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COMPARISON OF PERFORMANCES OF INDUSTRIAL SCALE INCLINED BED PADDY DRYERS

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ABSTRACT

An investigation was done to evaluate the overall performance of industrial inclined bed dryers (IBDs) in the two paddy processing complexes of Padiberas Nasional Berhad (BERNAS). Attempts have been made in analyzing drying characteristics, energy consumption and final quality of dried product during drying of freshly harvested high moisture Malaysian paddy (MAR-219). The overall results from the present IBD drying practices exhibited the lack of consistency in operating parameters such as drying air temperature, drying time and air flow rate between the two complexes even among the IBDs in each complex. Consequently, variation in moisture reduction, drying capacity, energy consumption and rice quality happened. In reducing paddy moisture from 22.5- 23 % wet basis (wb) initial moisture content to around 12.5 % wb final moisture content, the drying capacity of the dryers were found to be varied between 0.656 and 1.03 ton dry paddy per hour, while the holding capacity of each dryer was 15 ton. The thermal energy consumption of the IBDs varied from 2.28 to 5.16 MJ/kg water evaporated while electrical energy consumption was found to be 0.55 to 0.75 MJ/kg water removed. Almost same initial moisture content paddy dried using lower drying temperature of 38-39 ^oC with IBD yielded 1 to 4 % higher head rice yield while milling recovery and whiteness were comparable at acceptable milling degree and transparency . Below 23 % wb moisture paddy, it is recommended that drying air temperature should not be higher than 39 ^oC in order to maintain rice quality and minimize energy consumption.

Keywords: *Industrial paddy drying, Inclined bed dryer, drying characteristics, energy, rice quality.*

INTRODUCTION

Paddy drying is a serious issue in all paddy-producing countries. It sometimes becomes a crucial problem in humid tropical climates which is the most critical operation after harvesting a rice crop. Delays in drying, incomplete drying or ineffective drying will reduce grain quality and result in losses. In tropical countries the paddy is usually harvested at high moisture content between 20 and 25% wet basis [1, 2]. Although, new methods such as: combined microwave or infrared–hot air drying, steam drying, and spouted bed drying have been reported as efficient drying methods for quality rice [3-7], their use for industrial purpose are still limited. The most common dryer for paddy drying in Asia is fixed deep bed dryer either in the form of rectangular bins such as flat bed and inclined bed or circular bins [8]. However, inclined bed dryer (IBD), as illustrated in Figure 1, is very popular as single stage dryer for complete drying of paddy in commercial rice mills of Malaysia. Recently, IBD is found to be used as second stage dryer after fluidized bed dryer (FBD) in very few selected drying complex of Padiberas Nasional Berhad (BERNAS)-the national paddy custodian of Malaysia. IBD is a type of deep bed or fixed bed dryer in which the drying bed is inclined to get advantages for easy and faster discharge of paddy after drying. This dryer is usually used for drying of the high moisture (20-26 % wb) paddy with drying bed usually fixed at 1.0 m. The moisture gradient in final product after drying with fixed bed drying is usually higher (3-4%) [8].

