.6
165	164	144	12.3	1.4		
180	156	143	12.3	1.4	0.26	74.6

Table 3 Energy consumption of industrial-scale extruder and fluidized bed soybean dryer

Extruder		Fluidized bed dryer	
Testing hours	3	Testing hours	3
Capacity (ton/h)*	1	Capacity (ton/h)*	2
Outlet pre-conditioner temp. (°C)*	92	Inlet hot air temp. (°C)*	164
Outlet extruder temp. (°C)*	110	Drying room temp. (°C)*	148
Inlet moisture content (% d.b.)*	13	Inlet moisture content (% d.b.)*	12
Outlet moisture content (% d.b.)*	12	Outlet moisture content (% d.b.)*	1
Electrical energy consumed (MJ/ton of product)	928	Electrical energy consumed (MJ/ton of product)	204
Thermal energy consumed (MJ/ton of product)	625	Thermal energy consumed (MJ/ton of product)	911

* Average value

In evaluating the energy cost, we assume that LPG gas cost is 20 baht/kg and electricity cost is 2 baht/kWh. The results are shown that the total energy costs of such processes are insignificantly different. In accounting the operating cost for the fluidized bed dryer, the dryer was operated with no recycle air. However, if the exhaust air is fully recycled, the energy will then be saver 79%, comparing to that with no recycle air. Accordingly, the total energy cost become lower than 72% when compared to the extrusion cost. Note that the investment costs of fluidized bed dryer and extruder with capacity of 1 ton/h are 375,000 and 3,200,000 baht, respectively. It indicates that the investment of fluidized bed dryer is significantly lower.

CONCLUSIONS

Both extruder and fluidized bed dryer can be used in animal feed industry for eliminating the anti-nutritional factors and improving the degree of heat treatment. They can reduce the urease activity to adequate level, a long with the percentage of protein solubility falling in the range of standard level. The fluidized bed drying technique has a high potential for replacing the extrusion process since it could save the investment and energy cost around 88% and 72% when the system was operated by closed loop.

ACKNOWLEDGEMENTS

The authors would like to thank the Thailand Research Fund for the financial support this work. In addition, we wish to thank the SPM animal feed company limited for their cooperation while working at site.

REFERENCES

AACC. (1976) Official and Tentative Methods of the American Oil Chemists' Society. 2nd ed., AACC Method 22-90.

AOAC. (1965) Official Methods of Analysis. 10th ed., Washington, D.C.

Araba, M. & Dale, N.M. (1990) "Evaluation of protein solubility as an indicator of underprocessing of soybean meal". Poultry Science, Vol.69, no.10, pp.1749-1752.

Faber, J.L. & Zimmerman, D.R. (1973) "Evaluation of infrared-roasted and extruder-processed soybeans in baby pig diets". Journal of Animal Science, Vol.36, no.5, pp.902-907.

Liener, I.E. (1994) "Implications of antinutritional components in soybean foods". Crit. Rev. Food. Sci. Nutr., Vol.34, pp.31-67.

Liener, I.E. & Kakade, M.L. (1980) "Protease inhibitors". Toxic Constituents of Plant Foofstuffs, Liener, I.E., Ed.; Acdamic Press : New York, pp.7-71.

Osella, C.A.; Gordo, N.A.; González, R.J.; Tosi, E.; Ré, E. (1997) "Soybean heat-treated using a fluidized bed". Lebensm. Wiss u.-Technology, Vol.30, pp.676-680.

Renner, R. & Hill, F.W. (1960) "Studies of the effect of heat treatment on the metabolizable energy value of soybeans and extracted soybean flakes for the chick". Journal Nutrition, Vol.70, pp.219-225.

Soponronnarit, S.; Rordprapat, W.; Wetchacama, S. (1998) "Mobile fluidized bed dryer". Drying Technology, Vol.16, pp.1501-1513.

Stephenson, E.L. & Tollet, L. (1959) "Processing of soybeans for broiler feeding". Feedstuffs, Vol.31, pp.8.

Waldroup, P.W. (1982) "Whole soybeans for poultry feeds". World's Poultry Science Journal, Vol.38, pp.28-35.

White, C.L.; Greene, D.E.; Waldroup, P.W.; Stephenson, E.L. (1967) "The use of unextracted soybeans for chicks". Poultry Science, Vol.46, pp.1180-1185.

Wright, K.N. (1981) "Soybean meal processing and quality control". Journal American Oil Chemists' Society, Vol.58, pp.294-300.

DRYING 2002

DRYING 2002

Editors: C.W. Cao Y.K. Pan
X.D. Liu Y.X. Qu
Series editors: A S Mujumdar

IDS 2002
BEIJING CHINA

Volume ABC

DRYING 2002

DRYING 2002

Editors: C.W. Cao Y.K. Pan X.D. Liu Y.X. Qu

Series editors: A S Mujumdar

IDS 2002 BEIJING CHINA

Volume ABC

Drying' 2002-Proceedings of the 13th International Drying Symposium (IDS' 2002)
Beijing, China, 27-30 August' 2002, vol. B, pp. 1332

OPTIMIZATION OF HEAT PUMP FRUIT DRYER

U. Teeboonma, S. Soponronnarit and J. Tiansuwan

School of Energy and Materials
King Mongkut's University of Technology Thonburi
Suksawat 48 Rd., Bangkok 10140, Thailand

ABTRACT

The most important factors to examine the optimal condition of heat pump fruit dryer (HPD) and to minimize HPD cost are recycle air ratio (RC), evaporator bypass air ratio (BP), airflow rate (m_a), and drying air temperature (T_{di}). Mathematical models of papaya and mango glace' drying using HPD are developed and validated with the experimental results. The optimal criterion is minimum annual total cost per evaporating-water. From a simulation results, the optimal operating conditions of papaya glace'drying are as follows: recycle air ratio of 100%, evaporator bypass air ratio of 69%, airflow rate of 20.72 kg/h-kg of dry product, and drying air temperature of 55°C. The best conditions of mango glace' drying are recycle air ratio of 100%, evaporator bypass air ratio of 71%, airflow rate of 30.88 kg/h-kg of dry product, and drying air temperature of 55°C. For sensitivity analysis, the annual total cost per evaporating-water of HPD is linearly proportional to both interest rate and electricity price, as well as decreased with increasing life-time.

Keywords and Phrases: heat pump drying; mathematical model

INTRODUCTION

Conventional hot air dryers are widely used for fruit drying. However, the high temperature drying usually causes low quality of products. Heat pump dryer (HPD) is an alternative to dry products with lower energy consumption, less relative humidity, and lower temperature (Va'zquez et al., 1997). Preliminary studies found that the qualities of dried agricultural products using heat pump, in terms of color and smell, were better than those products using conventional hot air dryer (Prasertsan and Saen-Saby., 1998, Soponronnarit et al., 1998 and Strommen, 1994). To maximize specific moisture extraction rate, Clement et al. (1993) recommended that evaporator bypass air ratio should be around 60-70%. To minimize energy consumption, Soponronnarit et al. (1998) suggested that evaporator bypass air ratio should be around 86-90%. Achariyaviriya et al. (2000a) had developed empirical model of heat pump dryer and recommended that the best conditions giving maximum specific moisture extraction rate were airflow rate of 10.3 kg/h-kg of dry papaya, evaporator bypass air ratio of 85%, recycle air ratio of 100%, and drying air temperature of 56°C. In term of economics of using heat pump, electrical heater, and fuel burner to dry grain, Meyer and Grevenstein (1992), recommended that heat pump dryer was more economical than other systems though higher initial cost. Similar suggestion was made by Prasertsan and Sean-Saby's work (1998).

The purpose of this research is to find out the optimal operating conditions for minimizing annual total cost per evaporating-water of HPD. Mathematical model of papaya and mango glace' drying using heat pump dryer are developed, validated, and implemented in this optimization program.

MATERIALS AND METHODS

DEVELOPMENT OF MATHEMATICAL MODEL

The schematic diagram of heat pump fruit dryer is illustrated in Figure 1. The mathematical model of heat pump fruit dryer mainly comprises two parts: drying model and heat pump model. Both parts can be developed using the principle of mass and energy conservation for each control volume. The details are as follows:

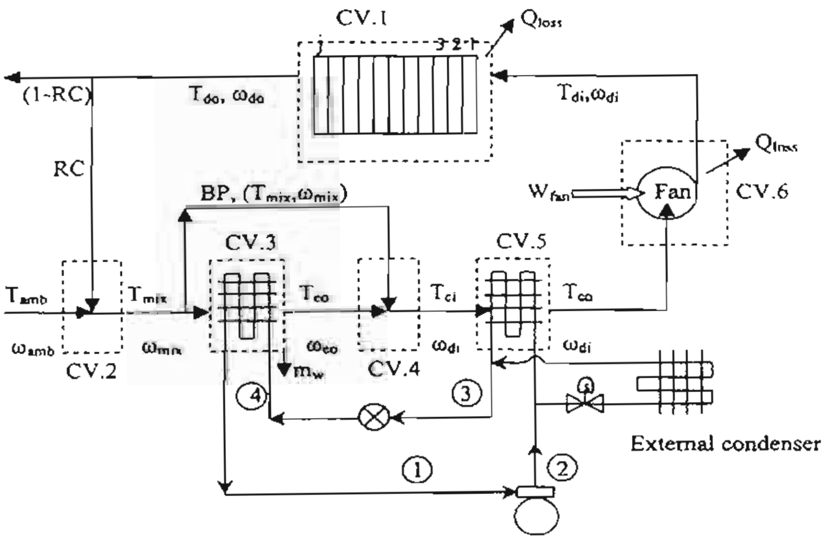


Figure 1. Diagram of heat pump dryer. (CV = Control volume)

Drying model

The near equilibrium model regarding thermal equilibrium between drying air and product is used in this study. The drying chamber in control volume 1 (CV.1) is divided into j sections as shown in Figure 1. This model is modified from previous drying model works (Achariyaviriya et al., 2000a, Chou et al., 1994, and Prasertsan et al., 1996). Energy and mass balance equation of CV. 1 for each j section, therefore, can be expressed generally as equations (1) and (2).

$$C_a T_{i,j} + \omega_{i,j}\left(h_{fg} + C_v T_{i,j}\right) + R\, C_{pd}\theta_{i,j} = C_a T_{o,j} + \omega_{o,j}\left(h_{fg} + C_v T_{o,j}\right) + R\, C_{pd} T_{o,j} + Q_{loss,j} \tag{1}$$

$$\omega_{f,j} - \omega_{i,j} = \left(M_{i,j} - M_{f,j}\right)R \tag{2}$$

The equations of drying kinetics, equilibrium moisture content, and specific heat of both mango and papaya glace' are obtained from Achariyaviriya et al. (2000b). Contrasted to Chou et al., 1994 and Prasertsan et al., 1996, drying rate varies with drying time.

Finally, fan power (CV.6) is given by equation (3).

$$W_{fan} = \frac{m_a}{3600}\left(C_a + \omega_{di} C_v\right)\left(T_{di} - T_{co}\right) + Q_{loss,6} \tag{3}$$

Heat pump model

There are three major models: compressor, evaporator and condenser. Details of each component are as follows:

1. Compressor model

   The polytropic compression process is assumed throughout this study. Hence, the compressor power of reciprocating compressor, described by Threlkeld (1972), is given by equation (4).

$$W_{comp} = \frac{m_r P_{comp,i} v_{comp,i}}{3600}\left(\frac{n}{n-1}\right)\left\{\left(\frac{P_{comp,o}}{P_{comp,i}}\right)^{\frac{n-1}{n}} - 1\right\} \tag{4}$$

2. Evaporator model

   From CV.3, equations of mass and energy balance can be written as follows:

$$m_w = m_a(1 - BP)\left(\omega_{mix} - \omega_{eo}\right) \tag{5}$$

$$Q_e = \frac{m_a}{3600}(1 - BP)\left\{C_a T_{mix} + \omega_{mix}\left(h_{fg} + C_v T_{mix}\right) - C_a T_{eo} - \omega_{eo}\left(h_{fg} + C_v T_{eo}\right) - m_w h_w\right\} \tag{6}$$

3. Condenser model

   From CV.5, equation of energy balance can be written as follows:

$$Q_{c,int} = \frac{m_a}{3600}\left(C_a + \omega_{di} C_v\right)\left(T_{co} - T_{ci}\right) \tag{7}$$

Furthermore, moist air and HCFC-22 properties are calculated using Wilhelm (1976) and Cleland (1986) equations, respectively.

Optimization model

The assumptions of conditions are as follows:

1. Drying chamber capacity is 100 kg of fresh product. Average initial moisture content of papaya and mango glace' are 40 and 60 % dry basis (d.b), respectively. Based on the fruit drying industrial standard of Thailand, moisture content of those must be reduced to a final moisture content of 18%d.b.
2. The variation of final moisture content of product between tray inlet and tray outlet is less than 3%d.b. The moisture content of products at tray inlet is normally lower than that at tray outlet. This is due to the fact that a drying air temperature decreases with tray length whilst a relative humidity increases. Commercially, it is one of the most important factors.
3. Total operating time is not longer than 41 hours. Total operating time consists of drying and preparative time. If long drying time, it is risk for fruits to be decomposed by infection of microorganisms. On the other hand, if short drying time, results in large size of heat pump. In addition, preparative time of Thai fruit gardener is approximate 6 hours.
4. To maintain constant drying air temperature, the external condenser must be included in the system. From previous works, the suitable size of external condenser is 60% of internal condenser.
5. The assumptions of economic analysis are life-time of 5 years, salvage value at the end of life-time of 10% of capital cost, interest rate of 8%, maintenance cost of 5% of capital cost, and electricity price of 3 Baht/unit.

