Pertanika J. Sci. & Technol. 23 (2): 297 - 309 (2015)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Drying Performances and Milling Quality of Rice during Industrial Fluidized Bed Drying of Paddy in Malaysia

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ABSTRACT

Field investigation on the operation of an industrial fluidized bed paddy dryer of 25 t/h capacity available in a processing complex of Padiberas Nasional Berhad (BERNAS) of Malaysia was carried out to assess its drying characteristics, energy consumption and quality of product during two paddy harvesting seasons. A grain drying simulation model was used to predict dryer performance which can be used as a basis for improving drying operations. For the first season (August-September), average drying rate was found to be 538 kg moisture/h to reduce moisture content (mc) from 36.98± 0.89% dry basis (db) to 27.58±0.79% (db) at 100-120°C of drying air temperature with a feed rate (capacity) of 7.75 t/h. In the second season (February-March), average drying rate was found to be 435 kg moisture/h to reduce mc from 28.14 ±0.68% (db) to 22.54 ± 0.69% (db) at 78-90°C drying air temperature with a feed rate of 9.5 t/h. The thermal and electrical energy consumptions were obtained as 7.57 and 0.97 MJ/kg water removed, respectively, for the first season, while 5.92 and 1.2 MJ/kg water removed for the second season. Higher head rice yield and whiteness and lower milling recovery were achieved during the first season than the second season at acceptable milling degree and transparency. Meanwhile, simulation results indicated that the dryer performed better in terms of increased drying capacity during the second than the first season; the dryer could be operated at 150°C to achieve almost double throughput capacity up to 20 t/h for the second season, while for the first season, high mc hindered the capacity to be at or below 7.75 t/h even when using higher a temperature of 160°C to reduce moisture to the desired final moisture of 24-25% (db). proportion of slower vehicles based on users' opinion poll.

Keywords: Drying simulation, drying rate, industrial fluidized bed paddy dryer, milling quality, energy consumption, head rice yield, drying performance

Article history:
Received: 19 May 2014
Accepted: 5 August 2014

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ISSN: 0128-7680

INTRODUCTION

Reduction of high moisture in paddy rapidly to a safe level of 22-23% (the moisture content is expressed as the percentage dry basis throughout this paper unless stated otherwise) has been suggested by many researchers (Igathinathane *et al*., 2008; Soponronnarit, 1997; Tirawanichakul *et al*., 2004; Poomsa-ad *et al*., 2001). Sutherland and Ghaly (1992), the pioneers of fluidization technique for paddy drying, showed that head rice yield was higher (i.e., between 58-61%) when paddy moisture content was reduced from 28.2% to 20.5 % but it was lower (i.e., between 15% to 24%) when the final moisture content was 19%. Tumambing (1993) developed a mathematical model and conducted an experiments on continuous fluidized bed drying of paddy with experimental conditions of 40-100°C drying air temperature, 25-20 cm bed thickness and 1.5-2.5 m/s of air velocity. The researcher claimed that a fluidized bed dryer offers promising alternative to be used for rapid pre-drying of paddy. Feasibility of paddy drying by fluidization technique also was conducted by Soponronnarit and Prachayawarakorn (1994), who reported the 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 was decreased or fraction of recycled air was increased. Soponronnarit *et al*. (1995) described the design and testing of a prototype fluidized bed paddy dryer with a capacity of 0.82 t/h. They used air temperature of 100-120°C, fraction of recycled air 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 paddy moisture contents from 45% to 24%. They also found that electrical and thermal energy consumptions in terms of primary energy were 0.53 and 1.79 MJ/kg water evaporated, respectively. Soponronnarit *et al*. (1996a) also developed a cross flow fluidized bed paddy dryer with a capacity of 200 kg/h and suggested that the final moisture content of paddy should not be lower than 23% so as to maintain quality in terms of both whiteness and head rice yield. They further added that energy consumption to reduce moisture from 30 to 24% was minimum at the drying air temperature of 115°C, air speed of 2.3 m/s, bed thickness of 10 cm and fraction recycled air of 0.8, while the drying capacity was near maximum. Soponronnarit *et al*. (1996b) investigated the performance of commercial fluidized bed dryer with capacities of 1-2, 2.5-5.0 and 5-10 t/h 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 of paddy and drying temperature. In order to reduce paddy moisture down to 22% (db) in a single pass, they recommended the use of maximum drying temperature of 150°C for acceptable quality of product. Based on the foregoing studies, the feasibility of fluidized bed dryer for drying of high moisture paddy is favourable because of its compact size, fast drying rate and low energy consumption with acceptable quality (Soponronnarit, 1999). Prachayawarakorn *et al*. (2005a) studied the performances of industrial pulsed and traditional fluidized bed dryers and reported that head rice yield and whiteness were similar in both dryers. In terms of energy consumption, they found that the pulsed fluidized bed dryer was more economical than the conventional dryer. Although extensive research has already been performed on batch fluidized bed paddy drying on laboratory scale, limited published works focusing on the 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 are available at present. Meanwhile, performance evaluation of a dryer promotes its successful and economic operation. Before starting the operation of any dryer, it is very important to select and fix the possible suitable air velocity, particularly air temperature and weir height, for a constant feed rate in order to minimize energy consumption and maximize drying capacity. Computer simulation is a cheap and time-saving method to predict drying parameters for designing and optimizing the operation of a dryer. The simulation approach is able to select suitable drying air temperature at a particular throughput capacity that meets the intended moisture reduction from freshly harvested wet paddy to achieve the desired level of the final moisture content, which will not otherwise be possible without extensive experimental works. The factors that limit the dryer operation can easily be sorted out. Hence, the present attempt was undertaken to obtain the practical information on industrial fluidized bed paddy drying in the Complex of BERNAS and to further suggest for improvement of the dryer operation to achieve quality rice.