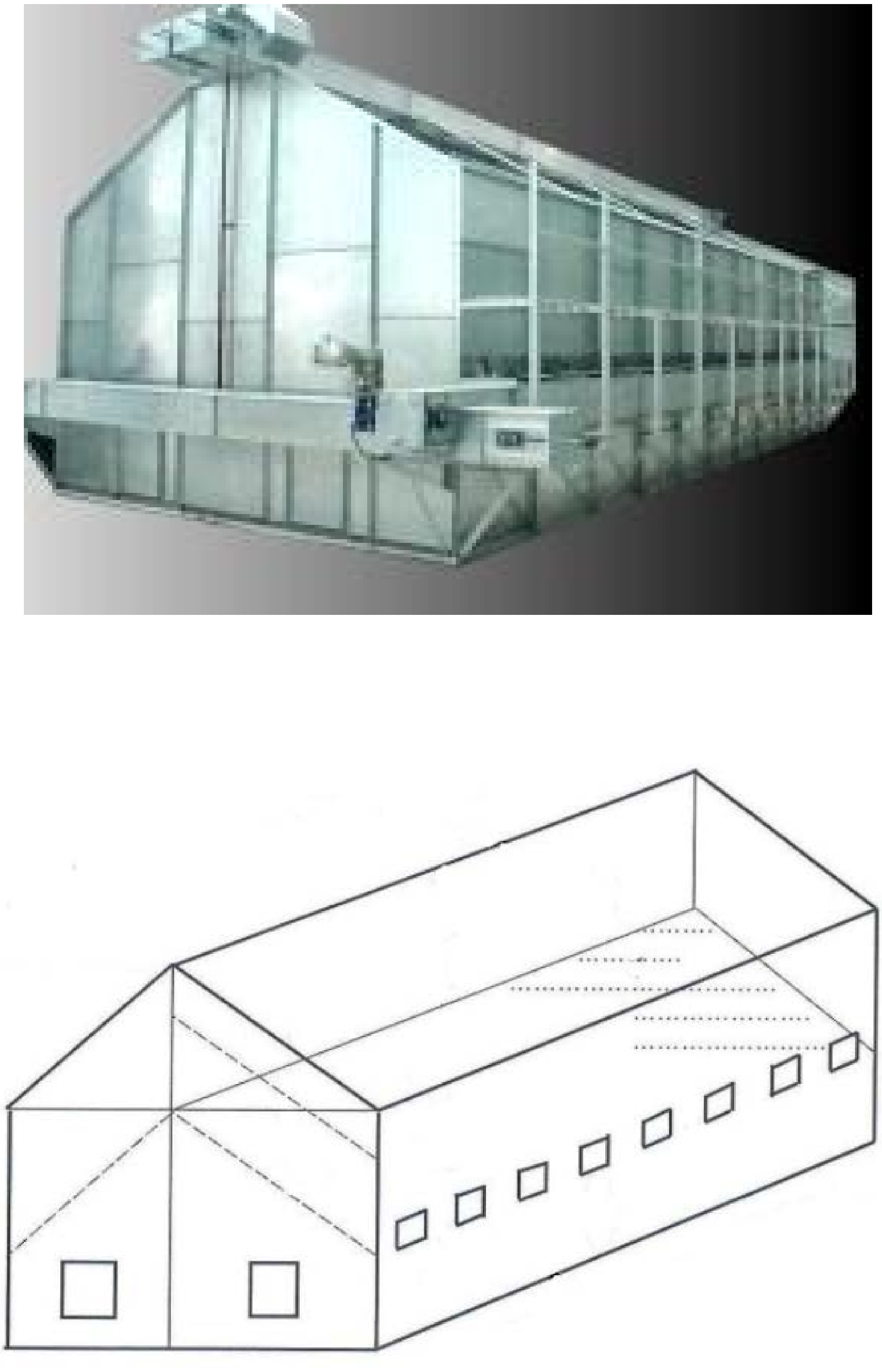

Fig. 1(a): Photographic view of industrial Inclined Bed Dryer

A numerous reviews on modelling and simulation on deep bed drying are found [2, 9-16] where-in results are discussed based on laboratory experiments, while the industrial scale study results are seldom reported in scientific journal. The drying characteristics and further analysis of the drying rate periods of Malaysian paddy were studied by Daud et al. [17] and Law et al. [18, 19]. However, still information on attempts to use IBD specifically for industrial drying of freshly harvested paddy containing high moisture and impurities are scare.