Objective function

In this study, it is the function of the annual total cost per evaporating-water of HPD. The total cost consists of drying chamber including trays, compressor, evaporator, condenser, fan, maintenance, and energy cost. The equation can be written as following:

Y = [Annual capital cost + Annual maintenance cost + Annual energy cost – Annual salvage] / Weight of annual evaporating-water

The drying chamber including trays and fan cost depend primarily on drying chamber capacity and airflow rate. The cost of compressor, evaporator, condenser, maintenance, and energy cost are depending on drying air temperature (T_{di}), evaporator bypass air ratio (BP) and recycle air ratio (RC) as well as airflow rate (m_a). Accordingly, the objective function can be expressed by equation (8).

$$\text{Minimize} \qquad Y = f(T_{di}, BP, RC, m_a) \tag{8}$$

Constraints

In this study, there are four major constraints.

$$45 \le T_{di} \le 55^{\circ}C \tag{9}$$

$$0 \le BP < 100\% \tag{10}$$

$$0 \le RC \le 100\% \tag{11}$$

$$400 \le m_a \le 2000\,kg/h \tag{12}$$

Cost functions

Price of heat pump dryer components in Thailand is gathered to construct the cost functions by using regression method. Size of drying chamber including trays is fixed with drying capacity. Moreover, the fan cost in this study is fixed because the selected fan size can cover over the range of airflow rate constraint. Consequently, three cost functions of cost function of compressor, evaporator, and condenser, can be expressed as equation (13), (14) and (15), respectively.

$$p_{comp} = -912W_{comp}^2 + 5088W_{comp} - 582 \tag{13}$$

$$p_e = -3Q_e^2 + 224Q_e + 735 \tag{14}$$

$$p_c = 8.26Q_c^2 + 184Q_c + 888 \tag{15}$$

The three cost functions, based on 1/08/2001 (1 USS = 44.5 Baht), are satisfied with the following conditions: $0.75 \le W_{comp} \le 3.0$ kW, $2.0 \le Q_e \le 7.0$ kW, and $2.2 \le Q_c \le 8.0$ kW.

SOLUTION ALGORITHM

The optimization procedure, using grid search method, can be summarized as follows:

1. The initial design variables are evaporator bypass air ratio of 0%, drying air temperature of 45°C, airflow rate of 400kg/h. and recycle air ratio of 0%. The procedure starts with the simulation model to calculate the size of heat pump components and energy consumption. The annual total cost per evaporating-water is then calculated and recorded for comparing with that of the next loop.
2. The value of BP is checked. If BP is within the constraint, the same calculation process is repeated using the BP steps of 1%.
3. The value of RC is checked. If RC is within the constraint, the similar calculation process is repeated using the BP steps of 1% and reset the value of BP as initial value.
4. The value of T_{di} is checked. If T_{di} is within the constraint, the same calculation process is repeated using the T_{di} steps of 1°C and reset the values of BP and RC as initial values.
5. The value of m_a is checked. If m_a is within the constraint, the similar calculation process is repeated using the m_a steps of 10 kg/h and reset the values of BP, RC and T_{di} as initial values.

The procedure is repeated until all workable conditions are calculated and also compared. Finally, the optimum conditions can be presented.

SENSITIVITY ANALYSIS CONDITIONS

The economical analysis of papaya and mango glace' drying are based on the annual total cost per evaporating-water of HPD. The assumptions in this study are as follows: interest rate of 6-10%, electricity price of 2-4 Baht/unit, and life-time of 1-10 years.

RESULTS AND DISCUSSION

VALIDATION OF MATHEMATICAL MODEL

The experimental conditions of papaya glace' drying for verifying model conducted by Rukprang (1996) are recycle air ratio of 100%, evaporator bypass air ratio of 63%, drying air temperature of 50°C, and airflow rate of 40.94 kg/h-kg of dry product. The conditions of mango glace' drying conducted by Ratsie (1998) are recycle air ratio of 100%, evaporator bypass air ratio of 63%, drying air temperature of 50°C, and airflow rate of 71.62 kg/h-kg of dry product.

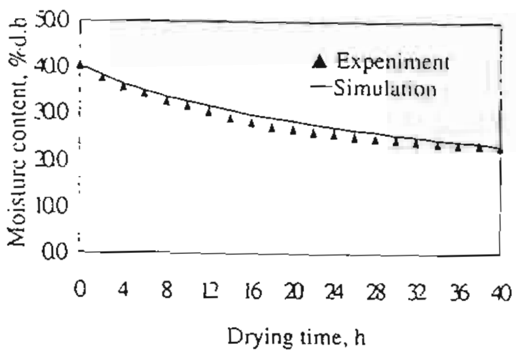


figure 2. Moisture content evolution of papaya glace' drying

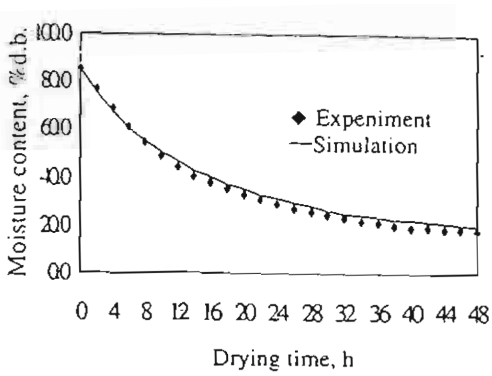


figure 3. Moisture content evolution of mango glace' drying

Figures 2 and 3 show the moisture content evolution of papaya and mango glace' drying. The simulation results are fairly agreeable with the experimental ones. The former is, however, slightly higher.

THE OPTIMAL CONDITIONS OF PAPAYA GLACE'DRYING

In cases where dried product leaving the drying chamber does not meet the desired particle The optimal operating conditions are evaporator bypass air ratio of 69%, recycle air ratio of 100%, drying air temperature of 55°C, airflow rate of 20.72 kg/h-kg of dry product, 255 batches/year, and evaporating water of 4007 kg/year. The optimal annual total cost is 17.25 Baht/kg evaporating-water, capital cost of 4.31 Baht/kg evaporating-water, maintenance cost of 0.92 Baht/kg evaporating-water, and energy cost of 12.02 Baht/kg evaporating-water. Heat pump components are 1.59 kW hermetic reciprocating compressor operating on HCFC-22, a 5.08 kW evaporator, a 6.67 kW internal condenser, and a 4.00 kW external condenser.

THE OPTIMAL CONDITIONS OF MANGO GLACE'DRYING

From simulation results, the optimal conditions of mango glace'drying are evaporator bypass air ratio of 71%, recycle air ratio of 100%, drying air temperature of 55°C, airflow rate of 30.88 kg/h-kg of dry product, 222 batches/year, and evaporating water of 5827 kg/year. The optimal annual total cost is 12.72 Baht/kg evaporating-water, capital cost of 2.99 Baht/kg evaporating-water, maintenance cost of 0.64 Baht/kg evaporating-water, and energy cost of 9.09 Baht/kg evaporating-water. Heat pump components are 1.64 kW hermetic reciprocating compressor operating on HCFC-22, a 5.92 kW evaporator, a 7.56 kW internal condenser, and a 4.54 kW external condenser.

SENSITIVITY ANALYSIS

Figure 4 shows the relationships between interest rate and annual total cost per evaporating-water of both products. Annual total costs per evaporating-water of both products are slightly increased with increasing interest rate. When the interest rate is 1% increased, annual total costs per evaporating-water of papaya and mango glace' drying are about 0.056 and 0.053% increased, respectively.

The relationships between electricity price and annual total costs per evaporating-water of both products are shown in Figure 5. Annual total costs per evaporating-waters are linearly proportional to electricity price. The annual total costs per evaporating-waters of papaya and mango glace' drying are approximately 0.67 and 0.69% per unit of electricity price increased, respectively. Increasing percentage of mango glace' drying cost is higher than that of papaya glace' drying because both compressor power and airflow rate of mango glace' drying are higher.

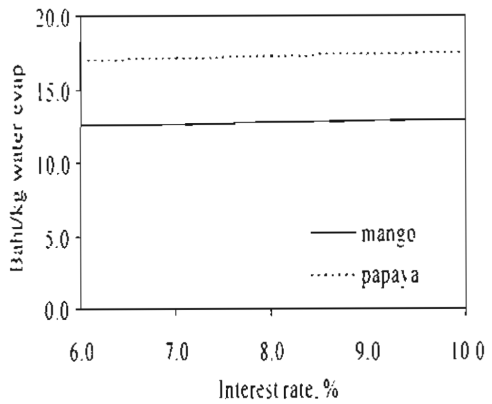


Figure 4.Relationships between interest rate and annual total costs per evaporating-water of mango and papaya glace' drying

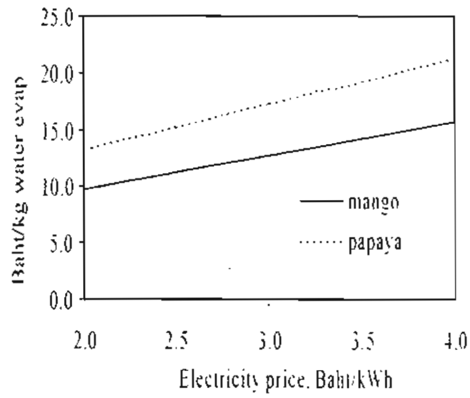


Figure 5.Relationships between electricity price and annual total costs per evaporating-water of mango and papaya glace' drying

Figure 6 presents the relationships between life-time and annual total costs per evaporating-water of both products. The annual total costs per evaporating-waters are exponentially decreased at first for three years of life-time. When life-time is longer than six years, annual total costs per evaporating-water of both products are nearly constant.

COMPARATIVE OPTIMAL CONDITIONS AND COST OF PAPAYA AND MANGO GLACE' DRYING

Airflow rate

The limitation of variation of final moisture content and total operating time affect significantly on airflow rate. Though, drying with low airflow rate can save energy cost, the various final moisture content or total operating time or both of them are not corresponding to assumption conditions. The optimal airflow rate of mango glace' drying is higher than that of papaya glace' drying. Based on the same conditions, effective diffusion coefficient of mango glace' drying is lower than that of papaya glace' drying because of different tissue structure (Achariyaviriya et al., 2000b).

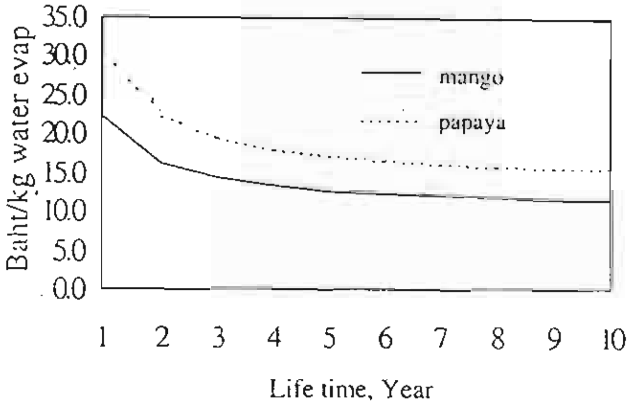


Figure 6. Relationships between life-time and annual total costs per evaporating-water of mango and papaya glace' drying

Evaporator bypass air ratio

Evaporator bypass air ratio (BP) affects on the quantity of moist air condensation or size of evaporator. High evaporator bypass air ratio can reduce size of evaporator, but drying time may be long because of low moist air condensation. The optimal airflow rate of mango glace' drying is higher than that of papaya glace' drying, so optimal evaporator bypass air ratio is higher. However, the net airflow passing evaporator of mango glace' drying is rather higher. Consequently, evaporator in case of mango glace' drying is larger than that in case of papaya glace' drying.

Drying air temperature

The optimal drying air temperature of both products is similar. As a result of high drying air temperature, the drying time can be reduced and results in high evaporating-water per year. Consequently, the annual total cost per evaporating-water is low.

Recycle air ratio

Under the average climatic of Thailand (Dry bulb temperature = 27°C, Relative humidity =73%) and physical properties of both products, heat pump dryer operated on closed-loop system is more economical than that operated on opened-loop or partially closed-loop system. It can be explained by the fact that both sensible heat and latent heat of air leaving the drying chamber are recovered. Additionally, it is easy to control drying conditions due to no effect of ambient conditions.

Annual total cost per evaporating-water

In case of mango glace' dryer, the size of heat pump is rather large and causes high capital cost; moreover, the number of batch per year of mango glace' drying is 15% lower than that of papaya glace' drying. Nevertheless, total cost per evaporating-water of mango glace' drying is approximately 26% lower than that of papaya glace' drying. It is clearly seen that the quantity of annual evaporating-water of mango glace' drying is about 45% higher than that of papaya glace' drying.

CONCLUSIONS

The theoretical models of papaya and mango galce' drying by using heat pump were developed and validated with the experimental results. They are then employed as tools in optimization. The optimal conditions are sought by using grid search method. Based on simulation results, the optimal conditions of each product are not similar, particularly for airflow rate and evaporator bypass air ratio. This is due to the difference of product properties such as initial moisture content and effective diffusion coefficient (microstructure of fruit tissue). For sensitivity analysis, annual total cost per evaporating-water is linearly related to both interest rate and electricity price and inversely proportional to life-time. Electricity price is the highest sensitive whereas interest rate is the lowest.

