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PERFORMANCE EVALUATION OF INDUSTRIAL SCALE FLUIDIZED BED PADDY DRYER

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ABSTRACT

Field investigation on industrial scale fluidized bed paddy drying in a processing plant of Padiberas Nasional Berhad (BERNAS) was carried out to asses drying characteristics, energy consumption and final quality of product during two paddy harvesting seasons. For the first season (August-September), average drying rate was found to be 538 kg/hr to reduce paddy moisture content from 36.98± 0.89% dry basis (db) to 27.58±0.79% db at 100-120 ^{o}C drying air temperature and 2.24 m/s bed air velocity with a feed rate of 7.75 t/hr. Meanwhile, in another season (February-March), average drying rate was found to be 435 kg/hr to reduce paddy mc from 28.14 ±0.68 % db to 22.54 ± 0.69% db at 78-90 ^{o}C drying air temperature and 2.24 m/s bed air velocity with a feed rate of 9.5 t/hr. The thermal and electrical energy consumptions in terms of primary energy in MJ/kg water removed were obtained as 7.57 and 0.97, respectively for the first season and 5.92 and 1.2 for the second season. Higher head rice yield and whiteness, and lower milling recovery were achieved during first season than second season at acceptable milling degree and transparency. Although less than expected throughput capacity resulted in lower performance of the dryer yet high moisture paddy drying with fluidized bed dryer using high temperature yielded high drying rate and product quality.

***Keywords**: Industrial fluidized bed paddy dryer, drying rate, milling quality and energy consumption.*

INTRODUCTION

Reduction of high moisture in paddy rapidly down to a safe level of 22-23 % (it is noted that the moisture content is expressed on the percentage dry basis throughout this paper unless stated otherwise) has been suggested by many researchers [1-4]. The feasibility of fluidized bed dryer for drying of high moisture paddy is great because of its compact size, fast drying rate, low energy consumption at acceptable quality [5]. Sutherland and Ghaly [6], the pioneers of fluidization technique for paddy drying, showed that head rice yield was higher between 58-61% when paddy moisture content was reduced from 28.2 to 20.5 % but it was lower between 15 to 24 % when final moisture content was 19%. Tumambing and Driscoll [7] developed mathematical model and conducted experiments on continuous fluidized bed drying of paddy with experimental conditions as follows: drying air temperature of 40-100°C; bed thickness of 5-20 cm and air velocity of 1.5-2.5 m/s. They claimed that fluidized bed dryer offers a promising alternative for rapid pre-drying of paddy. Feasibility of paddy drying by fluidization technique was conducted by Soponronnarit and Prachayawarakorn [8]. They reported that drying capacity of a dryer increased with specific air flow rate and drying air temperature while energy consumption was reduced when specific air flow rate decreased or fraction of recycled air increased. Soponronnarit et al. [9] described on design and testing of a prototype fluidized bed paddy dryer with a capacity of 0.82 ton/hour. They used air temperature of 100-120°C, fraction of air recycled of 0.66, specific airflow rate of 0.05 kg/s-kg dry matter, superficial air velocity of 3.2 m/s, and bed depth of 0.1 m, to reduce moisture content from 45 to 24%. They also found that electrical and thermal energy consumption in terms of primary energy were 0.53 and 1.79 MJ/kg water evaporated, respectively. Soponronnarit et al. [10] developed cross flow fluidized bed paddy dryer with a capacity of 200 kg/hour and suggested that the final moisture content of paddy should not be lower than 23% to maintain quality in terms of both whiteness and head rice yield. They added that energy consumption to reduce moisture from 30 to 24% was minimum at drying air temperature of 115°C, air speed of 2.3 m/s, bed thickness of 10 cm and fraction air recycled of 0.8 while the drying capacity was near maximum. Soponronnarit et al. [11] investigated the performance evaluation of commercial fluidized bed dryer with capacities of 1-2, 2.5-5.0 and 5-10 ton/hour having the provision of recycling the exhaust air while the heat source was from burning diesel or oil fuel. They reported that energy consumption decreased with increasing moisture content level of paddy and drying temperature. To reduce paddy moisture down to 22% (db) in a single pass they recommended the maximum drying temperature of 150 ^{o}C for acceptable quality of product. Prachayawarakorn et al. [12] studied the performance comparison of industrial pulsed and traditional fluidized bed dryer. They reported that head rice yield and whiteness were similar in both dryers. In terms of energy consumption they found that pulsed fluidized bed dryer was more economical than the conventional dryer. Although extensive research has already been performed on batch fluidized bed paddy drying in laboratory scale, however, very few published works are available on performance of large scale industrial paddy dryer quantifying the criteria such as drying characteristics, energy consumption and final quality of dried product with comprehensive statistical analysis. Performance evaluation of a dryer promotes its successful and economic operation. Hence the present investigation was to obtain the practical information on fluidized bed paddy drying plant, further suggestions are expected to be made to improve the present drying practices and to identify the scopes of future research and development on the industrial fluidized bed drying.