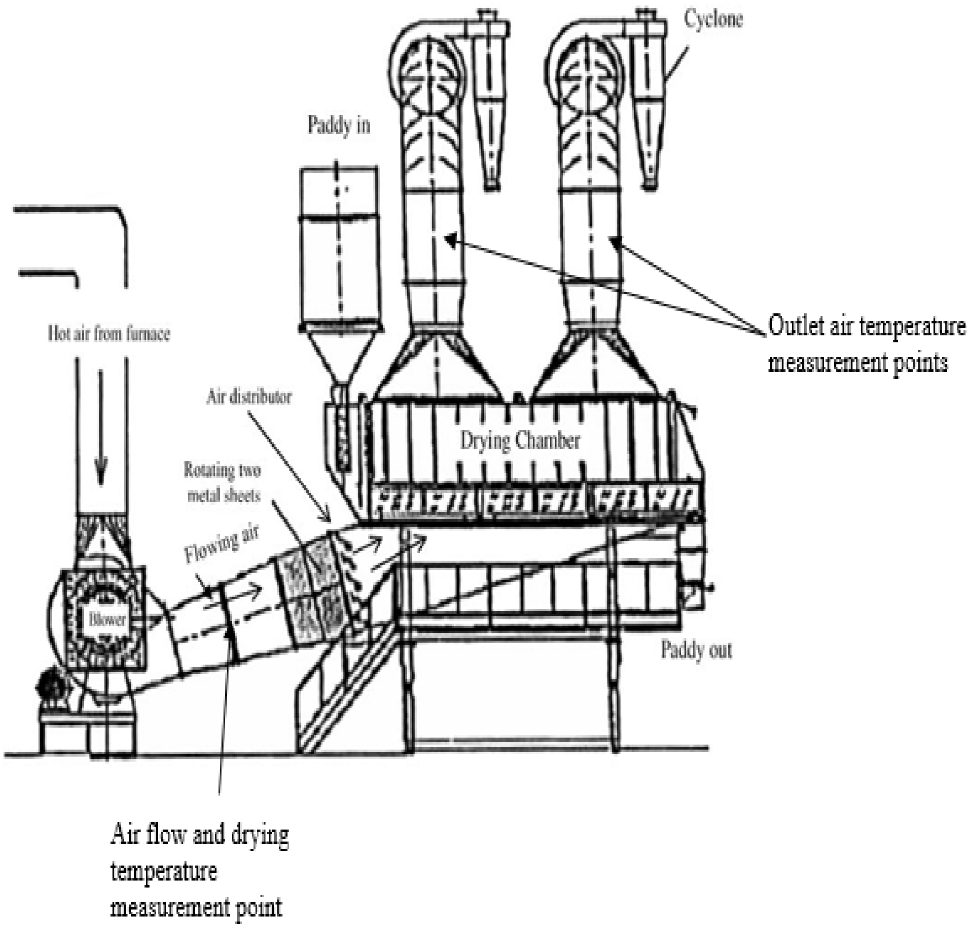


Fig.1: Schematic diagram of an industrial pulsed fluidized bed dryer
(Adapted from Prachayawarakorn et al. (2005a)