Paddy drying is a highly energy-intensive process and sensitive to the quality of rice [7]. The energy cost of the industry is possible to be reduced if an in-store dryer is used after the first-stage drying by LSU dryer [20]. To compare the energy consumption between industrial drying options, the observational data of drying paddy with the industrial scale dryers must be obtained [21]. It is well known that if the drying bed is >20 cm, then the bed is termed as deep bed. However, the suitable or optimum bed thickness for a specific temperature to dry a particular initial moisture content paddy to achieve better quality product at reasonable energy consumption is important for any dryer. Inconsistent operating parameters, such as drying air temperature, drying time and air flow rate among the drying process lines are found during industrial drying [22]. The effect of drying temperature on rice quality at particular bed thickness used in the industry warrants a thorough study for further efficient operation of the dryer. Necessarily, the performances of industrial dryers should be assessed to check its operational status.

Therefore, this study was undertaken to assess the actual drying practices using IBD in the two commercial paddy drying process complexes of BERNAS. The effect of temperature and air flow used in both the complexes on drying kinetics, energy consumption and final quality of product has also been observed to suggest for further improvement of the drying operation.

MATERIALS AND METHODS

Field observation and data collection

The commercial scale inclined bed dryers of the two paddy processing plants of BERNAS, Bukit Besar, kedah and Simpang Empat, Perlis, Malaysia were the dryers used for this study. The dryers consisted of inclined drying bed (10.72 m × 2.92 m and 9.783 m× 3.048 m b) at 38^{o}-45^{o} inclination with 9.5 mm stainless sieve, blower with 1.524×1.31×0.533 m impeller and 18.65 kW motor. Freshly harvested paddy 'MAR-219' variety, which is produced widely in Malaysia, was collected from the farmer's field of Bukit Besar, Kedah and Kuala Perlis for all the experiments. The drying operation with detailed operating conditions used during this study is illustrated in Table 1.

Table 1: Details of operating parameters used in industrial inclined bed dryer (IBD) for drying of freshly harvested high moisture paddy.

Location of plant	Identity of drying lines	Drying operating conditions
Bukit Besar Kedah, Malaysia	Control drying	T_{db}=27-32 ^{o}C; RH=55-75%; Vair=0.06 to 0.5 m/s
	IBD No.1	V= 0.24 $m^3/s/m^2$; T=38-39 ^{o}C; h=1.0 m
	IBD No.2	V= 0.27 $m^3/s/m^2$; T=38-39 ^{o}C; h=1.0 m
Simpang Empat, Perlis, Malaysia	Control drying	T_{db}=26-32 ^{o}C; RH=55-75%; V=0.06 to 0.15 m/s
	IBD No.1	V= 0.21 $m^3/s/m^2$; T=41-42 ^{o}C; h=1.0 m
	IBD No.2	V= 0.29 $m^3/s/m^2$; T=41-42 ^{o}C, h=1.0 m

[V: Average bed air velocity, T: Drying air temperature, h: Bed depth, T_{db}: Dry bulb temperature of ambient air, RH: Relative humidity of ambient air]

Shed drying was followed for drying of control samples .Necessary data such as: the amount of paddy, moisture content, impurities in paddy, drying air temperature, drying time, air flow and motor power were collected. The drying air is heated from the heat produced by the combustion of rice husk in cyclonic furnace. The paddy samples were collected from 27 points at 2 to 5 hours interval. Higher interval of 5- 3 hrs were considered at the beginning of drying in each IBD due to very low moisture drop, while this interval was 2 or 1 hr towards the end of drying process. This was adopted to ensure an appropriate final drying stage as well as to avoid over drying of paddy. The whole bed was divided into three sections along length and depth. The length of the paddy bed was specified as front, middle and back, while the depth of the paddy was specified as the top, middle and bottom. The top average, middle average and bottom average were defined as the average moisture content from every nine points from the top, middle and bottom sections, respectively, while the average moisture content was calculated by the arithmetic mean of paddy moisture content collected from the above-mentioned 27 points of each IBD. Indeed, sample collection from the above mentioned 27 points of each dryer was terrible and troublesome job which solely dependent on few other physical facilities in the complex hence it was not possible to maintain equal interval. The moisture content of the paddy was measured by the Satake digital grain moisture tester model "SS-6" with an accuracy of ±0.5%. Meanwhile, drying air temperature and relative humidity were measured by K-type thermocouple (HANNA, Italy) with ± 0.5°C accuracy and Thermo Hygrometer (H19564, HANNA, Taiwan), respectively. The inlet air velocity of dryers was measured by Thermal Anemometer (TESTO 4235, Italy) with ± 0.03 m/s accuracy. The cross-section area at the point of velocity measurement was measured previously and the volume of air was calculated by continuity equation (Eq. a). Bed air velocity of each dryer was calculated using the same equation. The collected data were used for calculating the energy consumption of the paddy drying by Eqs. b, c, and d according Jittanit *al* el. [7]. The energy consumed was divided into heat for heating air and electricity for driving fan. The specific energy consumption (both electrical and thermal) was finally calculated as mega joule (MJ) per kg water removed .