MATERIALS AND METHODS

The fluidized bed dryer (FBD) with 5.0 m × 1.22 m bed area and 25 t/hr capacity available at paddy processing plant of BERNAS, Simpang Empat, Perlis, Malaysia was used for this study. The average initial moisture content was 36.98± 0.89% and 28.14±0.68 % during first (August-September) and second (February-March) seasons, respectively. The freshly harvested paddy, MAR-219 variety, was used in both seasons. Drying temperature and air flow rate were 100-122 ^{o}C and 13.66 m^3/s, respectively during first season while these values were 78-90 ^{o}C and 13.66 m^3/s in the second season operation. All data were recorded when steady state condition of the operation of the dryer was existed. Dryer was operated in two seasons to take into account the seasonal variation in operating parameters of the dryer which were obviously found to be changed due to different initial moisture contents of paddy. The drying air is heated from the heat produced by the combustion of rice husk in cyclonic furnace.

The data collected were impurities and initial moisture contents of paddy, drying air velocity, temperature and relative humidity of air and moisture change of the paddy during drying. During operation of the dryer, samples were taken from inlet and outlet of dryer at an approximately 60 min interval and moisture reduction was determined in thrice replication. After fluidized bed drying, paddy moisture was further reduced down to around 14 % using ambient air for comparing the rice qualities in terms of head rice yield, whiteness, milling recovery, degree milling and transparency. The moisture content of the paddy was measured by the Satake digital grain moisture tester model "SS-6" with an accuracy of ±0.5%. Drying air temperature and relative humidity were measured by K-type thermocouple (HANNA Co. with ± 0.5^{o}C accuracy) and Thermo Hygrometer (H19564, HANNA), respectively. Air velocity at dryer inlet was measured using Thermal Anemometer (TESTO 4235 with ± 0.03 m/s). Knowing the cross-section area at the point of velocity measurement, the volume of air was calculated by continuity equation (Eq. a). Bed air velocity of was calculated using the same equation. The collected data were used for calculating the energy consumption of the paddy drying operation using Equations b, c, d and e according to Jittanit et al. [13]

$$Q = A \times V \quad \text{(a)}$$
$$E_{Total} = 2.6E_{elec} + E_{heat} \quad \text{(b)}$$
$$E_{elec} = P \times t \quad \text{(c)}$$
$$E_{heat} = m_a C_a (T_i - T_{mix}) \quad \text{(d)}$$
$$m_a = Q \times \rho_a \times t \quad \text{(e)}$$

where, Q is the drying air volume (m^3/s), A is the cross-sectional area of air inlet (m^2) and, V is the mean velocity of the drying air across the air inlet section (m/s), E_{total} is the total primary energy consumption (KJ), E_{elec} is the electrical energy consumption by the blower fan of the dryer (kJ), E_{heat} is the thermal energy consumption for heating the drying air (KJ), P is the power of the blower fan motor (kW), t is the total drying time (hour), m_a is the mass of the drying air (kg), ρ_a is the air density (kg/m^3), C_a is the specific heat of drying air (KJ/kg °C), T_i is the ambient air temperature and T_{mix} is the drying air temperature after heater. Drying time (residence time) of FBD was calculated as hold up capacity divided by feed rate according to Sooponronnarit et al.[14], while feed rate was calculated by dividing the total amount of paddy dried by total time of operation of FBD. Dried paddy samples were stored in refrigerator at 4-6 ^{o}C temperature in sealed poly packages for 3-4 weeks for further quality testing.