MATERIALS AND METHODS

Operating the Industrial Fluidized Bed Dryer

For the purpose of this study, an industrial pulsed fluidized bed dryer (FBD) with 5.0 m × 1.22 m bed area and 25 t/h capacity available at paddy processing plant of BERNAS, Simpang Empat in Perlis, Malaysia, was operated in a continuous mode during two usual paddy drying seasons. A schematic diagram indicating temperature and air flow measurement points is presented in Fig.1. This is almost similar to the dryer proposed by Prachayawarakorn *et al.* (2005a). The average initial moisture content was 36.98 ± 0.89 and 28.14 ± 0.68 % db during the first season (August-September) and the second season (February-March), respectively. The freshly harvested paddy of MR219 variety was dried in both the seasons. Drying temperature and air flow rate were 100-122°C and 13.66 m^3/s, respectively, during the first season while these values were 78-90°C and 13.66 m^3/s in the second season. All data were recorded when steady state condition of the operation of the dryer was observed. Dryer was operated in two seasons to take into account the seasonal variation in the operating parameters of the dryer, which were obviously found to be changed due to different initial moisture contents of the paddy. The drying air was from the heat produced by the combustion of rice husk in cyclonic furnace.

The collected data were impurities and initial moisture contents of paddy, drying air velocity, temperature, as well as relative humidity of air and moisture change of the paddy during drying. During operation of the dryer, samples were taken simultaneously from inlet and outlet of dryer at an approximately 60 min interval, while moisture reduction was determined in three replications. Control paddy samples were dried using ambient air, while paddy was spread at 1-2 cm bed thickness on plastic mat under shed. Besides paddy drying with industrial dryer, control drying was carried out so as to compare rice quality in terms of head rice yield, whiteness, milling recovery, milling degree and transparency with fluidized bed drying. It is important to note that after fluidized bed drying, the paddy samples were further dried to around 16% using ambient air for the present work. It is also worth mentioning that bulk paddy after fluidized bed drying was further dried using inclined bed dryer in the plant as per usual drying practice. The moisture content of the paddy was measured by the Satake digital grain moisture meter model “SS-6” with an accuracy of ±0.5%. The moisture meter was previously calibrated with standard oven method (at the temperature of 103°C for 24 hours) through determining paddy moisture content in the laboratory. Drying air temperature and relative humidity were measured by K-type thermocouple (HANNA Co. with ± 0.5°C accuracy) connected with data logger 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 air velocity measurement, the volume of air was calculated by continuity equation (Eq. 1). Bed air velocity was calculated using the same equation. The collected data were used for calculating actual energy consumption during paddy drying operation using Equations 2, 3,4 and 5 according to Jittanit *et al.* (2010) and Sarker *et al.* (2013a & 2014).

$$Q= A\times V \qquad [1]$$

$$E_{Total}= 2.6E_{elec}+E_{heat} \qquad [2]$$

$$E_{elec}= P \times t \qquad [3]$$

$$E_{heat}= m_aC_a\ (T_i-T_{mix}) \qquad [4]$$

$$m_a=Q\times\rho_a\times t \qquad [5]$$

Where, Q is the drying air volume (m^3/s), A is the cross-sectional area of air inlet (m^2), 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 the hold-up capacity divided by feed rate according to Soponronnarit *et al*. (1996a), while feed rate was calculated by dividing the total amount of paddy dried by total time of operation of FBD. The dried paddy samples were stored in a refrigerator at 4-6°C in sealed poly packages for 3-4 weeks for further quality testing. In addition, a computer drying simulation model (Sarker *et al*., 2013b) was used for the calculation in predicting dryer performances. The simulation programme was run at various feed rates using different drying temperatures ranging from 90 to 160°C, supposed to be the suitable drying temperature for fluidized bed drying of paddy (Poomsa-ad *et al*., 2001; Soponronnarit *et al*., 1994, 1996a; Sutherland & Ghaly, 1990) for selecting the possible maximum dryer throughput capacity for reducing paddy moisture content to 24-25% db, the safe level of moisture content after the fluidized bed drying for maintaining quality of rice.