$Q= A\times V$………………………………………………… (a)
$E_{elec}= P \times t$……………………………………………… (b)
$E_{heat}= m_a C_a (T_{mix}-Ti)$…………………………………….. (c)
$m_a=Q\times\rho_a\times t$ …………………………………………….. (d)

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_{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. Five to seven kilograms of dried paddy were collected from different layers of IBDs (i.e. top, middle and bottom) and mixed to represent the paddy sample of each IBD and stored in the refrigerator at 5-8°C after packing and sealing in poly packages for 3-4 weeks for further quality tests.

Assessment of Rice Quality

For determination of head rice yield, 125 gm of dried and cleaned paddy samples with two replications were dehusked with a Testing Husker (THU-35A, Satake Engineering Co., Ltd. Japan), 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 the Satake Test Grain Grader (TRG 05B) using a 5.2-mm S-type identical cylinder. The head rice yield 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 metre with four replications as sample obtained twice from each sample of HRY determination. 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 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, milling degree and transparency.

RESULTS AND DISCUSSION

Drying kinetics of industrial inclined bed paddy drying

Figure 2 to Figure 5 represent the drying kinetics of the inclined bed dryer obtained by plotting the percentage of the moisture content against drying duration. In case of Bukit Besar complex, it can be observed from Fig. 2 that the average percentages of moisture reduction by IBD-1 and IBD-2 were found to be 10.85% and 10.44%, respectively from an average initial moisture content of 23% at 20 hr drying time. On the other hand, Lower drying time of 18 hr and 13 hr were achieved for almost same moisture drops of 10.02% and 9.45% from an average initial moisture content of 22.5% by no IBD no 1 and IBD no. 2, respectively, for Simpang Empat dryers case. Differences in moisture drop were found in the individual IBD within the same drying complex. As shown in Table 1 and Figures 2 to 5, clear differences in air flow or bed velocity and air temperature in the drying chamber were observed, and thus, variations of moisture drop was exhibited. An uneven moisture gradient in paddy bed as shown in the drying curves of IBD no 1 (Fig. 4) was visible, which might be due to low air flow (refer to Table 1) and uneven bed thickness as noticed during the operation. However, different size of impurities (15-20%) in the bed might also be the cause of the uneven moisture gradient. Clear and distinct moisture gradient was observed by Prakash and Pan [23] during drying of different size of paddy. The higher moisture differences between the top, middle and bottom layers were noticed in IBDs of Simpang Empat than Bukit Bear as viewed in the plotting of Fig.2 to 5. It caused due to using higher drying temperature of 41-42^{o}C for drying of almost same initial moisture content paddy. The lower drying time was achieved at higher air flow rate as [23] in the case of IBD no 2 of Simpang Empat even though the bed thickness was fixed at 1.0 m throughout the drying period in all IBDs. This result matches with Mossman [24] reports.