Assessment of rice quality

For head rice yield (HRY) determination, 125 g dried and cleaned paddy sample with two replications was dehusked with a Testing Husker (THU-35A, Satake Engineering Co., Ltd.) while the bran was removed with a Satake Testing Mill (TM 05C) running for 45 sec for each amount of dehusked brown sample . Head-rice was separated by Satake Test Grain Grader (TRG 05B) using 5.2 mm S-type identical cylinder. HRY was defined in this study as the ratio of head-rice mass to original cleaned dried paddy mass. Whiteness, milling degree and transparency were measured using a Satake whiteness meter with four replications as obtained twice the values from each sample of HRY while milling recovery was calculated in duplicate replication, as the weight of total milled rice (including head rice and broken rice) divided by weight of sample and multiplied by 100. Percentage milling recovery was calculated as the weight of total milled rice including head rice and broken rice divided by weight of dried paddy sample and multiplied by 100. Rice milling degree is defined as the extent to which the bran layers of rice have been removed during the milling process.

Statistical Analysis

The statistical software package SAS 9.2 version was used for the analysis of variance (ANOVA) and Duncan's Multiple Range Test for head rice yield, whiteness, milling recovery, degree milling and transparency.

RESULTS AND DISCUSSION

Drying characteristics

Figure 1 (a & b) and Figure 2 (a & b) represent moisture reduction and evolution of temperature, respectively during drying of high moisture paddy by the fluidized bed paddy dryer. It indicated that moisture drop ranged from 8.42 to 10.1 % in the first season operation during drying of 34-40% initial moisture content paddy at drying temperature of 100-120 ^{o}C and air velocity of 2.24 m/s. Moisture drop during second season operation was obtained in range of 2.83 to 7.2% from initial moisture content of 27-30% db at drying temperature of 78-90 ^{o}C and bed air velocity of 2.24 m/s . The residence time was calculated as 2.75 min and 2.24 min for the first and second season, respectively, which were longer than the usual values as reported by other researchers [10, 12]. As residence time was calculated as hold up capacity divided by the average feed rate obtained for the entire operating time, hence, lower moisture drop at longer residence time was observed here than those results reported by Sooponronarrit *et al*. [10] and Prachayawarakorn *et al*. [12]. It indicated the clear operational limitations of the dryer. On the other hand, shorter residence time was found for higher feed rate during the second season. Nevertheless, higher feed rate was achieved at the same adjustment of FBD in the second season because of low initial moisture content and less impurities in paddy. Higher moisture drop in the first season was noticed due to higher initial moisture content of paddy and higher drying temperature. Likewise, similar results were also reported by Sooponronarrit *et al*. [10, 14] and Prachayawarakorn *et al*. [12].