Assessment of Rice Quality

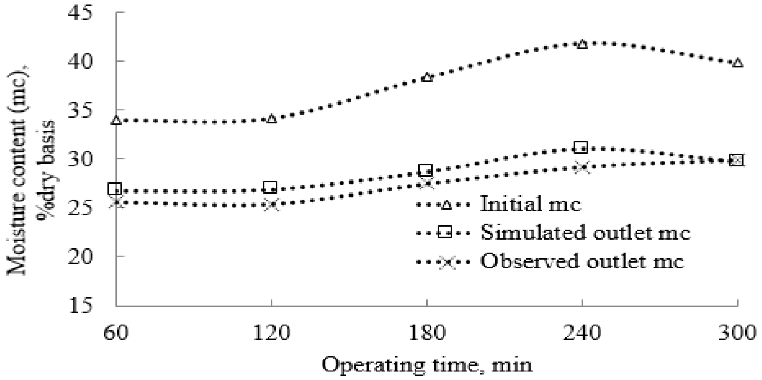
For head rice yield (HRY) determination, 125 g dried and cleaned paddy sample, with two replications, was dehusked with a Testing Husker (THU-35A, Satake Engineering Co., Ltd.), while the bran was removed with a Satake Testing Mill (TM 05C) running for 45 sec for each amount of dehusked brown rice samples. 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 double sub-samples obtained from each sample of HRY. Percentage milling recovery was calculated as the weight of total milled rice (including head rice and broken rice) divided by the 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

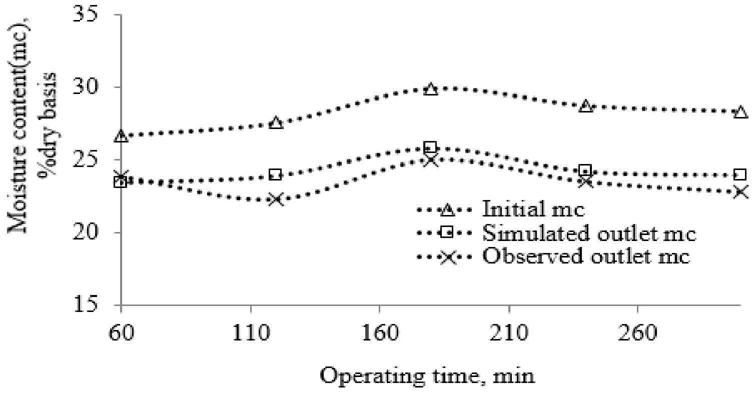
The statistical analysis was carried out by using a single factor experiment in completely randomized design (CRD). The only factor was drying method (two drying methods: Control drying and fluidized bed drying). Each drying method was replicated twice. The statistical software package SAS 9.2 version was used to calculate the mean values, standard error mean (SEM) and the analysis of variance of obtained values on head rice yield, whiteness, milling recovery, milling degree and transparency. Meanwhile, Duncan's Multiple Range Test analysis was employed to determine the differences in the rice quality parameters between control drying and fluidized bed drying in case of each season. In addition, analysis was done to compare the quality of milled rice between two seasons with only fluidized bed drying method was considered as the factor.

RESULTS AND DISCUSSION

Simulation Results Compared with Observed Results

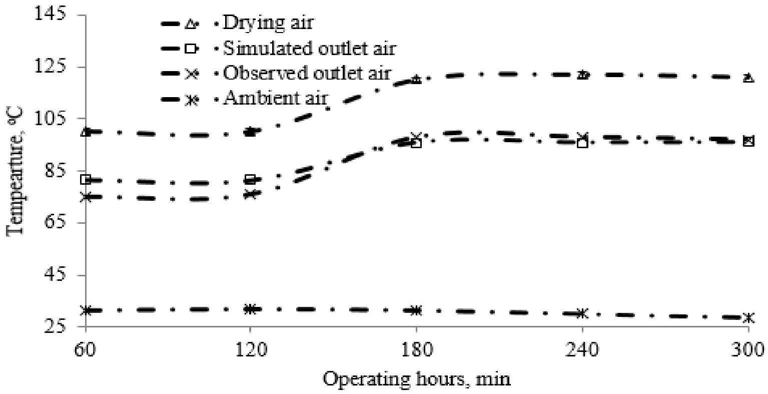


a. **First season**
[Feed rate=7.75 t/h, drying air temperature=100-120°C, air velocity= 2.24 m/s and weir height=10 cm]