NOMENCLATURE

C	specific heat	kJ/kg °C
m	mass flow rate	kg/h
n	polytropic index	-
P	pressure	kPa
p	price	Baht
Q	heat load	kW
R	mass ratio of grain to air	kg dry matter / kg dry air
T	temperature	°C
W	power	kW

GREEK LETTERS

ω	humidity ratio	kg H_2O / kg dry air
θ	initial temperature at each loop of product	°C

SUBSCRIPTS

a	air
c	condenser
comp	compressor
d	drying
e	evaporator
f	final
i	inlet or initial
int	internal

j	section number
o	outlet
pd	product
r	refrigerant

ACKNOWLEDGEMENT

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

REFERENCES

1. Achariyaviriya, S., Soponronnarit, S. and Terdyothin, A., 2000a, Mathematical model development and simulation of heat pump fruit dryer, Drying Technology, 18(1&2) pp. 479-491.
2. Achariyaviriya, S., Soponronnarit, S. and Terdyothin, A., 2000b, Diffusion models of papaya and mango glace' drying, Drying Technology, 18(7) pp. 1605-1615.
3. Chou, S.K., Hawlader, M.N.A., Ho, J.C., Wijeysundera, N.E. and Rajasekar, S., 1994, Performance of a heat-pump assisted dryer, International Journal of Energy Research, 18 pp. 605-622.
4. Cleland, A.C, 1988, Computer subroutines for rapid evaluation of refrigerant thermodynamic properties, International Journal of Refrigeration, 9 pp.346-351.
5. Clement, S., Jai, X. and Jolly, P., 1993, Experimental verification of a heat pump assisted-continuous dryer simulation model, International Journal of Energy Research, 17 pp. 19-28.
6. Meyer, J.P. and Greyvenstein, G.P., 1992, The drying of grain with heat pumps in South Africa: A techno-economic analysis, International Journal of Energy Research, 16 pp. 13-20.
7. Prasertsan, S., Saen-saby, P., Ngamsritrakul, P. and Prateepchaikul, G., 1996, Heat pump dryer part1: simulation of the model, International Journal of Energy Research, 20 pp. 1067-1079.
8. Prasertsan, S. and Saen-saby, P., 1998, Heat pump drying of agricultural materials, Drying Technology, 16(1&2) pp.235-250.
9. Ratsie, S., 1998, Drying of mango glace' by heat pump, Master of Engineering Thesis, School of Energy and Materials, King Mongkut's University of Technology Thonburi, Thailand.
10. Rukprang, P., 1996, Fruit drying using heat pump, Master of Engineering Thesis, School of Energy and Materials, King Mongkut's University of Technology Thonburi, Thailand.
11. Soponronnarit, S., Nathakaranakule, A., Wetchacama, S., Swasdisevi, T. and Rukprang, P., 1998, Fruit drying using heat pump, RERIC International Energy Journal, 20 pp. 39-53.
12. Strommen, I., 1994, New applications of heat pumps in drying Processes, Drying Technology, 12(4) pp. 889-901.
13. Threlkeld, J.L. 1972, Thermal environmental engineering, Prentice Hall, New Jersey, U.S.A.
14. Va'zquez, G., Chenlo, F., Moreria, R. and Cruz, E., 1997, Grape drying in a pilot plant with a heat pump, Drying Technology, 15(3&4) pp.899-920.
15. Wilhelm, L.R., 1976, Numerical calculation of psychometric properties in SI unit, Transaction ASAE, 19(2) pp.318-321.

Proceedings of the International Conference on Innovations in Food Processing Technology and Engineering, 11-13 December 2002, AIT, Bangkok, Thailand

CHARACTERISTICS OF PARBOILED RICE IN SUPERHEATED-STEAM FLUIDISED-BED DRYER

Chaiyong Taechapairoj[1], Somchart Soponronnarit[1],
Somkiat Prachayawarakorn[2]
[1]School of Energy and Materials, [2]Faculty of Engineering
King Mongkut's University of Technology Thonburi
Suksawat 48 Road, Bangkok 10140, Thailand
E-mail: chaiyong_t@yahoo.com

ABSTRACT

Characteristic properties of parboiled rice in a superheated-steam fluidised-bed dryer have been investigated. The operating conditions were carried out at the initial moisture contents of 41-42.5% dry basis, three beds heights of 10, 12.5 and 15 cm, superheated steam temperatures of 150 and 170°C with a constant pressure of 106.1 kPa and a fixed superficial velocity of 3.1 m/s. The experimental results were shown that the inlet temperature had much more effect on removal of moisture content than the bed height. For the paddy quality, the head rice yield after reducing moisture content to 18% dry basis was higher than 60% (average reference value of 52%) whereas the color of rice whiteness become darker and white belly is significantly affected by the inlet temperature. The lipid contents of samples were dependent upon the temperatures and the bed depths. Higher temperature and lower bed depth provided the slightly high lipid content. In addition, the lower values of peak viscosity, breakdown viscosity and setback viscosity were also found under high temperature.

Keywords. rapid visco analyzer (rva); superheated steam; white belly.

INTRODUCTION

Parboiled rice is made from paddy, which is subjected to a hydrothermal treatment. In parboiling process, paddy is steeped in water until it attains moisture content between 42 and 54% dry basis (d.b.). The traditional parboiling process involves soaking rough rice overnight or longer in water at ambient temperature, followed by boiling or steaming the steeped rice at 100°C to gelatinize the starch, causing the grain expandsion until the hull's lemma and palea start to separate. The parboiled rice is then cooled and sun-dried before storage and milling. In modern parboiling practice, paddy is soaked in hot water, steamed to complete gelatinization and dried while still jacketed in their brown bran layer. This forces the nutrients from the bran layer to be penetrated into the endosperm and seals some of the vitamins into the rice kernel before the rice is milled (Dimopoulos & Muller, 1972). Parboiled rice is a more nutritious form of rice than non-enriched, regular milled white rice.

According to the above-mentioned parboiled rice process, it is now very inconvenient in practice. The steaming and drying stages for such typical parboiled rice process can be combined in one stage when the superheated-steam is applied. The superheated-steam drying has been attracted a wide interest in many applications (Blasco and Alvarez, 1995; Iyota et al., 2002 ; Looi et al., 2002). Earlier studies have illustrated some advantages of superheated-steam drying (Tang et al., 2000; Iyota et al., 2001; Tatermoto et al., 2002): high drying rate and deodorization of products.

The purpose of the present work is to produce the parboiled rice by superheated-steam fluidized-bed. The drying characteristics of paddy, pasting properties and lipid content, are investigated. In addition, the head rice yield, whiteness and white belly of paddy were also determined.

MATERIALS AND METHODS

Sample Preparation

Long grain paddy of Chainat1 (CNT1) variety from the Rice Experiment Station at Ayutthaya Province, Thailand, was used for experiments. In preparation, paddy was cleaned and soaked at initial temperature of 80^{o}C for 3.5 h to obtain moisture content ~ 42% d.b.. Then, the water was drained out and the paddy was tempered in the same tank for 1 h prior to drying.

Drying

After soaking, paddy samples were taken to a batch superheated steam fluidised dryer as shown in Fig. 1. The system of the fluidised-bed dryer consists of five main components: a cylindrical chamber with an inner diameter of 15 cm and a height of 100 cm, a 13.5 kW electrical heater for converting saturated steam to superheated steam, a backward-curved blade centrifugal fan driven by a 2.2 kW motor, a reverse flow cyclone and a small boiler with a 31 kg/h capacity of generated steam. Superheated steam temperature was controlled by a PID controller with an accuracy of ± 1^{o}C. Before using steam for drying, hot air at a given temperature was used for warming up the system until the temperature in every part reached the desired temperature. Then, the steam was replaced accordingly. The steam generator was generated the saturated steam at 106 kPa (absolute pressure) with the corresponding temperature of 100°C. When the saturated steam was flowed through the electrical heater, the additional heat was supplied to raise the steam temperature up to the desired level. It was subsequently flowed through the fluidised bed dryer. After that, the dust particles and the immature grains being suspended in the exhaust steam were collected at the cyclone. Finally, the cleaned exhaust steam was reused again.

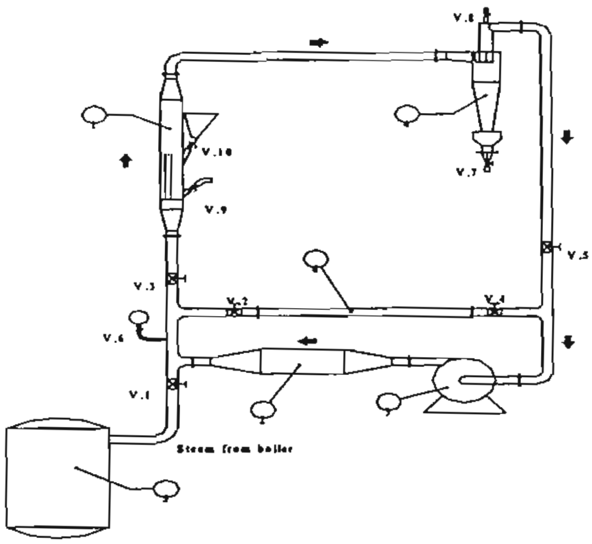


Fig. 1. A schematic diagram of the superheated-steam fluidized bed dryer: 1) fluidized bed dryer, 2) heater, 3) fan, 4) cyclone, 5) boiler and 6) bypass line

The experimental conditions were set up as follows: initial moisture contents of 41-42.5% dry basis, bed depths of 10-15 cm, superheated steam temperatures of 150-170°C, a fixed superficial velocity of 3.1 m/s. Temperatures at different positions were measured by Chromel-Alumel thermocouples (Type K) connected to a data logger with an accuracy of ± 1°C. After drying, the paddy kernels were slowly cooled down to ambient temperature and kept in a polypropylene bag. Then, it was ventilated with an ambient airflow rate until its moisture content reached 16 % dry basis. Finally, A 300 g sample was kept in a seal plastic bag for 2 weeks before testing head rice yield, whiteness and white belly.

The moisture content of paddy was determined by an electrical air oven at a temperature of 103°C for 72 h. Paddy qualities in terms of head rice yield and whiteness was determined quantitatively and compared to the reference sample (paddy dried by the ambient air). The methods were followed with the guideline of the Ministry of Agriculture and Cooperatives, Thailand. Head rice is defined as milled rice having kernel length at least three-fourths of its original length. The head rice yield was calculated from the mass of white rice that remains as head rice after milling divided by the mass of paddy sample.

White rice grains were graded manually into translucent, discoloured and while belly grains. The colour of translucent rice samples was measured by a Kett digital whiteness meter (Model C-300). Before measuring the colour of sample, the whiteness meter was calibrated with a white coloured reference, presenting a standard value of 86.3.

RVA measurement

Pasting properties of parboiled rice flour were determined by a Rapid Visco Analyser model-4 (Newport Scientific Pty Ltd., Warriewood, Australia) utilising Thermocline. Following AACC Method 61-02 (AACC, 1995), the sample (3 g, 14% moisture basis) was mixed with distilled water in an RVA aluminum canister to make the total weight of slurry 28 g. The mixture was stirred at 900 rpm for 10 s, then at 160 rpm for the remainder of the test. The mixture was held at 50^{O}C for 1 min and then heated to 95^{O}C at 12^{O}C/min. After that, holding at 95^{O}C was 2.5 min. The sample was then cooled down to 50^{O}C at 12^{O}C/min, where it was kept for 2.1 min. These tests were done in duplicate. A plot of paste viscosity in arbitrary RVA unit (RVU) versus time was used to determine the peak viscosity (PV), trough final viscosity (FV), breakdown viscosity (BKV = PV- trough) and setback viscosity (SBV = FV-trough). Peak viscosity (PV) indicates the water-biding capacity of mixture. It is often correlated with the final product quality, and also provides an indication of the viscous load likely to be encountered by a cook. Breakdown viscosity measures the degree of disintegration of the granules or paste stability. Setback viscosity is a measure of gelling or retrogradation tendency (Dengate, 1984).

Lipid content

Lipid content was determined using the method of Folch et al. (1957) with some modifications for the rice flour extraction. Parboiled rice flour was extracted with chloroform-methanol (2:1 by volume). The extract was shaken for 5 min and settled for 30 min before being decanted through folded filter paper. One-fourth of filtrate of water was added and shaken to create two liquid phases. The lower phase and the upper phase were composed of chloroform-methanol-water in the corresponding proportions of 86:14:1 and 3:48:47 (by volume), respectively. The final lipid extract was evaporated at 35^{O}C under stream of oxygen-free nitrogen.

RESULTS AND DISCUSSION

Drying curves

Fig. 2 shows the relationship between the grain temperature, moisture content and drying time. Since the steam was condensed, the grain in moisture content was observed during the first half minute of drying time and the grain temperature increased rapidly to higher than 80°C. At this period, the moisture content of paddy varied between 40-43% d.b., depending on the temperature and bed depth. After the temporary rise in moisture content, it started decreasing monotonically.

As inlet superheated steam temperature was increased, the drying rate was increased. On the other hand, the drying rate was decreased with increase in the bed depth (10-15 cm). According to these results, it indicated that the inlet superheated steam temperature had a greater effect on the drying rate than the bed depth.