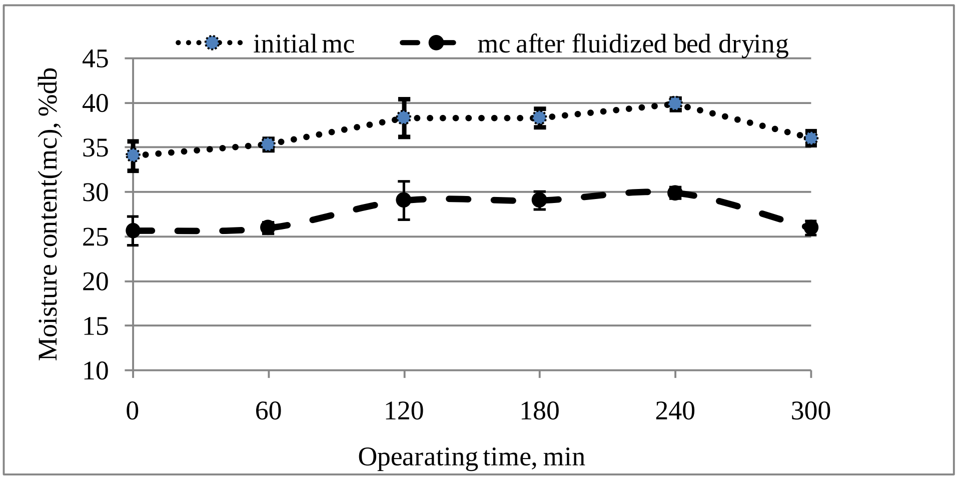

Fig. 1(a): Moisture reduction of paddy during industrial fluidized bed drying
[First season: Inlet air temp: 100-122 ^{o}C, Air velocity:2.24 m/s, Bed depth:10 cm, Feed rate:7.75 t/hr. Data are plotted as mean ±SEM (n=3)]

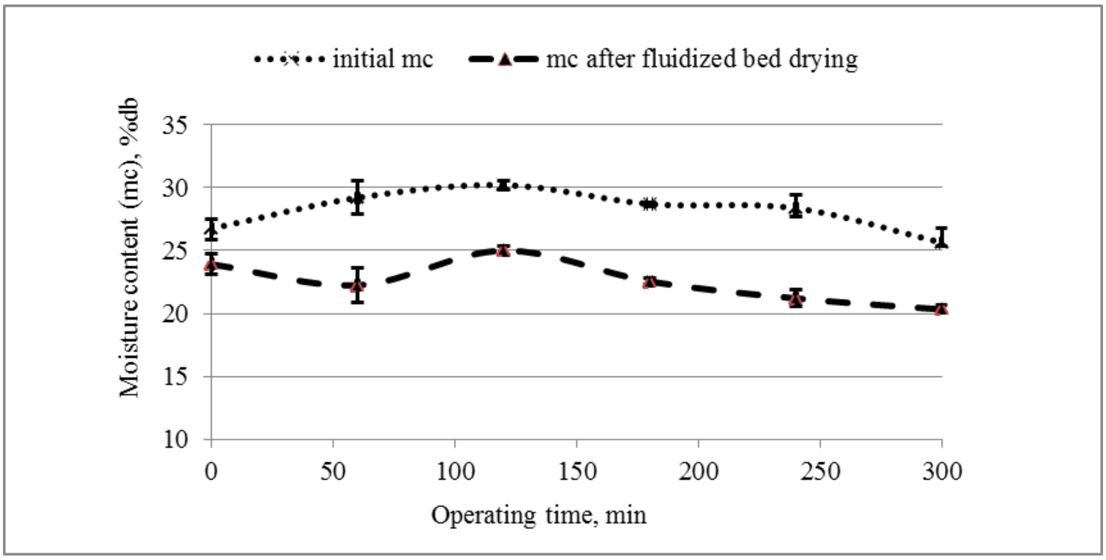

Fig. 1(b): Moisture reduction of paddy during industrial fluidized bed drying
[First season: Inlet air temp: 78-90 ^{o}C, Air velocity: 2.24 m/s, Bed depth:10 cm, Feed rate:9.5 t/hr, Data are plotted as mean ±SEM (n=3)]