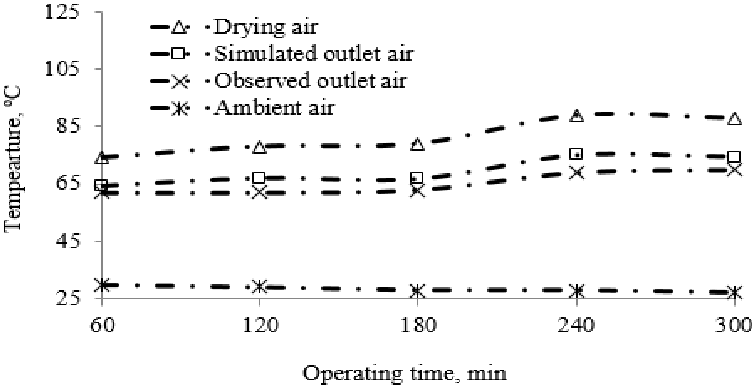
b. Second season
[Feed rate=9.5 t/h, drying air temperature=78-90 °C, air velocity= 2.24 m/s and weir height=10 cm]

Fig. 2: Comparison of simulated and observed moisture content



a. **First season**

[Feed rate=7.75 th^{-1}, Paddy initial moisture content=34-41.84% (db), air velocity= 2.24 ms^{-1} and weir height=10 cm]



b. **Second season**

[Feed rate=9.5 th^{-1}, paddy initial moisture content=30.77-33 % (db), air velocity= 2.24 ms^{-1} and weir height=10 cm]

Fig. 3: Comparison of simulated and observed outlet air temperature.

Fig.2 and Fig.3 represent moisture reduction and evolution of temperature, respectively, during drying of high moisture paddy by the fluidized bed paddy dryer. The simulated outlet moisture content and outlet air temperature were also plotted to indicate a very good agreement with the observed results. Moreover, the mean relative deviation (MRD) values were obtained as 4.86 and 7.62 % for the outlet moisture content during the first and second seasons, respectively, and 11.01 and 10.59% for the outlet air temperature for the two seasons also proved the accuracy of prediction. From Fig.2, it is clearly noticed that moisture drop ranged from 8.42 to 10.1% in the first season operation when drying paddy of 34-40% initial moisture content at the drying temperature of 100-120°C and bed air velocity of 2.24 m/s. Moisture drop during the second season operation was obtained in the range of 2.83 to 7.2% from the initial moisture content of 27-30% at the drying temperature of 78-90°C and the 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 seasons, respectively. The simulated outlet paddy moisture was slightly overestimated. The drying air temperatures for drying of various initial moisture content paddy by the dryer were between 78 to 120°C in the two operational seasons. Consequently, both corresponding observed and simulated outlet air temperatures were found to be varied in each season, as shown in Fig.3. Although the drying air temperature was noticed to be changed with the initial paddy moisture content by the operator during dryer operation at the plant site, it is crucial to emphasise that selecting appropriate operating temperature of the dryer in order to achieve possible maximum throughput capacity. This will be further discussed in the following section in relation to the application of simulation approach in determining suitable drying parameters.

Drying Rate

The drying rate obtained during the operation of fluidized bed dryer with corresponding operating parameters used in the two seasons are presented in Table 1. It revealed that the higher drying rate of 538 kg moisture/h was achieved at feed rate of 7.75t/h during the first season, whereas comparatively lower drying rate of 435 kg moisture/h was achieved at the higher feed rate of 9.5t/h in the second season. These drying rates are much lower compared to the results reported by Prachayawarakorn *et al*. (2005). It is noted that higher drying rate was achieved in the first season due to higher drying temperature used for the drying of comparatively higher initial moisture content paddy, as shown in Table 1. A similar phenomenon during fluidized bed drying was also reported by the other authors (e.g. Tatemoto & Sawada, 2012; Kozanoglu *et al*., 2012; Srisang *et al*., 2011). The dryer was found to be operated at a much lower capacity than the design capacity, and this justified its lower performance. During the operation of the dryer, it was noticed that the paddy flow through the intake elevator and pre-cleaner was not consistent, and this reduced the throughput capacity. In addition, high moisture and high impurities in the paddy had caused problems due to clogging and thus hindering smooth and steady throughput. However, a consistent paddy flow could be ensured through continuous inspection and necessary adjustments to the elevator and pre-cleaner.