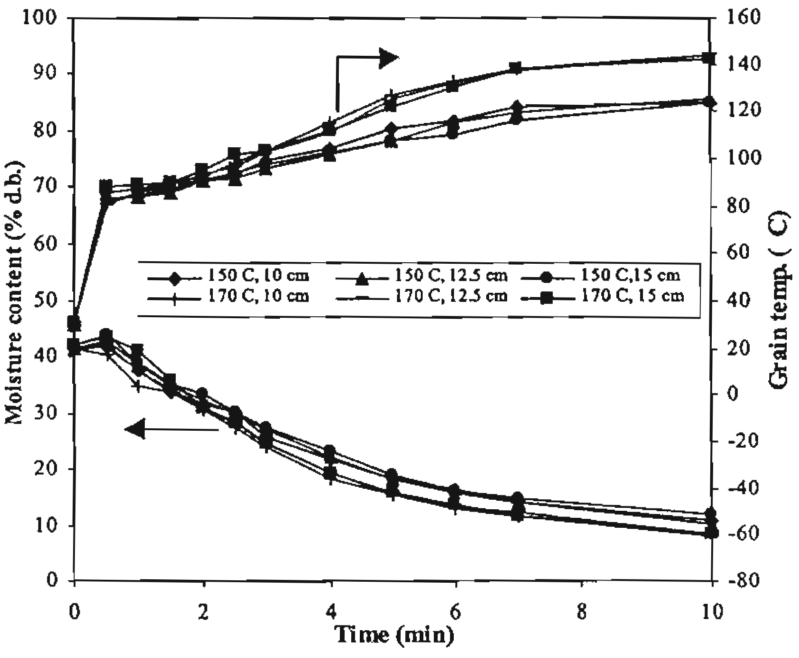


Figure 2. Variation in moisture content and grain temperature of paddy at different bed depths and inlet superheated-steam temperatures

Head rice yield

The relationship between head rice yield and final moisture content in superheated-steam fluidized bed dryer at different conditions is shown in Fig. 3. The head rice yield is rather constant and has almost the same value for the final moisture content above 18% d.b.. This may be due to the effect of partial gelatinization occurred in the kernel. To confirm our results, we measured quantitatively the white belly occurred, as will be shown in Fig. 4. In gelatinization steps, when high moist paddy is heated up and grains temperature reaches the temperature between 65 and 70^{O}C, its starch cell will swell and loss of birefringence (Atwell et al., 1998; Zobel, 1984). This causes the disintegration of protein bodies in the endosperm. As a result, the starch and protein expand and fill in the internal air spaces between granules. The starch granules are then closely appressed, and creates strong cohesion between them, resulting in reduction of fissures and cracks within the grain kernels (Ranghavendra Rao & Juliano, 1970). Consequently, the paddy becomes rigid and tough, and can resist milling. As shown in Fig. 3., the head rice yields rapidly decreases if the moisture content of paddy reduces below 18% d.b.. This may be caused by the prevalent contribution of the tension near the surface and the compression at the centre of kernel, leading to fissure development although some of the fractures and void space on the grain surface disappeared in the early drying period due to swelling of starch granules.

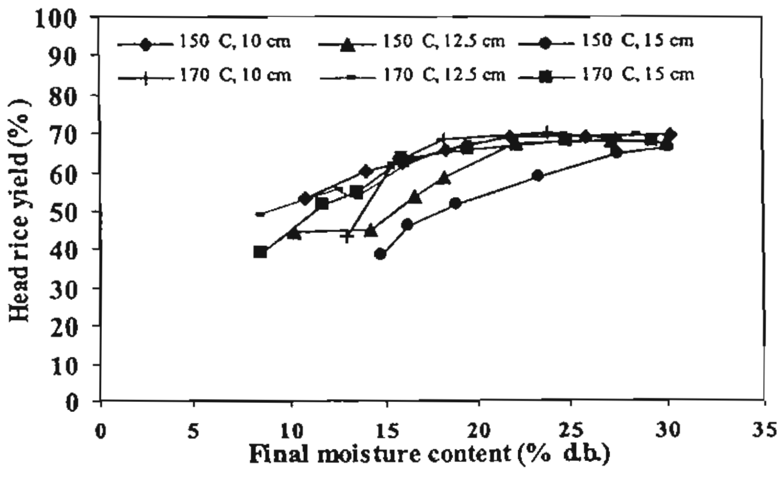


Figure 3. Relationship between head rice yield and final moisture content duringdrying in superheated steam

White belly

Kernel which has an opaque white area higher than 50% of its total area is considered as the white belly category, according to Thai Standard Rice (Ministry of Commerce, Thailand, 1997). The percentage of white belly shown in Fig. 4 was calculated by the number of white belly kernels divided by the total number of head rice kernels. It was found that the superheated steam temperature influenced on percentage of white belly. As the percentage of white belly decreased with increase in superheated steam temperature. However, bed depths had no effect on the percentage of white belly. According to these results, it indicated that the higher temperature caused the lower moisture reduction, thus giving the higher gelatinization.

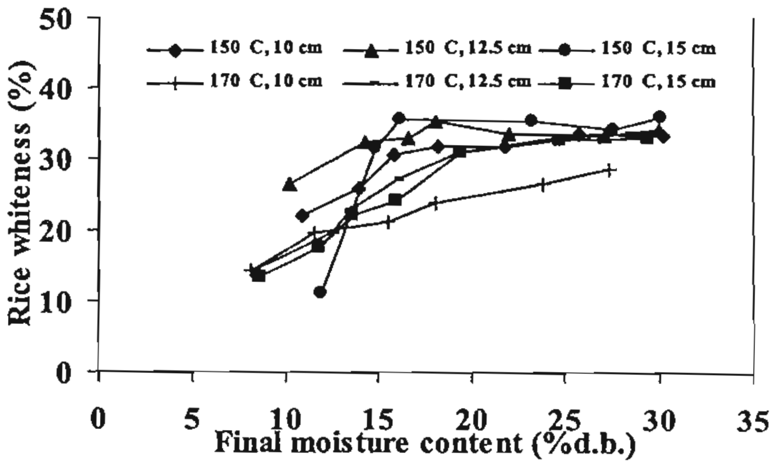


Figure 4 Relationship between percentage rice with white belly and final moisture content during drying in superheated steam

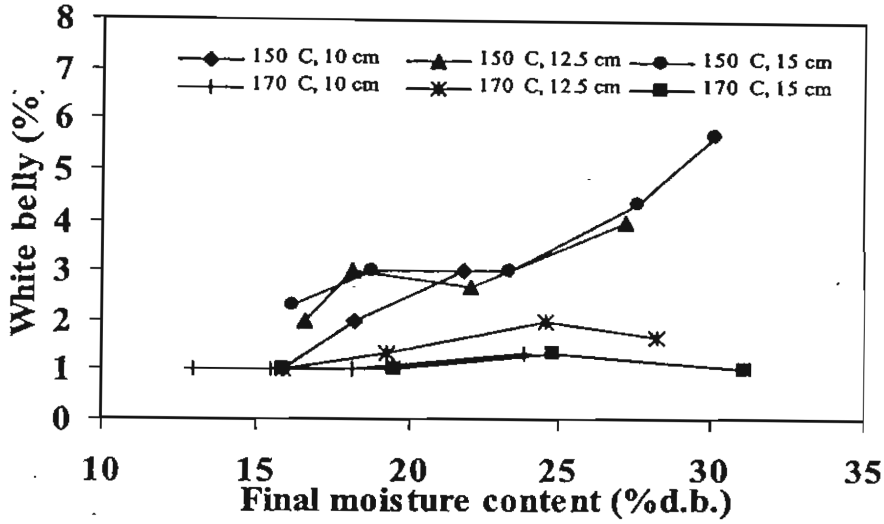


Figure 5. Relationship between rice whiteness and final moisture content during drying in superheated steam (Initial moisture content = 41.5-42.5% d.b.)

Rice whiteness

The change of the color of samples at steam temperatures of 150 and 170°C and initial moisture content of 42% d.b. is shown in Fig. 5. The rice whiteness curves in the first 3 minutes of drying steeply changes from the original value of 43-43.5. The rice whiteness is rather constant and has almost the same value (30-35) for the final moisture content in range of 18-30% d.b.. The main cause of the change in the color is partly due to the steam condensation onto the paddy surface. The resulting bran and the colour pigments contained in the husk covered around kernel are dissolved and then absorbed by the endosperm. To justify the explanation, the quantity of bran after milling was checked, representing by the values of 5.3-7.1% which are lower than that from the reference sample (13-15%). In addition, it can be elucidated by testing the lipid content as shown in Table 1, showing higher lipid contents in the parboiled rice than in the raw rice.

The temperature used for drying is also important factor influencing the degree of whiteness; the higher temperature causes the lowering of whiteness. The illustration of this effect can be seen in the case of bed depth 10 cm and temperatures 150 and 170°C, showing a value of 34 at 150°C and 26 at 170°C for both at the final moisture content of 24-26% d.b.

Table 1. Changes in the amount of lipid content in milled white parboiled dried under superheated-steam drying

	Raw white rice	Parboiled rice					
		150°C			170°C		
		10 cm	12.5 cm	15 cm	10 cm	12.5 cm	15 cm
Lipid content (%dry basis)	0.20	0.40	0.23	0.23	0.65	0.35	0.21

Pasting behaviour

Typical RVA viscograph of pastes prepared from raw rice and parboiled rice under superheated steam is shown in Fig. 6 and in Table 2. The PV, BKV and SBV of the parboiled rice dried at 150 and 170°C are found to be lower than those of the raw rice. Moreover, the two major parameters of flour pasting curve, PV and BKV, considerably decrease with increase in superheated steam temperature. The gelatinization during drying makes the granules more resistant to hydration when heated to water. This leads to reduce the swelling of parboiled rice flour at high temperature. The resulting PV and BKV decrease (Fig. 6). For FV and SBV, they are often used as an indicator of the firmness of cook rice (Ranghavendra Rao & Juliano, 1970; Priestley, 1976; Ali and Bhattacharya, 1980). High value of FV, SBV indicate high firmness texture. The viscograph shows that the higher the superheated-steam temperature, the lower the firmness.

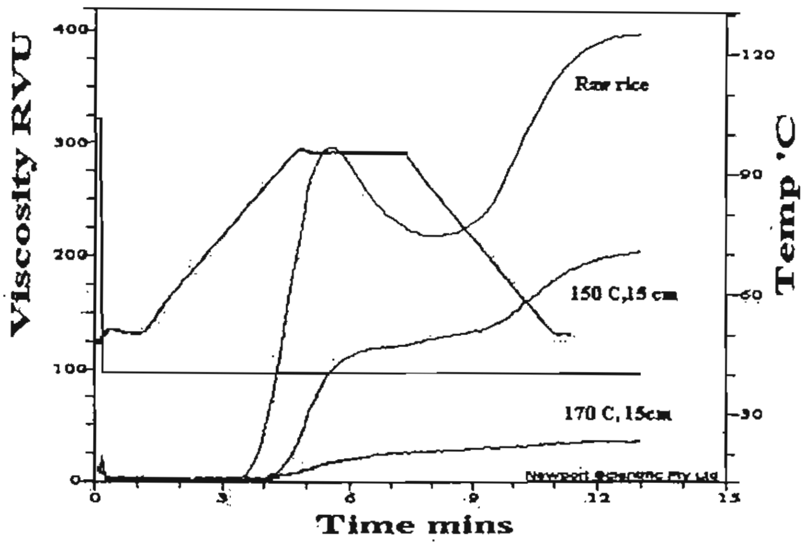


Figure 6. Viscograph of raw and parboiled rice dried under superheated steam

Table 2. Effect of superheated steam temperature on pasting properties of raw and parboiled rice flour

	PV rvu	Trough rvu	BKV rvu	FV rvu	SBV rvu
Raw rice	296	218	79	399	181
150°C 15 cm	120	113	8	205	92
170°C 15 cm	25	20	5	35	15

CONCLUSIONS

The characteristics of pasting properties of parboiled rice dried by superheated-steam fluidized-bed drying under temperatures, 150 and 170°C, and bed depths, 10, 12.5 and 15 cm, were determined. The values of peak viscosity, breakdown viscosity of parboiled rice were lower than those of the raw rice. The inlet temperature had much more effect on the removal of moisture than the bed height. The high temperature and low bed depth provided the high lipid content. Rice whiteness was apparently darken at high temperature. In addition to such qualities, the percentage of white belly kernels decreases with increase in inlet drying temperature. To maintain high head rice yield, it is recommended that the final moisture content of paddy should not be dried lower than 18% dry basis.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to the Thailand Research Fund for financial support, Faculty of Engineering and Industrial Technology Silpakorn University for supporting RVA instrument, Division of Agricultural Engineering, Department of Agriculture for testing quality of milling and Pathum Thani Rice Research Center for testing the physical quality of rice.

REFERENCES

AACC ,1995, Approved method of the American Association of Cereal Chemist (9th ed.). St. Paul, MN: AACC.

Ali, S. Z. and Bhattacharya, K. R. 1980, Pasting behaviour of parboiled rice, J. Texture Stud., 11, 239-245.

Atwell, W.A., Hood, L.F., Lineback, D.R., Varrino Marston, E., and Zobel, H.F. 1998, The terminology and methodology associated and basic starch phenomena, Cereal Foods World, 33, 306-308, 310-311.

Blasco, R. and Alvarez, P.I., 1995, Flash drying of fish meals with superheated steam: isothermal process, Drying Technology, 17(4&5),. 775-790.

Dengate, H. N. 1984, Swelling pasting, and gelling of wheat starch, Advances in Cereal Science and Technology, Vol. 6, Pomeranz, Y. (ed), American Associated Cereal Chemistry, St.Paul, Mn, USA, pp.49-82.