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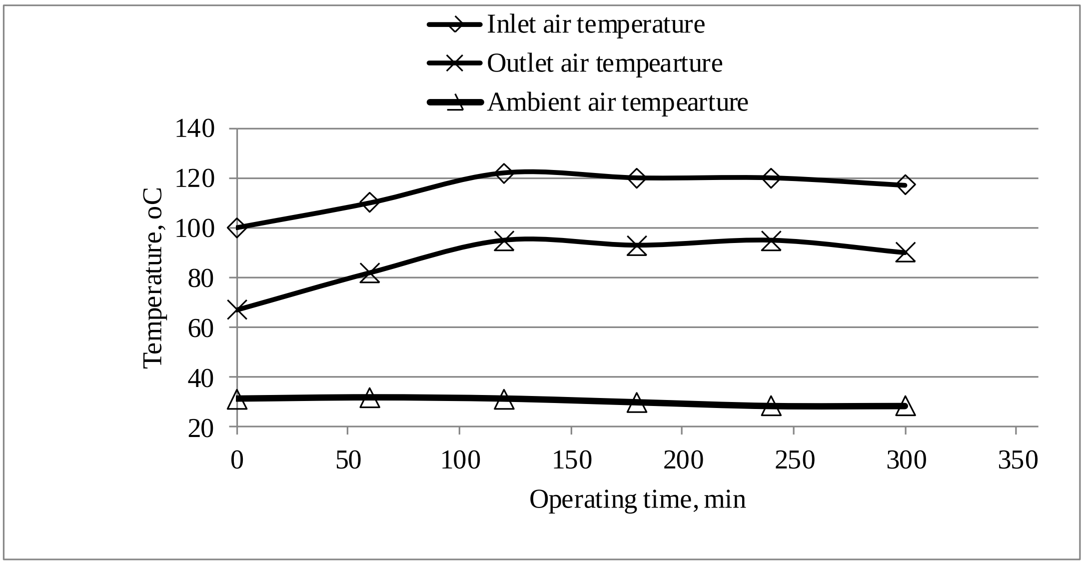
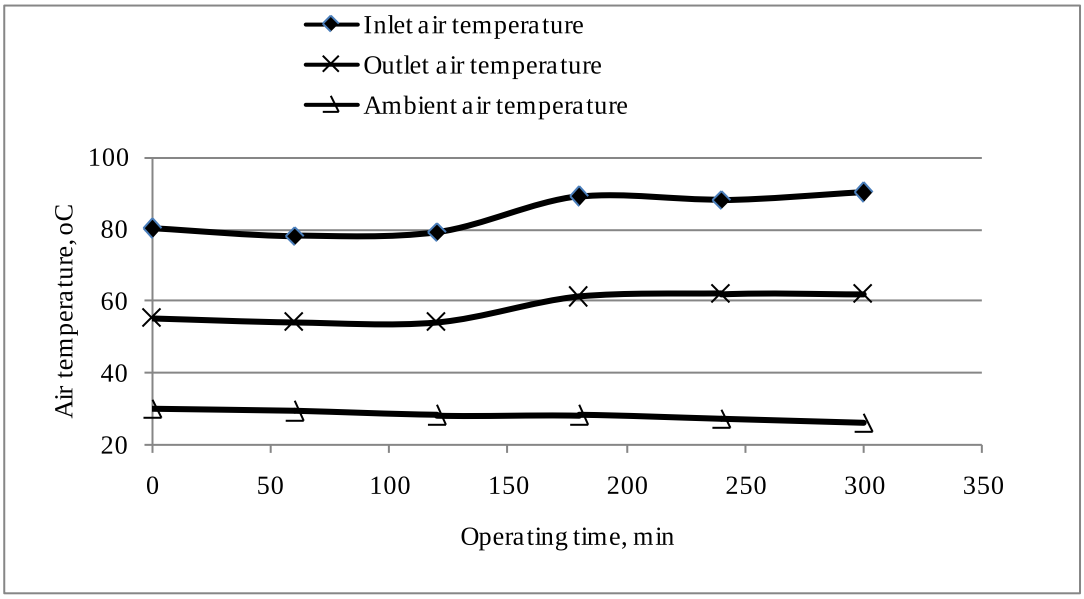


Fig. 2 (a): Evolution of temperature during industrial fluidized bed paddy drying



[First season: Air velocity:2.24 m/s, Bed depth:10 cm, Feed rate:7.75 t/hr]
Fig. 2 (b): Evolution of temperature during industrial fluidized bed paddy drying
[Second season: Air velocity: 2.24 m/s, Bed depth: 10 cm, Feed rate: 9.5 t/hr]

Drying rate

The drying rate based on the operating parameters used during operation of fluidized bed dryer is displayed in Table 1. It revealed that higher drying rate of 538 kg/hr was achieved at feed rate of 7.75 t/hr in the first season. Whereas, comparatively lower drying rate of 435 kg/hr was found at feed rate of 9.5 t/hr in the second season. These drying rates are much lower compared to the results reported by Prachayawarakorn *et al*. [12] and Sooponronarrit *et al*. [10]. It is noted that higher drying rate achieved in the first season was due to higher drying temperature as displayed in Table 1. Similar phenomenon during fluidized bed drying was reported by the other authors [16-18]. The dryer was found to be operated at much lower capacity than the design capacity which justified its lower performance. During operation of the dryer, it was noticed that the paddy flow through the intake elevator and pre-cleaner was not consistent, which reduced the throughput capacity. In addition, high moisture and high impurities in the paddy had caused problems due to clogging thus hindering smooth and steady throughput. However, a consistent paddy flow could be ensured by continuous inspection and necessary adjustments of the elevator and pre-cleaner.