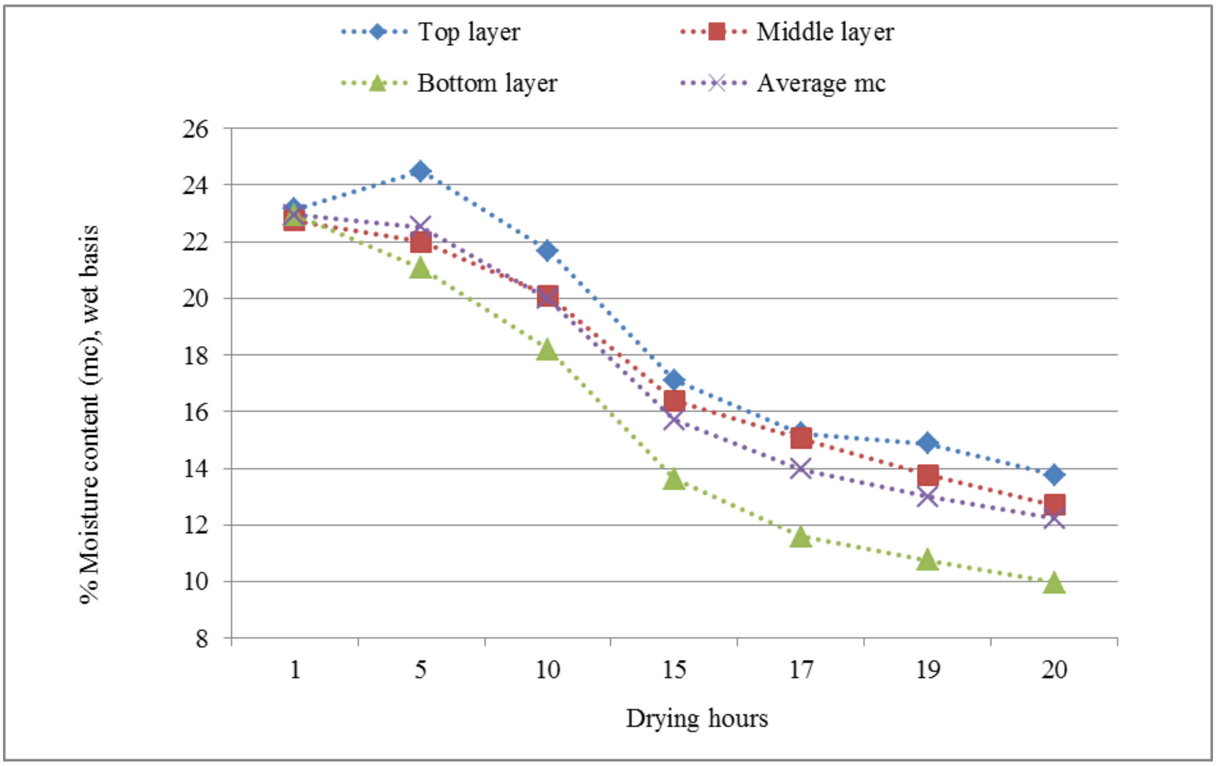

Fig. 2: Drying curve during inclined bed paddy drying.
[In case of IBD no 1, Bukit Besar, at Temp=38-39 ^{o}C, air flow=0.24 $m^3/m^2/s$ and bed depth=1.0 m]