Dimopoulos, J. S., and Muller, H.G. 1972, Effect of processing conditions on protein extraction and composition and on some other physicochemical characteristics of parboiled rice, Cereal Chemistry, 49, 54-62.

Folch, J., Lees, M. and Sloane-Stanley, G.H. 1957, A simple method for isolation and purification of total lipids from animal tissues, Journal of Biological Chemistry, 226, 497-509.

Iyota, H., Nishimura, N., Onuma, T. and Nomura, T., 2001, Drying of sliced raw potatoes in superheated steam and hot air, Drying Technology, 19 (7), 1411-1424

Iyota, H., Nishimura, N., Nomura, T., Konishi, Y. and Yoshida, K., Effect of initial initial steam condensation on color changes of potatoes during drying in superheated steam, Proceedings of the 13th International

Drying Symposium, Beijing, China, 27-30 August 2002, Vol. B, 1352-1359.

Looi, A.Y., Golonka and Rhodes, M., 2002, Drying kinetics of single porous particles in superheated steam under pressure, Chem. Eng. J. , 87, 3, 329-338.

Ministry of Commerce, Thailand, 1997, Thai Standard Rice, http://203.151.17.19/document/grain/english/standard.htm, last revised on 20 June 2002.

Priestley, R. J., 1976, Studies on parboiled rice. I. Comparison of the characteristics of raw and parboiled rice, Food Chemistry, 1, 5-14.

Ranghavendra Rao, S. N. and Juliano, B. O. 1970, Effect of parboiling on some physicochemical properties of rice, Journal Agricultural Food Chemistry, 18, 289-294.

Tang, Z., Cenkowski, S. and Muir, W.E., 2000, Dehydration of sugar-beet pulp in superheated steam and hot air, Trans. of the ASAE, 43(3), 685-689.

Tatermoto, Y., Mawatari, Y., Sakurai, K., Noda, K. and Komatsu, N. Drying characteristics of pours material in superheated steam fluidized bed, Proceedings of the 13th International Drying Symposium, Beijing, China, 27-30 August 2002, Vol. A, 624-633.

Zobel, H.F. (1984). Gelatinization of starch and mechanical properties of starch pastes, In R. L. Whistler, J. N. Bemiller, & E. F. Paschall, Starch: Chemistry and technology 2nd ed. (pp.285-309), London: Academic Press.

Proceedings of the International Conference on Innovations in Food Processing Technology and Engineering, 11-13 December 2002, AIT, Bangkok, Thailand

EXPERIMENTAL STUDY OF MULTISTAGE DRYING OF PADDY USING A SERIES OF CONVECTIVE HOT-AIR AND FIR IRRADIATION

Naret Meeso[1] Adisak Nathakaranakule[2] Thanid Madhiyanon[3] and Somchart Soponronnarit[2]
[2]School of Energy and Materials
King Mongkut's University of Technology Thonburi
Suksawat 48 Road, Bangkok 10140, Thailand
[3]Factulty of Engineering
Mahanakorn University of Technology
Bangkok 10530, Thailand

ABSTRACT

The use of far-infrared radiation (FIR) in the drying of hygroscopic materials such as agricultural crops considerably reduces the drying time due to direct transmission of its energy to the water inside the material. The objective of this work is to experimentally investigate drying kinetics of paddy as well as milling quality for each relevant process. The experiments were conducted into three categories which dried paddy from 33 down to around 16.5%d.b.. FIR displays the remarkable feature of drying capability interpreted by experimental observation that there is a presence of phenomena of moisture immigration from inside toward the outside of grain theoretically caused by heat generated within the grain. This gave an idea to combine convective and FIR drying for enhancing drying efficiency. However, FIR may can be used for accelerating moisture diffusion inside the grain but not for completely moisture leveling such as a main function of tempering. This was reflected by the experimental results that drying paddy by a series connection of convective and FIR drying without tempering process but immediately followed by cooling process adversely affected to milling quality of grain. The other experimental categories that had tempering process in-between were able to be applied without having any substantial effects on grain quality.

Keywords. far-infrared radiation; fluidized bed; processing time; tempering; ventilation; multistage drying

INTRODUCTION

Several studies have been made to investigate and determine strategy to manage moist paddy after harvest. Soponronnarit (1995) proposed a systematic which included aeration of ambient air through moist paddy bulk during the waiting period before drying. Two-stage drying was necessary to reduce the moisture content (MC) of paddy rapidly to 23%dry basis (d.b.) in the first stage using a fluidized bed dryer. This was followed by slow drying in the second stage to reduce the MC from 23 to 16%d.b. using aeration of ambient air in a shed or other types of dryer.

The above strategy, when paddy was dried in the first stage, the immigration of moisture from inside toward the surface of grain contributed to the relative large moisture gradient inside the kernel. This problem could be solved by applying tempering in-between. Steffe et al. (1979) studied the suitable tempering period of paddy between the first and the second stages of drying. They found that the MC of tempered paddy could reduce more than paddy without tempering; besides, head rice yields (HRY) were more than paddy without tempering after drying in the second stage. Steffe and Singh (1980) found that the drying temperature and the drying time were the main factors for tempering. With this principle, Soponronnarit et al. (1999) used the tempering and the ambient air ventilation as the paddy drying process after fluidized bed drying. Their results showed that MC was reduced from 33 to 16.5%d.b. within approximately 53 minutes. Additionally, paddy quality was acceptable. Poomsa-ad et al. (2002) suggested to maintain paddy quality highly, the moist paddy should not be reduced lower than 22.5%d.b. in the first stage corresponding to lower grain temperature of 100°C and then followed by tempering for 30 minutes. Under this condition, the relative HRY was higher than 100%.

For far-infrared radiation (FIR) drying, Sakai and Hanzawa (1994) described that the radiation was emitted as an electromagnetic wave from the heat source. The radiation impinged upon a product surface; moreover, it penetrated directly into the product. One part of the radiative energy was absorbed by the product; besides, it induced the changes in the vibrational state of water molecules, which led to heating. This state corresponded to wavelengths in the range of 2.5-100 μm (FIR) [Shimizu (1991)]. Generally, the main components of foodstuffs are water and organic compounds, such as proteins and starches, which absorbed FIR at wavelengths greater than 2.5 μm [Shoji (1986), Sandu (1986)]. Bekki (1991) found that maximum absorption of IR by medium grain rough rice occurred at a wavelength of 2.5 μm. The significant absorption was also noted at wavelengths of 6.0 and 9.5 μm.

In the study of penetration depth of FIR in grains, Sandu (1986), Nindo et al. (1995) found that FIR penetrated just under 1 mm; therefore, FIR drying was appropriate for the thin layers of small grains such as paddy and wheat. The objective of this study is to experimentally investigate the combination effects of hot air convective and far-infrared irradiation on drying kinetics and milling quality of paddy.

MATERIALS AND METHODS

To provide high MC paddy for the experiments, paddy was rewetted and kept in a cooling room at temperature of 3-5°C for 7 days. Before the experiments, paddy was kept in ambient air until grain temperature was closed to ambient air temperature.

Table 1. The experimental conditions of the paddy drying process

The drying processes		The conditonal numbers 1	2	3
FB	Air temp.,(°C)[(1)]	150	150	150
	Bed thickness,(cm)[(1)]	9.5	9.5	9.5
	Air velocity,(m/s)[(1)]	2.6	2.6	2.6
	Time,(min)[(1)]	2 and 3	2 and 3	2 and 3
FIR	Temp. of the radiative chamber, (°C)	80	80	×
	Bed thickness	a single layer of grain	a single layer of grain	×
	The distance between radiator and paddy, (cm)[(2)]	15	15	×
	Time,(sec)	30	30	×
TEM	Temp., (°C)	80	×	80
	Time,(min)	15 and 20	×	30
AAV	Bed thickness,(cm)[(1)]	3	3	3
	Air velocity,(m/s)[(1)]	0.15	0.15	0.15
	Time,(min)	60	60	60

• Condition No.1 consists of fluidized bed (FB) drying, far-infrared radiation (FIR), Tempering (TEM), and ambient air ventilation (AAV).
• Condition No.2 consists of FB, FIR, and AAV.
• Condition No.3 consists of FB, TEM, and AAV.
(1) Recommendation adopted from Poomsa-ad et al. (2002).
(2) Recommendation adopted from Abe and Afzal (1997).

This experiment was divided into three conditions as explained in Table 1. The first condition, paddy was dried by a batch-type fluidized bed dryer as shown in Fig. 1. Next, it was propagated by a box-type FIR dryer as shown in Fig. 2, which set the temperature of the radiative chamber equal to the paddy temperature after fluidized bed drying. After that, 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 fluidized bed drying. Lastly, it was ventilated by ambient air ventilator, which had a diameter of 20 cm. The second one was the same as the first one except no tempering. The third one is like the first one except no FIR irradiation, but tempering time was not so equal as the first one.

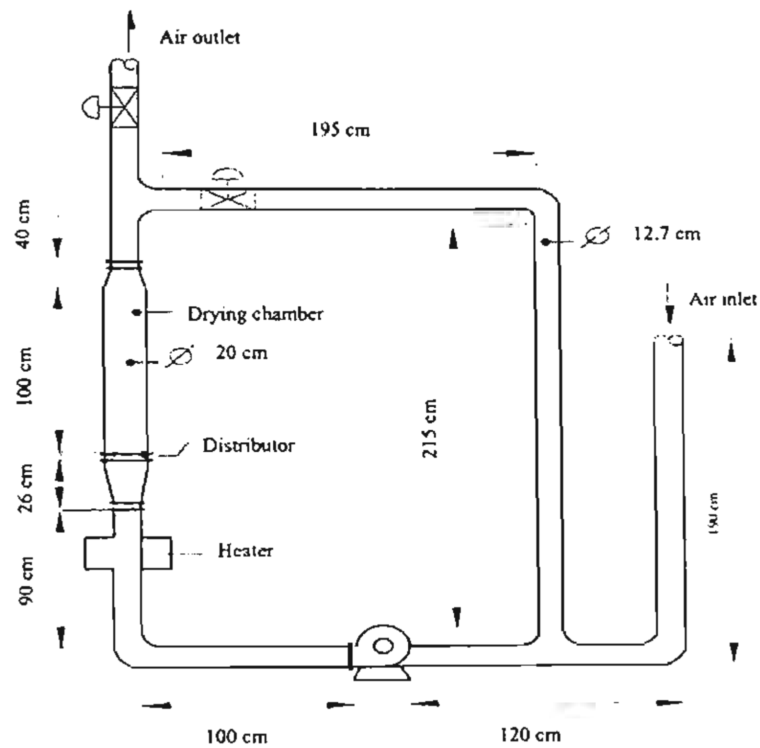


Figure 1.
Schematic diagram of the batch-type fluidized bed dryer

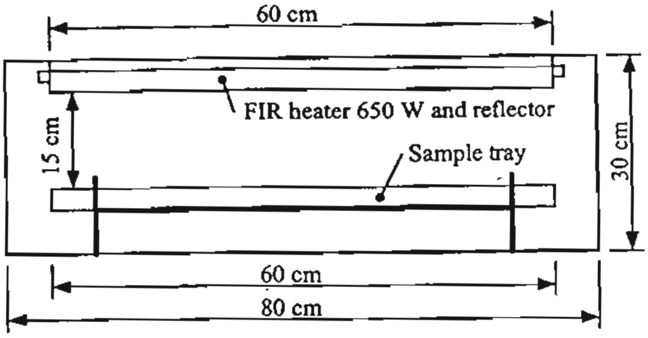


Figure 2. Schematic diagram of the box-type FIR dryer

The paddy samples of each conditions were taken every step for both MC and quality determinations. The MC of paddy was determined by drying 50 g of paddy sample at temperature of 103°C for 72 hours in an oven. The paddy quality in terms of head rice yield and whiteness was determined by using the test method of the Ministry of Agriculture and Cooperatives; moreover, whiteness was measured by Kett C-300 whiteness tester.

RESULTS AND DISCUSSION

Evolution of moisture content of paddy during three drying processes

Table 2 (a) and (b) present the experimental results of grain moisture for each of successive stage corresponding to the operating conditions as shown in Table 1. In general, MC was reduced from 32.3-34.9%d.b. to 19.4-22.0%d.b. before ventilated by ambient air. An approximate decrease of 0.5-1.0%d.b. during FIR irradiation period was observed which caused by radiative energy penetrating into the grain kernel and resulted in water vaporized there and thus moisture vapour migrated toward the surface of grain.

To highlight the effects of FIR irradiation and tempering, moisture ratio were plotted versus cooling time as shown in Fig. 3(a),(b). All moisture ratio curves in both figures represented different experimental conditions; however, the general shape of these curves were very similar. These curves displayed that MC of grain progressively dropped immediately at the beginning of the brief transition and thereafter gradually reduced at the rate nearly be the same. This was not surprising for high moisture reducing rates of the first and third experimental conditions with having tempering process in-between. The tempering period allows moisture move from the inside to outside of grain, which comparatively easily to evaporate when exposes to high airflow rate in cooling process. A longer tempering time gave a higher rate of moisture reduction. Therefore, the moisture ratio of third condition had the fastest decreasing rate, when compared with other conditions, especially during the first five minutes of grain cooling process. As a result, final moisture content after ambient air ventilation was the lowest. However, for the second condition, that grain dried by fluidized bed and followed by FIR without tempering, the results also reflected an evidence of moisture redistribution inside the kernel although the moisture ratio reducing rate of this condition was the slowest. This can be explained by a phenomena of FIR irradiation that heat is generated inside the material leading to moisture transfer in the same direction of heat flow, i.e., from the inside to outside surface of material, and hence increasing moisture at the outer surface with a corresponding decrease in the moisture inside the material. This result thus may raise an idea to allow moisture to be continuously conveyed to the grain surface by FIR irradiation and simultaneously removed by the convective hot air should may enhance the drying rate in falling rate period of convective-drying. This means that combined convective-FIR drying may be more effective than the successive drying processes in aspect of drying kinetics especially in falling rate period that drying kinetic under tempering process governed by internal factors. However, this hypothesis should be further investigated.