Table 1. Drying rate of an industrial fluidized bed dryer with capacity of 25 t/hr during two operating seasons.

Operational season	Paddy initial mc (%db)	Paddy mc after FBD (%db)	Drying temperature (°C)	Bed air velocity (m/s)	Feed rate (t/hr)	Drying rate (kg/hr)
First	34-40	25-30	100-120	2.24	7.75	538
Second	27-30	20-24	78-90	2.24	9.5	435

Energy consumption

The specific energy consumption calculated from the obtained data is depicted in Figure 3. The specific electrical energy consumption in terms of primary energy was found as 0.97 MJ/kg water evaporated during first season while it was 1.2 MJ/kg water evaporated in the case of second season. On the other hand, the dryer consumed specific thermal energy consumption of 5.91MJ/kg water evaporated and 7.58 MJ/kg water evaporated, respectively during first and second season drying processes. At almost similar drying conditions, higher electrical energy consumption was noticed in this case than the results reported by other authors [11, 12 and 19], while thermal energy consumption was comparable with the values reported by Prachayawarakorn et al. [12, 19]. It might be possible to minimize the energy consumption in FBD of the present set-up by ensuring that its operation is attained at a possible maximum capacity using suitable drying temperature.

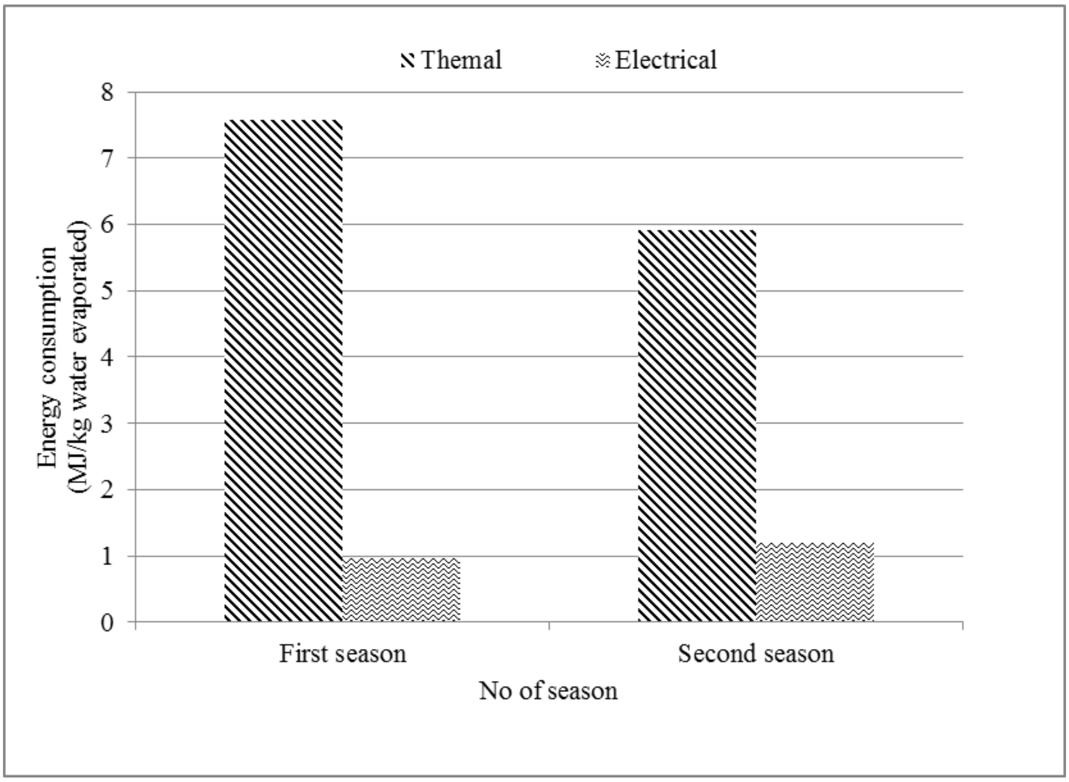


Fig 3 : Energy consumption in industrial fluidized bed paddy drying

Paddy quality assessment

The head rice yield, whiteness, milling recovery, degree milling and transparency obtained from fluidized bed drying are presented in Table 2. Head-rice yield, whiteness and milling recovery of rice samples after drying were almost identical at acceptable milling degree and transparency to those which were dried using ambient air as a control over both seasons. From Table 2 it is clear that the head rice yield obtained from the first season was comparatively higher (around 3%) than second season. Higher initial moisture content of 34-40% paddy dried using higher temperatures 100-120 °C by FBD gave higher head rice yields which were similar with the previous finding [20]. Moreover, lower drying temperature (78-90°C) used by FBD for drying the paddy having relatively lower initial moisture content (27-30%) during the second season yielded lower head rice yield and whiteness. It is noted that use of higher drying temperature has great advantage. Unfortunately, the head rice yield achieved from the industrial scale dryer is still lower than the results obtained by other researchers [6,15].