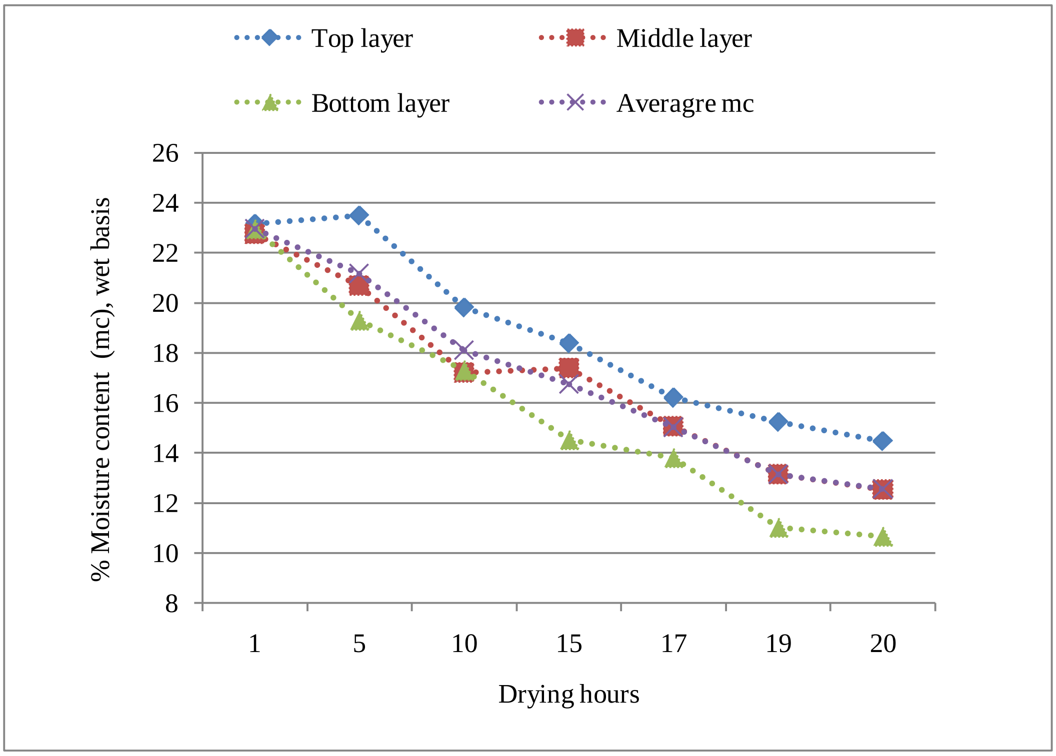

Fig. 3: Drying curve during inclined bed paddy drying.
[In case of IBD no 2, Bukit Besar, at Temp.=38-39 °C, air flow= 0.27 $m^3/m^2/s$ and bed depth=1.0 m]