Table 2. Evolution of moisture content (MC) of paddy during three drying processes

(a)		**The conditonal numbers**		
The drying processes		1	2	3
Initial MC	(% d.b.)	32.3	32.3	32.3
MC after FB	(% d.b.)	23.0	23.1	22.3
MC after FIR	(% d.b.)	22.2	22.1	×
MC after TEM	(% d.b.)	×	×	×
MC after AAV	(% d.b.)	18.1	18.4	17.4

- Conditional No.1 consists of fluidized bed (FB) drying 2 min, far-infrared radiation (FIR) 30 sec, Tempering (TEM) 20 min, and ambient air ventilation (AAV) 60 min.
- Conditional No.2 consists of FB 2 min, FIR 30 sec, and AAV 60 min.
- Conditional No.3 consists of FB 2 min, TEM 30 min., and AAV 60 min.

Table 2 (Continued)

(b)		The conditonal numbers		
The drying processes		1	2	3
Initial MC	(% d.b.)	34.9	34.9	34.9
MC after FB	(% d.b.)	20.8	20.9	19.6
MC after FIR	(% d.b.)	20.3	20.0	×
MC after TEM	(% d.b.)	×	×	×
MC after AAV	(% d.b.)	16.6	16.8	15.0

- Conditional No.1 consists of fluidized bed (FB) drying 3 min, far-infrared radiation (FIR) 30 sec, Tempering (TEM) 15 min, and ambient air ventilation (AAV) 60 min.
- Conditional No.2 consists of FB 3 min, FIR 30 sec, and AAV 60 min.
- Conditional No.3 consists of FB 3 min, TEM 30 min., and AAV 60 min.

Evolution of head rice yield of paddy during three drying processes

The experimental results for two minutes drying by fluidized bed as presented in Table 3(a) illustrated that HRY was reduced about 2.8-3.5%d.b. after grain experienced in irradiation by FIR for 30 seconds. Even grains just dried by fluidization air normally have almost uniform of temperature inside, which follows from high Biot number relating to the internal diffusion to the external convective resistance for cereal grains. However when FIR dissipating inside, temperature distribution within the grain will be non-uniform. This results to stresses developed within the grain and may hence leading to lower head rice yield at the end of FIR period. This can be reasoned that radiative power is not uniformly absorbed by each point inside the grain since the intensive of power absorption generally depends on the depth from grain surface and water concentration associated with the relative interior point, thus causes the non-uniform heat generation and temperature within the grain.

(a)

(b)

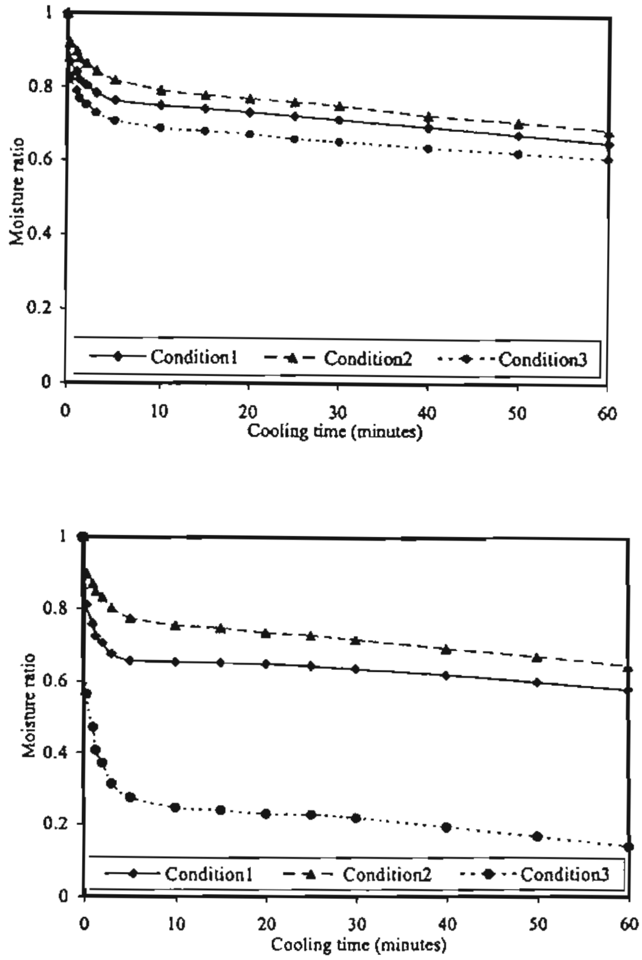


Figure 3. Effect of FIR and tempering on moisture content decreased by ambient air ventilation

The results from Table 3(a) suggested that to minimize grain breakage, tempering process that results in moisture and stress relaxation must be taken into account before grain entering to cooling process such as experiments under the first and third conditions. This also inlines with the study of Poomsa-ad et al. (2002). The experiment followed the second condition that starting drying process from convective-drying, followed by FIR and then immediately cooling by ambient air significantly affected head rice yield. This can be attributed to the compressive stress developed near the outer grain surface by the large moisture gradient resulted from sharp decrease in surface grain moisture at the beginning of transition period. Despite of the presence of some degree of moisture relaxation during FIR drying which directly assisted to release stress developed during convective drying as reflected by the MR curves of second condition in Figure 3(a) and (b); however, this relaxation was not much enough to counteract the stress developed during cooling period. The effect of tempering was also clearly seen from the result of Table 3(b) that HRY corresponding to 30 min-tempering (condition 3) is higher compared with that of 15 min-tempering, this is influenced by more completely moisture leveling of 30 minutes-tempering and hence more resistance to the stresses promoted in the latter process . The serious loss in grain quality for 3 minutes drying by fluidized bed as shown in Table 3 (b) resulted from grain staging in hot air for too longtime until grain MC reached to the level that was not flexible to release moisture stresses developed within the grain. This observation can be conferenced by the study of Poomsa-ad et al. (2002).

Table 3. Evolution of head yield (HRY) of paddy during three drying processes

(a)		The conditonal numbers		
The drying processes		1	2	3
Initial HRY	(%)	48.4	48.4	48.4
HRY after FB	(%)	48.2	47.7	47.4
HRY after FIR	(%)	45.4	44.2	×
HRY after TEM	(%)	NA	×	49.5
HRY after AAV	(%)	47.4	28.8	46.5

• All experimental conditions were the same as shown in Table 2(a)

(b)		The conditonal numbers		
The drying processes		1	2	3
Initial HRY	(%)	40.7	40.7	40.7
HRY after FB	(%)	16.9	17.2	13.8
HRY after FIR	(%)	11.8	12.3	×
HRY after TEM	(%)	NA	×	15.0
HRY after AAV	(%)	12.4	2.5	16.0

• All experimental conditions were the same as shown in Table 2(b)

Evolution of whiteness of paddy during three drying processes

Table 4 showed whiteness of paddy after drying of three conditions. All experiments showed that whiteness in the first, second and third conditions decreased about 6, 7.1 and 7.8 points respectively. For all conditions whiteness was in a good criteria as comparison with the commercial criterion (approximately 37).

Table 4. Evolution of whiteness (wh) of paddy during three drying processes

The drying processes		The conditonal numbers		
		1	2	3
Initial wh	(point)	52.9	52.9	52.9
wh after FB	(point)	49.5	48.6	49.5
wh after FIR	(point)	48.1	48.2	×
wh after TEM	(point)	NA	×	48.2
wh after AAV	(point)	46.9	45.8	45.1

• All experimental conditions were the same as shown in Table 2(a)

CONCLUSIONS

1. FIR experimentally presents the potential for a remarkable ability to facilitate moisture diffusion inside the grain with a consequence of arising an idea to use combined convective and FIR drying which FIR is used as a supplementary heat source to overcome the limitation of drying rate in the falling period.

2. Relaxing moisture gradients, on the other hand relaxing moisture stresses, developed in the proceeding convective drying period by FIR could not resist moisture stresses promoted during cooling period caused by sharp decrease in MC. This leads to attain substantial loss in milling quality.

3. As result from (2), it is able to conclude that tempering process is still necessary to achieve high milling quality neither process having FIR or not.

ACKNOWLEDGMENTS

The author would like to thank the Thailand Research Fund for financial support, Pathumtani Rice Research Center for testing quality of milling and Department of Microbiology, King Mongkut's University of Technology Thonburi for providing a FIR dryer.

REFERENCES

Abe, T. and Afzal. T.M..1997. Thin-layer infrared radiation drying of rough rice. J. agric. Engng Res.. 67 : 289-297.

Bekki, E.. 1991. Rough rice drying with a far-infrared panel heater. Journal of the Japanese Society of Agriculture. 53(1) : 55-63.

Nindo, C.I., Kudo, Y. and Bekki, E.. 1995. Test model for studying sun drying of rough rice using far-infrared radiation. Drying Technology. 13(1&2) : 225-238.

Poomsa-ad, N., Soponronnarit, S., Prachayawarakron, S. and Terdyothin, A.. 2002. Effect of tempering on subsequent drying of paddy using fluidization technique. Drying Technology. 20(1) : 195-210.

Sakai, N., Hanzawa, T.. 1994. Applications and advances in far-infrared heating in Japan. Trends in Food Science & Technology. 5 : 357-362.

Sandu, C.. 1986. Infrared radiative drying in food engineering : a process analysis. Biotechnology Progress. 2 : 109-119.

Shimizu, M.. 1991.. New Food Industrial. 33(8) : 23-30.

Shoji, Y.. 1986. Machine equipment of Food Industrial. 23(2) : 63-67.

Soponronnarit, S.. 1995. Strategy for managing moist paddy. The Royal Institute Journal. 20(4) : 115-125 (in Thai).

Soponronnarit, S., Wetchacama, S., Swasdisevi, T. and Poomsa-ad, N.. 1999. "Managing moist paddy by drying tempering and ambient air ventilation. Drying Technology 17(1&2) : 335-344.

Steffe, J.F. and Singh, R.P.. 1980. Theoretical and practical aspects of rough rice tempering. Trans. of the ASAE. 23 : 775-782.

Steffe, J.F., Singh, R.P. and Bakshi, A.S.. 1979. Influence of tempering time and cooling on rice milling yields and moisture removal. Transaction of ASAE. 22 : 1214-1218, 1224.

Proceedings of the International Conference on Innovations in Food Processing Technology and Engineering, 11-13 December 2002, AIT, Bangkok, Thailand

COMPARATIVE STUDY OF FLUIDIZED BED PADDY DRYING USING HOT AIR AND SUPERHEATED STEAM

Wathanyoo Rordprapat, Somchart Soponronnarit,
Adisak Nathakaranakule[2], and Warunee Tia[2]
School of Energy and Materials
King Mongkut's University of Technology Thonburi
Suksawat 48 Road, Tungkru, Bangkok 10140, Thailand
E-mail: R_wathanyoo23@hotmail.com

ABSTRACT

Comparison of fluidized-bed paddy drying between using superheated steam and hot air was conducted to investigate rice qualities in terms of head rice yield, whiteness, and white belly. The experimental conditions were set at initial paddy moisture content of 43.3 and 45.5 % dry basis, drying temperature of 150°C, bed depth of paddy of 10 cm, and superficial velocities of 1.3 and 1.5 U_{mf}. The experimental results showed the advantage of superheated steam drying in head rice yield over hot air drying. Gelatinization process activated by suitable paddy temperature and moisture content, which resulted from high heat transfer rate of steam and early-stage condensation, was the main effect to this benefit. Higher increasing rates of head rice yield were seen in higher superficial velocities of steam and hot air due to high heat transfer rate of both media to paddy, which finally resulted in longer time for gelatinization process. The early-stage condensation and Mallard reaction; activated by heat, cause the whiteness of paddy dried by superheated steam decreased below that of hot air drying, which the change in color was only affected by the latter reaction. The gelatinization process also helped reducing white belly of milled rice in superheated steam and hot air drying, especially during the first minute of drying. Percentage of white belly below 1.5 % (good commercial level) could be achieved after five-minute drying.

Keywords. head rice yield, hot air, superheated steam, white belly

INTRODUCTION

Comparative study in fluidized-be drying between using superheated steam and hot air has not been found in the literature reviews above.