TABLE 1: Drying rate of an industrial fluidized bed dryer with capacity of 25 t/h 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/h)	Drying rate (kg/h)
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 electrical and thermal energy consumption calculated from the observed data is presented in Fig.4. The specific electrical energy consumption in terms of primary energy was found as 0.97 MJ/kg water evaporated during the first season and 1.2 MJ/kg water evaporated in the case of the second season. On the other hand, the specific thermal energy consumptions were found to be 5.91MJ/kg water evaporated and 7.58 MJ/kg water evaporated, respectively, during the first- and second-season drying processes. In almost similar drying conditions, higher electrical energy consumption was noticed in this case as compared to the results reported by other authors such as Soponronnarit *et al.* (1996b) and Prachayawarakorn *et al.* (2005a, 2005b), while thermal energy consumption was comparable with the values reported by Prachayawarakorn et al. (2005a, 2005b). Hence, it might be possible to minimize the energy consumption in the FBD of the present setup by ensuring that its operation is attained at a possible maximum capacity using suitable drying temperature.

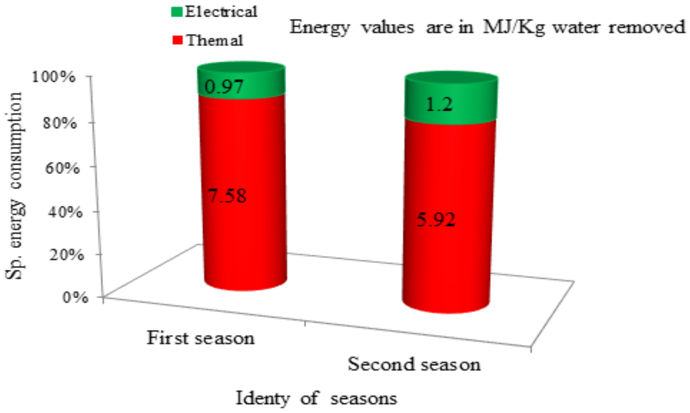


Fig. 4: Energy consumption during industrial fluidized bed paddy drying.

Paddy Quality Assessment

Table 2 presents the means with standard error mean (SEM) values of the head rice yield, whiteness, milling recovery, milling degree and transparency from the fluidized bed drying and control drying. Head-rice yield, whiteness and milling recovery of the rice samples dried by fluidized bed dryer were almost identical at acceptable milling degree and transparency to those which were dried using ambient air as the control drying over both seasons. From the statistical analysis shown in Table 2c, it is clear that the head rice yield of paddy dried by FBD during the first season was comparatively higher (around 3%) than that obtained during the second season. Higher initial moisture content paddy (34-40%) dried by FBD using higher air temperatures 100-120°C resulted in higher head rice yields, which are similar with the previous findings reported by Taweerattanapanish *et al.* (1999). Lower drying temperature (78-90°C) used by FBD for the drying of paddy having relatively lower initial moisture content (27-30%) during the second season yielded lower head rice yield and whiteness. It is noted that the use of higher drying temperature (above 90°C) has a great advantage in drying high moisture paddy by fluidization technique. Unfortunately, the head rice yield achieved from this industrial dryer is still lower than the results obtained by other researchers (see Sutherland & Ghaly, 1992; Soponronnarit*et al.*, 1998). However, if tempering, the important step after the high temperature fluidized bed drying as reported by many researchers (Soponronnarit *et al.*, 1999; Taweerattanapanish *et al.*, 1999; Poomsa-ad *et al.*, 2001; Prachayawarakorn *et al.* 2005b) could be applied, rice quality might be improved. Therefore, tempering could be adopted after fluidized bed drying in the paddy processing plant.

TABLE 2: Comparison of the milling qualities of rice

a. Milling qualities during first season

Drying method	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±0.17 ^{a}	39.2±0.18 ^{a}	64.1±0.47 ^{a}	86±1.0^{a}	1.56±0.09 ^{a}

b. Milling qualities during second season

Drying method	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}

c. Comparison of milling qualities of fluidized bed paddy drying between two seasons

Drying method	HRY (%)	Whiteness (%)	Milling recovery (%)	Milling degree (%)	Transparency
FBD-first season	48.9 ±0.16^{a}	39.33 ±0.21^{a}	64.06 ±0.47^{ba}	86 ±1^{a}	1.56 ±0.09^{a}
FBD-second season	46.1 ±0.29 ^{b}	37.7 ±0.58^{b}	67.03 ±0.49 ^{a}	84.7 ±0.25^{a}	1.65 ±0.02^{a}