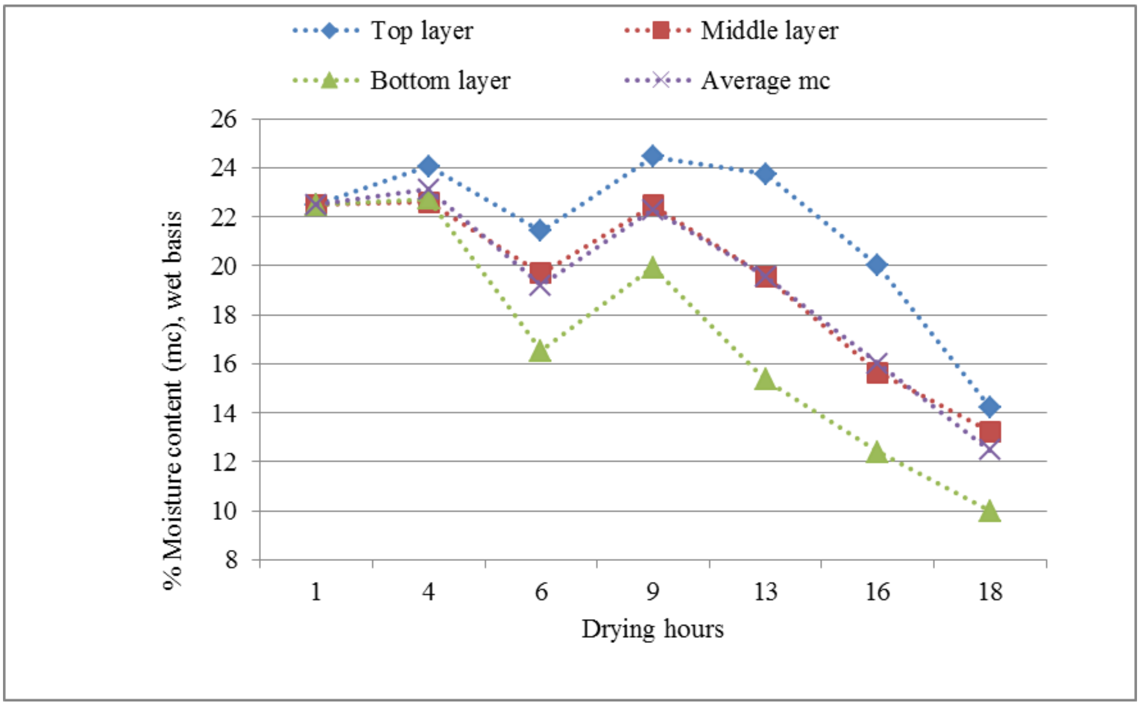

Fig. 4: Drying curve during inclined bed paddy drying.
[In case of IBD no 1, Simpang Empat, at Temp.=41-42 °C, Air flow= 0.21 $m^3/m^2/s$ and bed depth=1.0 m]

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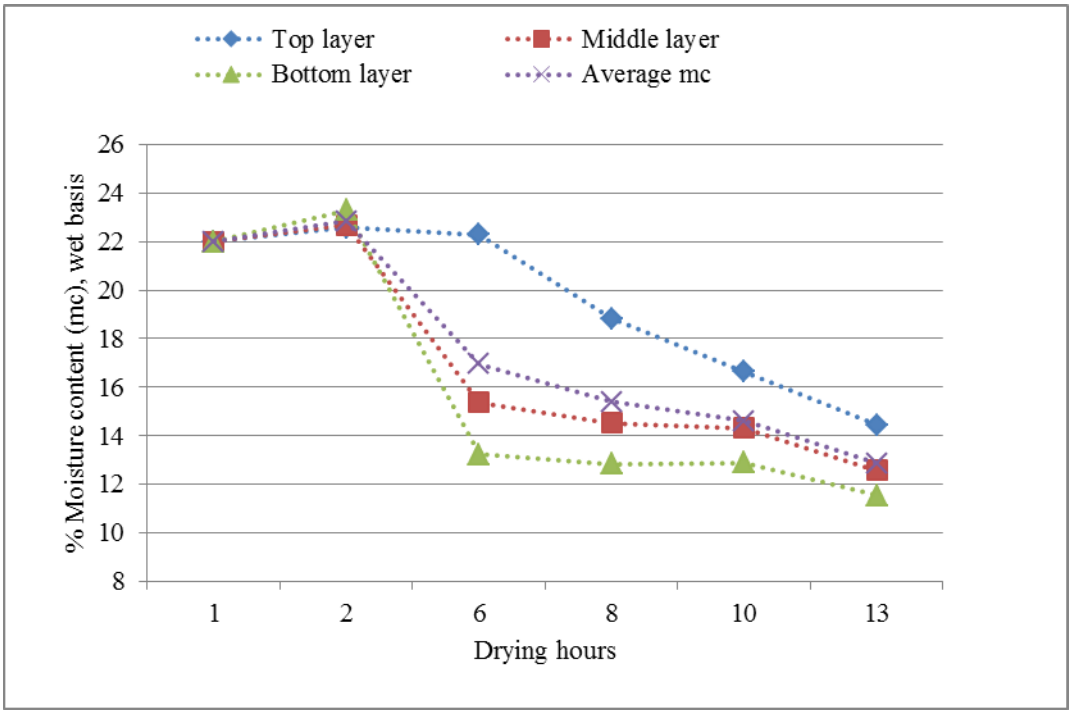

Fig. 5: Drying curve during inclined bed paddy drying.
[In case of IBD no 2, Simpang Empat, at Temperature=41-42 °C, air flow=0.29 $m^3/m^2/s$ and bed depth=1.0 m]

Uniformity of paddy moisture content

Especially, in fixed-bed dryers, the grains at the air inlet dry faster than at the air outlet resulting in a moisture gradient in the grain bulk at the end of the drying process [8]. Similar phenomenon was observed during the present study as viewed in Fig.2 to Fig. 5. It is interesting that few hours after starting the drying process, moisture content of the top layer grain was noticed to be increased. This happened due to migration of air vapour from bottom and middle layer to top layer by diffusion thus lead to increase moisture grain. An abrupt moisture drop as depicted in Fig.4 in case of IBD no.1 at 6hr drying time indicated the limitation of sample collection and moisture determination as well which can be ignored. From the drying curves it is also clear that bottom layer grain of the IBDs are dried faster even over dried especially in case of higher drying temperature as shown in Fig. 3 and Fig 4. Over drying is one of the factors that usually causes lower head rice yield.