Feasibility of hot air fluidized bed paddy drying was studied by Sutherland and Ghaly, (1990). The authors found that the final moisture content significantly affects on the head rice yield. Soponronnarit et al., (1994) have contributed significantly to research on the fluidized bed paddy drying development. They found that minimum fluidized bed velocity (U_{mf}) was 1.65 m/s, for drying with hot air. Taweerattanapanish et al., (1999) studied the fluidized bed drying of paddy using hot air. The drying air temperatures were in the range of 140-150°C. They found that head rice yield was increased with reference rice. Inprasit et al.,(2001) studied the effects of drying air temperature and grain temperature, for different types of dryer designs and operations. The author found that at high grain temperature and longer tempering time the starch granules inside paddy were partially gelatinized, resulting in accelerated aging that affected the grain qualities in a way similar to parboiling of rice. Dhuchakallaya et al., (2000) studied the fluidized bed paddy drying using superheated steam, drying temperatures of 150 and 170°C. They found that minimum fluidized bed velocity (U_{mf}) was 2.55 m/s, head rice yield was increased whilst the color of paddy was changed from white to brown color, cooking and eating qualities found that similar parboiled rice. Iyota et al., (2001) studied drying of raw potato slices using atmospheric pressure superheated steam and hot air at 170 and 240°C. They found that, in case of superheated steam drying, moisture content temporarily increased due to steam condensation in the initial stage of drying as well as starch gelatinization rapidly developed. Meanwhile, in case of hot air drying, starch gelatinization occurs more slowly than with superheated steam drying, Furthermore, surface measurements showed that samples dried by superheated steam were more reddish than ones dried by hot air.

The past research works showed paddy dried by hot air or dried by superheated steam separately and no comparatively experiments were conducted thus, this research was to comparatively study the rice qualities dried using hot air and superheated steam fluidized bed dryers. The qualitative indicators used for evaluating the paddy are head rice yield, whiteness, and percentage of white belly.

MATERIALS AND METHODS

The schematic diagrams of superheated steam and hot air fluidized bed dryers are illustrated in Figure 1(a) and (b) respectively.

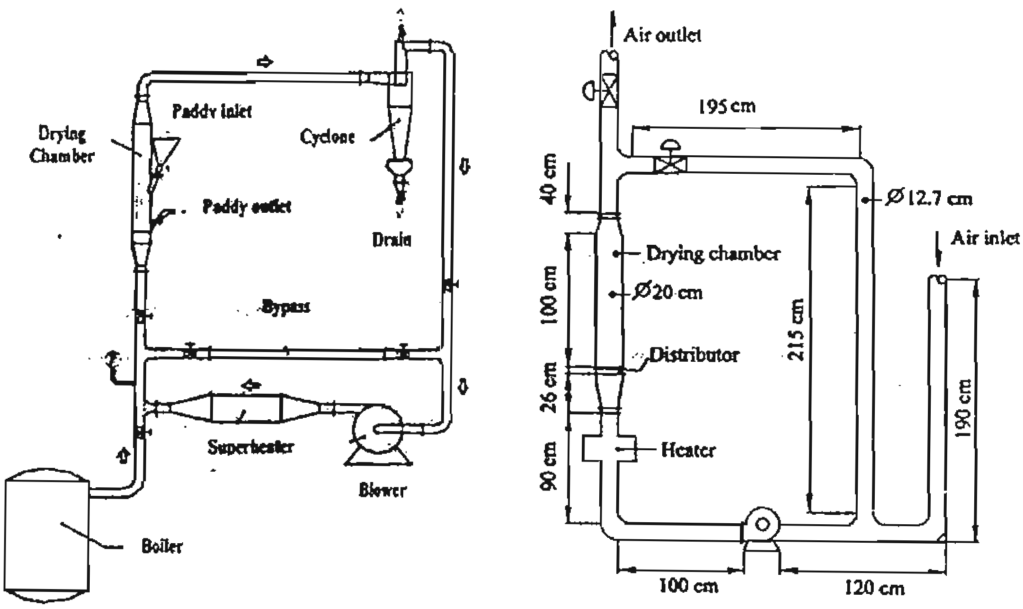
The superheated steam fluidized bed dryer comprised five components, i.e. a cylindrical chamber with an inner diameter of 15 cm and a height of 100 cm, a 13.5 kW electrical heater for converting saturated steam to superheated steam, a backward-curved blade centrifugal fan driven by a 2.2 kW motor, a reverse flow cyclone, and a small boiler capable of generating steam at a rate of 31 kg/h. Superheated steam temperatures were controlled by PID-controller with an accuracy of $\pm 1^{o}C$.

The hot air fluidized bed dryer, comprised three components: a cylindrical chamber with an inner diameter of 20 cm and a height of 100 cm, a 12 kW electrical heater, and a backward-curved blade centrifugal fan driven by a 1.5 kW motor.

(a) Superheated steam fluidized bed dryer (b) Hot air fluidized bed dryer

Figure 1.The schematic diagrams of fluidized bed dryers

Long grain rough rice (Supanburi 1 variety) from Pathum Thani Rice Research Center in Pathumthani Province, Thailand was used in experiments.



The rice was cleaned and soaked in water with initial temperature of 80°C for 4 h, before being tempered for another one hour. The experimental conditions were set up at initial paddy moisture content of 43.3 - 45.5% d.b, the bed depths of paddy 10 cm, superheated steam temperatures of $150^{o}C$, superficial velocities of 1.3 and $1.5U_{mf}$. Grain temperature and drying air temperature were measured by thermocouples Type K connected to a data logger giving an accuracy of $\pm 1^{o}C$. The moisture content of paddy was determined by hot air oven at a temperature $103^{o}C$ for 72 h. Paddy kernels after drying were slowly cooled down to ambient temperature and kept in a polypropylene bag. They, then, were gently ventilated with an ambient air until their moisture contents reached 16 % d.b. Finally, two samples were taken from the dried kernels. First 300 g sample was kept in a seal plastic bag for two weeks before testing head rice yield, whiteness and white belly. Another 250 g sample was shelled by Rubber Roll Husk, polished by Satake Rice Polisher, and graded by Rice Grader, before its color was measured by Kett degital whiteness meter (Model C-300), which was calibrated with a white reference color.

RESULTS AND DISCUSSION

Experimental results for on conditions of superheated steam and hot air drying, i.e. drying rate, grain temperature changing rate, head rice yield, whiteness, and percentage of white belly, are discussed as follow:

DRYING AND GRAIN TEMPERATURE CHANGING RATES

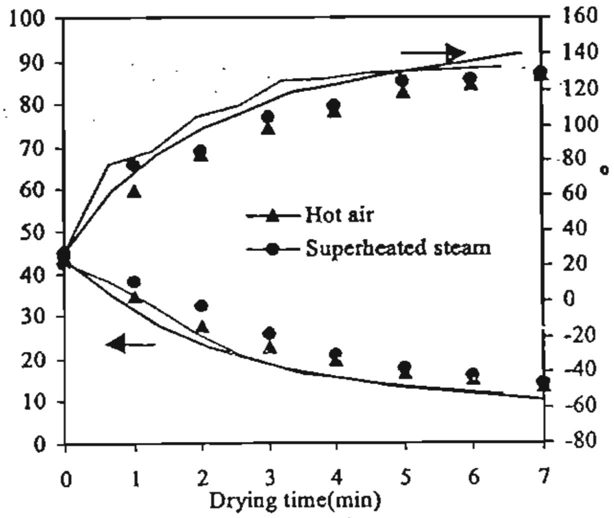


Figure 2. Drying and temperature changing rates of paddy dried by superheated steam and hot air (drying temperature 150°C, bed depth of paddy 10 cm and superficial velocity of $1.3U_{mf}$)

Figures 2 and 3 showed the changes of moisture contents and grain temperatures of paddy dried by superheated steam and hot air with drying times at a drying temperature 150°C, a bed depth of paddy 10 cm, and superficial velocities 1.3 and $1.5U_{mf}$.

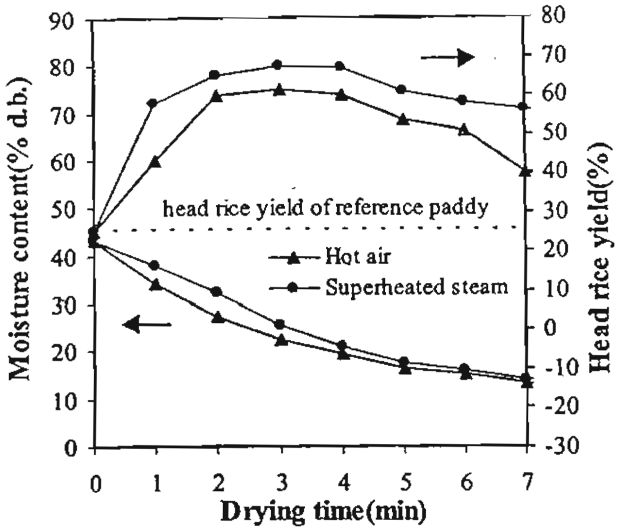


Figure 2 indicated that at the first four minutes, moisture content of paddy dried by superheated steam decreased slower than that dried by hot air. This was because moisture content of paddy dried by superheated steam increased due to condensation, which noticeably occurred during the first minute of this drying method. This early-stage condensation was also reported in researches of Iyota et al. (2001) and Dhudhakallya (2000). After four minutes, the drying rates of both drying methods were almost the same because of closer paddy temperature, leading to the equality of moisture diffusion inside the paddy. In contrary, the temperature of paddy dried by the superheated steam increased faster than that dried by hot air during the first minute of drying. This phenomenon was due to latent heat from steam condensation added to paddy during the early-stage of drying, and due to superior heat transfer properties of superheated steam compared with hot air (Mjumdar, 1995)

The drying and paddy temperature changing rates in the 1.5-U_{mf} (Figure 3) condition was in the same tendency as the 1.3-U_{mf}. Nevertheless, faster drying rate and higher increasing rate of paddy temperature were observed due to high mass flow rates of superheated steam and hot air in this condition.

Figure 3. Drying and temperature changing rates of paddy dried by superheated steam and hot air (drying temperature 150°C, bed depth of paddy 10 cm and superficial velocity of $1.5U_{mf}$)

Head rice yield

The changing rate of moisture content and head rice yield for drying temperature of 150°C, the bed depth of 10 cm, and the superficial velocities of 1.3 and $1.5U_{mf}$ are presented in figures 4 and 5

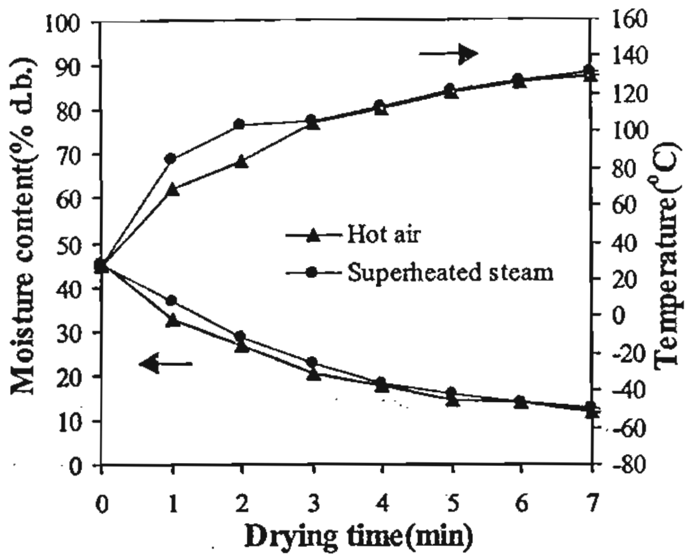


Figure 4. The changing rate of moisture content and head rice yield of paddy dried by superheated steam and hot air (drying temperature 150°C, bed depth of paddy 10 cm, and superficial velocity of $1.3U_{mf}$)

The changing rates of moisture content and head rice yield for superheated steam and hot air drying methods were presented with head rice yields of reference paddy of each method; obtained from paddy dried by ambient air, in Figures 4 and 5.

As shown in Figure 4, head rice yields of both drying methods increased beyond those of their references after first minute of drying. Furthermore, the head rice yield of paddy dried by superheated steam was higher than that dried by hot air. These results could be explained by the gelatinization process of starch, which helped joining cracks inside paddy kernels, therefore increasing head rice yield. This process activates at different suitable temperature and moisture content for each material. For paddy, the suitable temperature and moisture content for forming gel were at. 70-74°C and 24-25% w.b respectively (Kongseri, Ng, 2001, Taweerattanapanish et al 1999). From this suitable condition, temperature was the main factor causing the differences of head rice yield between paddy dried by both drying methods and reference paddy. Superheated steam made paddy temperature increase rapidly to gelatinization temperature at the early stage of drying, while the moisture content of paddy during this stage was still in the suitable range of the process (see Figures 1 and 2). This was the reason why the head rice yield of paddy dried by superheated steam was higher than that dried by hot air, which had slower temperature increasing rate and faster drying rate, thus less suitable condition for gelatinization. The slow gelatinization process in hot air compared with superheated steam drying was reported by Iyota et al. (2001). Head rice yields for both drying methods started to decrease after four minutes of drying. At this drying time, paddy kernels had high temperature and moisture gradient, causing stress develop inside the kernels, as a result cracked or broken rice after milling.

The results of head rice yield for the case of 1.5 U_{mf} (Figure 5) were similar to 1.3 U_{mf} and could be explained by the same reasons. Comparing between both velocities, it was found that the head rice yield in 1.5 U_{mf} case increased faster and dropped earlier than that in 1.3 U_{mf}. These were due to the faster reaching paddy gelatinization temperature and higher drying rate of the 1.5 U_{mf} case, resulted from higher mass flow rate, thus higher heat transfer rate between both medias and paddy kernels.