Table 2: Qualities of rice obtained from industrial fluidized bed drying

First season					
Sample ID	HRY (%)	Whiteness (%)	Milling recovery (%)	Milling degree (%)	Transparency
Control	*46.5±0.64[a]	39.3±0.21[a]	63.6±0.91[a]	87±0.95[a]	1.56±0.03[a]
FBD	48.9±0.165[a]	39.2±0.18[a]	64.1±0.47[a]	86±1.0[a]	1.56±0.09[a]
Second season					
Sample ID	HRY (%)	Whiteness (%)	Milling recovery (%)	Milling degree (%)	Transparency
Control	44.6±0.20[a]	37.1±0.15[a]	67.8±0.36[a]	77±0.29[b]	1.90±0.0[a]
FBD	46.1±0.29[a]	37.7±0.58[a]	67.3±0.49[a]	86±1.0[a]	1.60±0.03[b]

[*]Mean values ± standard error mean (SEM). [a-d] The test values: Same letters for the different quality attributes in each column mean that the values are not significantly different ($p > 0.05$)].

CONCLUSION

An assessment on the actual operating status and final quality of product during paddy drying with the commercial fluidized bed dryer was carried out. The actual throughput capacity was found to be less than half of its design capacity thus exhibited lower performance. Nevertheless, the dryer performed better in yielding better head rice yield and in reducing moisture from paddy with higher initial moisture of 34-40% content using higher temperature of 100-120^{o}C in the case of first season than low initial moisture paddy of 27-30% using lower temperature of 78-90^{o}C at 2.24 m/s air velocity in the second season case. The dryer showed drying rate of 538 kg/hr and 435 kg/hr, respectively for first and second season. The thermal and electrical energy consumptions in terms of primary energy in MJ/kg water removed were obtained as 7.57 and 0.97, respectively for the first season and 5.92 and 1.2 for the second season. So, at initial moisture content higher than 28% dry basis, it is recommended that inlet-air temperature should be higher than 100 ^{o}C in order to achieve better quality rice. In addition, the throughput capacity can be increased by continuous supervision of intake elevator, pre-cleaner and rotary feeder so as to avoid any inconsistency in paddy flow due to variation of impurities and moisture content in freshly harvested field paddy.

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REFERENCES

[1] Igathinathane, C., Chattopadhyay, P.K. and Pordesimo, L.O. (2008) Moisture diffusion modelling of parboiled paddy accelerated tempering process with extended application to multi-pass drying simulation. Journal of Food Engineering 88, 239-253.

[2] Soponronnarit, S. (1997) Drying of Grain and Some kinds of Food, seventh ed. King Mongkut's University of Technology Thonburi, Thailand, 338 pp. (in Thai).