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

TABLE 3: Simulated final moisture content during drying with industrial fluidized bed dryer of 25 t/h design capacity

Drying air temperature, ^{o}C	First season			Second season		
	At capacity (feed rate)			At capacity (feed rate)		
	7.75 t/h	10 t/h	15 t/h	10 t/h	15 t/h	20 t/h
90	*-	-	-	24.88	26.02	26.69
100	-	-	-	24.32	25.52	26.25
110	-	-	-	23.80	25.05	25.82
120	26.67	27.77	29.33	23.32	24.60	25.82
130	26.16	27.26	28.83	-	24.19	25.40
140	25.70	26.78	28.37	-	23.79	25.00
150	25.28	26.35	27.92	-	23.42	24.25
160	24.92	25.69	27.51	-	-	-

(Usual average initial paddy moisture content (mc) during first and second season were taken as 36% (db) and 30 % db, respectively, while bed height of 10 cm and bed air velocity of 2.25 m/s were maintained for all the simulation runs in both seasons;

*- values were not calculated as these are either much more higher or lower than the desired final moisture (bolded values) of 24-25%)

Application of Simulation Approach in Determining Suitable Drying Parameters

Previous researchers (Pomona-ad *et al*., 2001; Soponronnarit *et al*., 1994; 1996a; Sutherland & Ghaly, 1990) reported that for quality rice after fluidized bed drying, paddy final moisture content should not be lower than 24-25 %. Hence, in order to achieve this desired level of the final moisture content, a good number of drying simulation runs were done at different feed rates and drying air temperatures. The simulation results are shown in Table 3. It must be noted that the approach used in determining suitable operating parameters was based on simulation results. During the first season, when the initial moisture content was very high (36 %), it is clearly noticed that the dryer could reduce moisture content to 23-24 % when operating at higher drying temperatures of up to 160°C with low throughput capacity (i.e., feed rate) of less than 7.75 t/h. However, if the final moisture content to be achieved ranged from 24 to 25%, the dryer could then be operated at the maximum throughput of 7.75 t/h. By using higher drying temperature of 160°C, throughput capacity could be increased in the range of 10 and 15 t/h to result in the final moisture content of 26% and 27.51%, respectively, as can be seen at the bottom rows of Table 3. In the case of the second season, when the initial moisture content is comparatively lower (30 %), the dryer could reduce moisture content of paddy to 23-24%, even at 110°C. Although the capacity achieved was only 10 t/h, it is still higher than the drying capacity of the first season with higher initial moisture. From Table 3, it is clear that the dryer could be operated at higher capacity of 20 t/h to reduce moisture content to around 24-25% from 30% by using the drying temperature of 150°C. Consequently, if the dryer is run at its maximum possible throughput capacity, both specific electrical and thermal energy consumptions would be minimal. However, this simulation approach can be used to select suitable combination of operating parameters for possible maximum throughput capacity through determination of expected final moisture with reasonable energy consumption.

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 exhibiting lower performance of the dryer. Nevertheless, the dryer performed better in yielding around 3% higher head rice yield during drying paddy with higher initial moisture content of 34-40% using higher temperature of 100-120°C in the case of the first season than that of the low initial moisture paddy of 27-30% using lower temperature of 78-90°C in the second season. The dryer exhibited the drying rates of 538 kg moisture/h and 435 kg moisture/h for the first and second seasons, respectively. 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. Hence, when the initial moisture content is higher than 28% dry basis, it is recommended that inlet-air temperature should be higher than 100°C in order to achieve higher head rice yield. Also, throughput capacity of the dryer could be increased by using higher drying air temperature based on the initial paddy moisture content. In addition, continuous supervision of intake elevator, pre-cleaner and rotary feeder is necessary to avoid any inconsistent paddy flow due to variation of impurities and moisture content in freshly harvested paddy. Simulation approach, which was found to be reliable in predicting the average outlet paddy moisture content and outlet air temperature during the drying process, could be readily used in determining suitable operating parameters to achieve possible maximum throughput capacity of industrial fluidized bed dryer as it allows rapid calculation of the required changes in the manipulated variables in response to any sudden change of dryer condition.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to BERNAS, Malaysia, for the financial support, as well as for the use of drying and milling site for data collection. Our heartiest gratitude also goes to the Food Analysis Laboratory of UPM-BERNAS for facilitating the milling test.

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