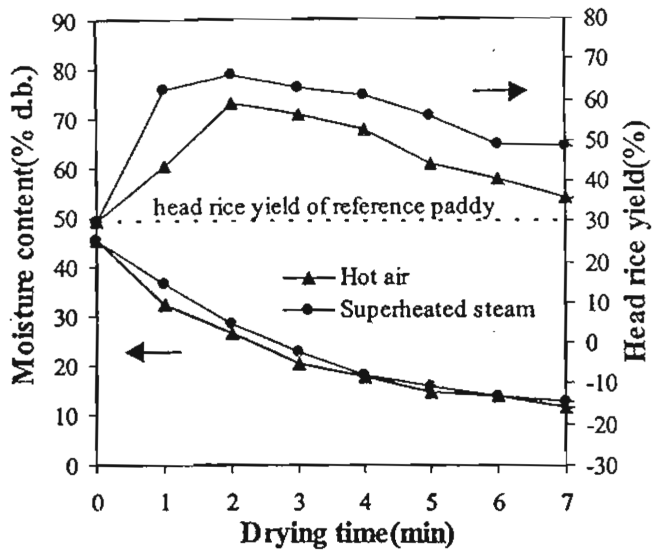


Figure 5. The changing rates of moisture content and head rice yield of paddy dried by superheated steam and hot air (drying temperature 150°C, bed depth of paddy 10 cm, and superficial velocity $1.5U_{mf}$)

Whiteness

Whiteness of rice at the first minute of superheated steam drying decreased much faster than that of hot air drying, as seen in Figures 6 and 7. The fast drop of whiteness in the superheated steam drying was due to rapid increase in paddy temperature which accelerated mallard reaction and transition of color substances from rice husk and rice bran into endosperm [Khan (1974), Yapet et al. (1988) and Inprasit et al. (2001)]. Longer drying time increased paddy temperature in both drying methods, which induced mallard reaction and caused whiteness of rice slightly drop. Thus, higher paddy temperature in superheated steam drying resulted in faster decrease in whiteness when compared with hot air drying. Interestingly, in case of 1.5 U_{mf}, the whiteness slightly increased after 2 minutes of superheated steam drying, (see Figure 7). This phenomenon, confirmed by several repetitions, may be resulted from high moisture diffusion rate, caused by high paddy temperature and moisture content at this drying time. The high diffusion rate may move color substances out of paddy kernels. More experiments and analysis are needed for the phenomenon.

in superheated steam drying also accelerated the decreasing rate of white belly at the early-stage of drying. The higher superficial velocity, the fast decreasing rate of white belly. However, the effect of superficial velocity in hot air drying to the white belly decreasing rate was vice versa.

ACKNOWLEDGEMENT

The authors would like to express their sincere thanks to the Thailand Research Fund for financial support and Pathum Thani Rice Research Center for testing physical qualities of rice.

REFERENCES

Sutherland, J.W. and Ghaly, T.F. 1990. Rapid Fluid-Bed Drying of Paddy Rice in the Humid Tropics, Presented at the 13th ASEAN Seminar on Grain Post harvest Technology, Bruei Darussalam, pp. 1-12.

Soponnarit, S. and Prachayawarakorn, S., 1994. Optimum Strategy for Fluidized Bed Paddy Drying, Drying Technology, Vol. 12(7), pp. 1667-1686.

Taweerattanapanish, A., Soponronnarit, S., Wetchacama, S., Kongseri, N and Wongpiyachon, S., 1999. Effect of Drying on Rice Yield Using Fludization Technique, Drying Technology, Vol.17, No.1&2, p.345-353.

Inparsit, C and Noomhorm, A., 2001. Effect of Drying Air Temperature and Grain Temperature of Different Type of Dryer and Operation on Rice Quality, Drying Technology, Vol, 19(2), pp.389-404.

Isares Dhudhakallya, 2000. Fludized Bed Paddy Drying Using Supperheated Steam, Master of Engineering Dissertation, Energy of Material, Bangkok, thailand, King's Mongkut University of Thanburi.

Iyota, H., Nishimura, N., Onuma, T. and Nomura, T. 2001. Drying of Sliced Raw Potatoes in Superheated Steam and Hot Air, Drying Technology, Vol. 19(7), pp. 1411-1424.

Mujumdar, A.S, 1995. Superheated steam drying, in A.S. Mujumdar(Ed.). Hand book of Industrial Drying, 2nd Edition, Marcel Dekker, New York, pp. 1071-1086.

Kongseri, Ng, 2001. Chemical Quality Analysis of Jasmine Rice, Pathum Thani Rice Research, Rice Research Institute, Department of Agriculture, Tanyaburi, Pathum Thani, pp. 1-18.

Khan, A. V., Amilhussin, A., Arbolida, J. R., Manolo, A. S. and Chancellor, W. J. 1974. Accelerated drying of rice using heat-conduction media. Trans. ASAE 17:949-955.

Yap, A., Juliano, O. B. and Pereze, C. M. 1988 Artificial Yellow of Rice at 60°C. In Proceeding of the eleven[th] ASEAN Technical Seminar on Grain Post harvest Technology 23-26 August 1988 Kuala Lumpur, Malasia Published by the ASEAN Grain Post harvest Program Bangkok Thailand.

Proceedings of the International Conference on Innovations in Food Processing Technology and Engineering, 11-13 December 2002, AIT, Bangkok, Thailand

EFFECT OF DRYING TEMPERATURE ON PHYSICAL PROPERTY OF HIGH AND LOW AMYLOSE CONTENT PADDY

Supawan Tirawanichakul[1], Somkiat Prachayawarakorn[2], Patcharee Tungtrakul[3], Warunee Warunyanond[3] and Somchart Soponronnarit[1]

[1]School of Energy and Materials, [2]Faculty of Engineering, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok

[3]Institute of Food Research and Product Development, Kasetsart University (KU), Bangkean, Bangkok

E-mail: TSupawan@hotmail.com

ABTRACT

The main objective of this work was to study the effect of drying temperatures on physical qualities of rice in terms of head rice yield, whiteness and hardness. Two varieties of long grain paddy (Indica rice) used in the experiments were Suphanburi 1 and Pathumthani 1. Suphanburi 1 and Pathumthani 1 varieties contained amylose content of 27% and 15-17.8%, respectively. The batch drying experiments were set up at an airflow rate of 2.5 m/s and a bed depth of 9.5 cm. Paddy was dried from an average initial moisture contents of 25.6-33% dry basis (d.b.) to 22% d.b. using hot air temperatures between 40 and 150°C. After drying, the paddy was tempered and followed by ventilation with ambient air until its final moisture content was reduced to 16.3% d.b.

The results have shown that whiteness and head rice yield for paddy containing any moisture content level up to 33% d.b. when subjected to be dried at temperatures below 80°C insignificantly changes from that of the reference sample, which was dried by the ambient air ventilation. Drying at temperature above 100°C provides relatively higher head rice yield and the slightly more yellow around the surface of white rice. The texture analysis was concluded that the hardness of rice with high amylose content and low amylose content were not significant effected by drying air temperature ranging between 40°C and 150°C at paddy moisture content of 18% d.b. after fluidized bed drying. The experimental results implied most of the physical properties of rice were not changed by drying temperature except the yellowing of rice. The yellowness of rice depended on the non-enzymatic reaction during drying.

Keywords. paddy fluidized bed drying; physical qualities; hardness; rice

INTRODUCTION

The management of highly moist paddy under the tropical climate is an extremely serious problem because the high humid air condition in tropical region can encourage the excessive mould growth and the yellowing of grain. To avoid the deterioration of paddy, a rapid drying technique such as fluidization technique is often used. The fluidized bed dryer type has the advantages of high drying capacity and uniform grain moisture distribution.

Driscoll and Adamczak (1988) reported that high moisture content of paddy must be reduced to 22% d.b. within 24 hours to prevent substantial losses. They also stated that the fluidized bed dryer gave better economy, gentle grain handling and shorter drying time, comparing to the LSU dryer.

Sutherland and Ghaly (1990) studied the fluidized bed drying of paddy using temperatures of 40-90°C to reduce the moisture content from of 28.2%-35% d.b. to 20.5%-23.5% d.b., respectively. They found that head rice yield between 58-61% was obtained for reducing the moisture content of 28.2% dry basis to 20.5% d.b. For reducing the moisture content of 35% d.b. to the moisture content of 23.5% d.b. at temperatures of 60-90°C, the head rice yield was in a range of 55-58%. According to these results, there was an insignificant relationship between head rice yield and drying temperature.

Satayaprasert and Vanishserwatana (1992) studied fluidized bed drying of corn at temperatures of 60-90°C using air velocities of 2.7-4.2m/s and bed depths of 3-12 cm. The results indicated that drying rate could be expressed by a logarithmic equation, which was virtually implied the moisture transport to be controlled by internal diffusion. Soponronnarit and Prachayawarakorn (1992) contributed to the research and development on fluidized bed drying. They concluded that the drying air temperature and the final moisture content was the greatest effect on paddy quality. They recommended that the drying temperature should not be higher than 115°C and the final moisture content of paddy after drying should not be lower than 24-25% d.b.

Quality indexes which are used as an important criterion for evaluating the quality of rice are the rice yellowing (or whiteness) and head rice. Many researchers have studied on yellowness or whiteness [Quitco (1982); Gras and Bason (1989); Soponronnarit et al. (1998) and Yap et al. (1988)]. Gras and Bason (1989) reported that the loss of the nutritive value of rice was occurred when the rice had an intense yellowness. Moreover, the accumulation of fungal metabolites (Fusarium sp. Aspergillus flavous) might be expected to produce typically the distinctly yellowed individual rice kernel while the non-enzymic browning might cause the overall change in hue [Quitco (1982)].

Due to the operation at high drying air temperature for the commercial fluidized bed paddy dryer, the head rice yield and whiteness must be maintained and accepted for markets. Thus, the tempering process, which was recommended by many researchers [Steffe et al. (1979); Zhang and Litchfield (1991) and Soponronnarit et al. (1999)], was used for tempering paddy after fluidized bed drying. Soponronnarit et al. (1999) suggested to temper the grain between each drying pass because during the tempering period, the moisture profile in rice kernel equalizes through moisture diffusion and this equalization would decrease the stress, caused by moisture gradient within the kernel. Thus, the head rice yield after the next drying pass could be maintained. Poomsa-ad et al. (2001) recommended that in drying paddy at high temperature by fluidization technique, it should not be removed the water content lower than 22.5% d.b. in a single stage drying, corresponding to the grain temperature lower than 100°C, with subsequent tempering for 30min. This condition can maintain high head rice yield.

Therefore, the main objective of this work is to study the effect of drying temperatures, ranging of 40-150°C, on physical quality of rice in terms of head rice yield, whiteness and hardness.

MATERIALS AND METHODS

Materials

The two varieties of long grain rough rice (Suphanburi 1 and Pathumthani 1) provided by the National Rice Research Center, Thailand, were rewetted, mixed and kept in a cold storage at a temperature range of 3-7°C for a week. The local varieties Suphanburi 1 and Pathumthani 1 contain amylose contents of 27% and 15-17%, respectively. The desired initial moisture content of rewetted paddy was about 25-33 % d.b. Before starting the experiments, paddy was placed in the outside until grain temperature was close to ambient temperature.

FIGURE 1 shows a schematic diagram of batch fluidized bed dryer. The dryer comprises of a cylinder-shaped drying chamber, a 12 kW electric heating unit and a backward curve-blade centrifugal fan driven by a 1.5 kW motor. The drying air temperature was controlled by a PID controller with an accuracy of ±1°C. A mechanical variable speed unit was used for regulating air flow rate. A constant air velocity of 2.5 m/s was set up and the bed depth was 9.5 cm.

Methods

FIGURE 2 shows a schematic diagram of drying system used in this work. The desired final moisture content after fluidized bed drying was about 22.0% d.b. Tempering process was then used for grain relaxation (The second step was shown in FIGURE 2). In this stage, the fluidized paddy would be put into a glass bottle and kept in an oven at the same temperature as the grain temperature. After the tempering time of 30 minutes as recommended by Poomsa-ad et al. (2001), the paddy was ventilated suddenly with a constant ambient airflow rate of 1.5 m/s until its moisture content reached 16.3% d.b.

The inlet air temperature and grain temperature after drying were measured by K-typed thermocouples connected to a data logger with an accuracy of ±1° C. The wet paddy at moisture contents of 25-33% d.b. were dried at the drying temperatures of 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140 and 150°C. The determination of paddy moisture content was followed by the AOAC standard method [AOAC (1984)].

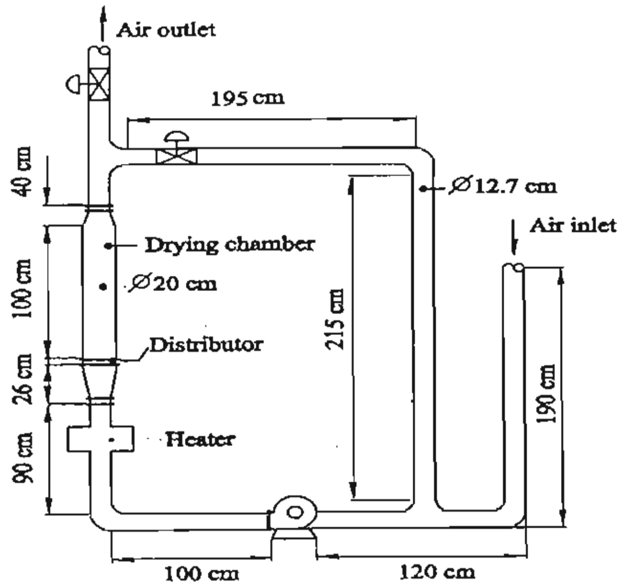


Figure 1. Illustrative diagram of batch fluidized bed dryer (Poomsa-ad et al. 2001).