[3] Tirawanichakul, Y., Prachayawarakorn, S., Varanyanond,W. and Soponronnarit, S. (2004) Simulation and grain quality for in-store drying of paddy. Journal of Food Engineering 64, 405-415.

[4] Poomsa-ad, N., Soponronnarit, S., Terdyothin, A. and Prachayawarakorn, S. (2001) Head rice yield after drying by fluidization technique and tempering. In: Proceedings of the 2nd Asian-Oceania Drying Conference, Penang, Malaysia August 20–22, 717-726.

[5] Soponronnarit, S. (1999) Fluidised bed grain drying. Proc. 3rd Asia-Pacific Drying Conference, (1–3 September), Bangkok, Thailand.

[6] Sutherland, J.W. and Ghaly, T.F.(1992) Rapid fluid bed drying of paddy rice in the humid tropics. In Proceedings of the 13th ASEAN Conference on Grain Post-harvest Technology. Brunei Darussalam.
[7] Tumambing, J.A. (1993) Mathematical modelling and design of a continuous fluidized bed dryer for pre-drying of paddy in the humid tropics. PhD Thesis, The University New South Wales, Sydney, Australia. (Unpublished),
[8] Soponronnarit, S. and Prachayawarakorn, S. (1994) Optimum strategy for fluidized bed paddy drying. Drying Technology 12:1667-1686.
[9] Soponronnarit S, Yapha M and Prachayawarakorn S. (1995) Cross-flow fluidized bed paddy dryer: prototype and commercialization. Drying Technology 13, 2207-16.
[10] Soponronnarit, S., Prachayawarakorn, S. and Sripawatakul, O. (1996a) Development of cross-flow fluidized bed paddy dryer. Drying Technology. 14:2397-2410
[11] Soponronnarit, S., Prachayawarakorn, S. and Wangji, M. (1996b) Commercial fluidized bed paddy dryer. In Proceedings of the 10th International Drying Symposium, 638-644. Krakow, Poland.
[12] Prachayawarakorn, S., Tia, W., Poopaiboon, K., and Soponronnarit, S. (2005) Comparison of performances of pulsed and conventional fluidized-bed dryers. Journal of Stored Products Research 41, 479–497.
[13] Jittanit, W., Saeteaw, N. and Charoenchaisri, A. (2010) Industrial paddy drying and energy saving options. Journal of Stored Products Research 46, 209-213.
[14] Soponronnarit, S., Prachayawarakorn, S. and Wangji, M. (1996b) Commercial fluidised-bed paddy dryer. In: Strumillo, C.; Pakowski, Z. (Eds), Proceedings of the 10th International Drying Symposium, vol. (A), Krakow, Poland, 30 July–2 August, 638-644
[15] Soponronnarit, S., Srisubati, N. and Yoovidhya, T. (1998) Effect of temperature and relative humidity on yellowingrate of paddy. Journal of Stored Products Research 34, 323–330.
[16] Tatemoto, Y. and Sawada, T. (2012) Numerical analysis of drying characteristics of wet material immersed in fluidized bed of inert particles. Drying Technology 30 (9), 979-988.
[17] Kozanoglu, B., Flores, A., Guerrero-Beltrán, J.A. and Welti-Chanes, J.(2012) Drying of pepper seed particles in a superheated steam fluidized bed operating at reduced pressure. Drying Technology 30 (8), 884-890.
[18] Srisang, N.; Prachayawarakorn, S.; Varanyanond, W.; Soponronnarits, S. (2011) Germinated brown rice drying by hot air fluidization technique. Drying Technology 29 (1), 55-63.
[19] Prachayawarakorn, S.; Poomsa-ad, N.; Soponronnarit, S. (2005a) Quality maintenance and economy with high-temperature paddy-drying processes. Journal of Stored Products Research 41, 333-351
[20] Taweerattanapanish, A., Soponronnarit, S., Wetcharama, S., Kongseri, N. and Wongpiyachon, S. (1999) Effects of drying on head rice yield using fluidization technique. Drying Technology, 17 (1–2), 345–353.