Energy consumption in industrial inclined bed dryers

The energy consumption calculated from the obtained data is shown in Figure 6 and Figure 7. The results indicated that the thermal energy consumption ranged from 2.28 to 3.46 MJ/kg water evaporated and 5.1 to 5.16 MJ/kg water evaporated, respectively in the case of IBDs of Bukit Besar and Simpang Empat. Meanwhile, the specific electrical energy consumption ranged from 0.0.55 to 0.7 MJ/kg water removed and 0.72 to 0.75 MJ/kg water removed for the complexes. Obviously, IBDs consumed higher thermal energy because of using higher drying temperature in the case of Simpang Empat dryers. However, electrical energy consumption did not vary so much except IBD no 2 of Simpang Empat complex when drying time was very short because of higher air flow of 29 $m^3/s/m^2$.

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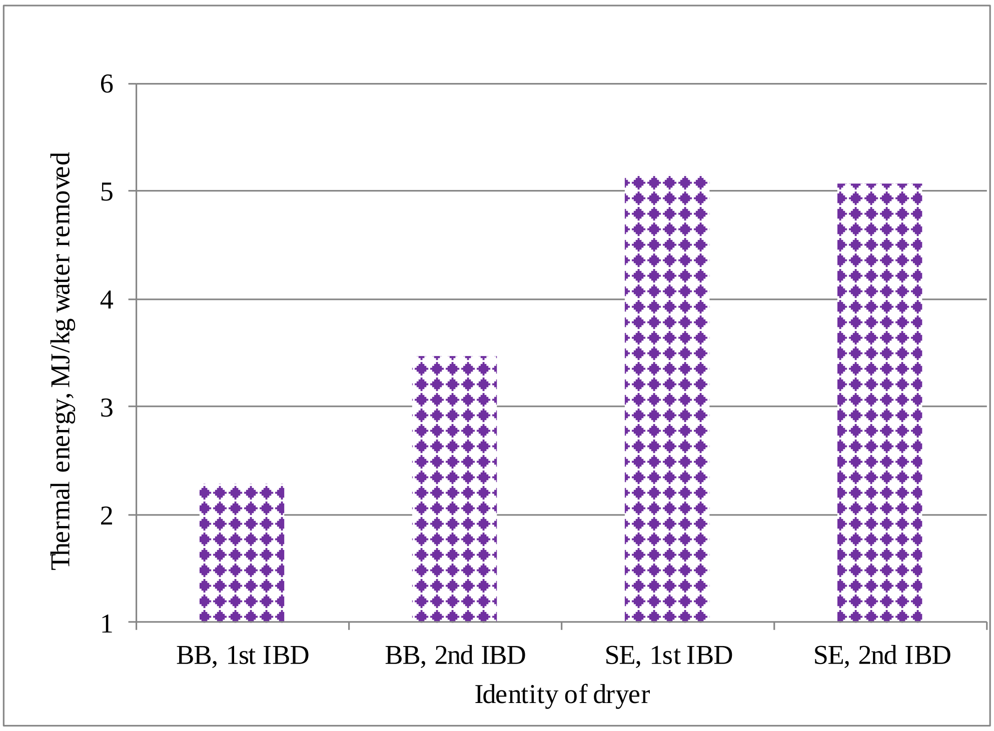


Fig. 6: Thermal energy consumption in paddy drying with inclined bed dryer of the two complexes of BERNAS.[BB: Bukit Besar, SE: Simpang Empat, IBD: inclined bed dryer]

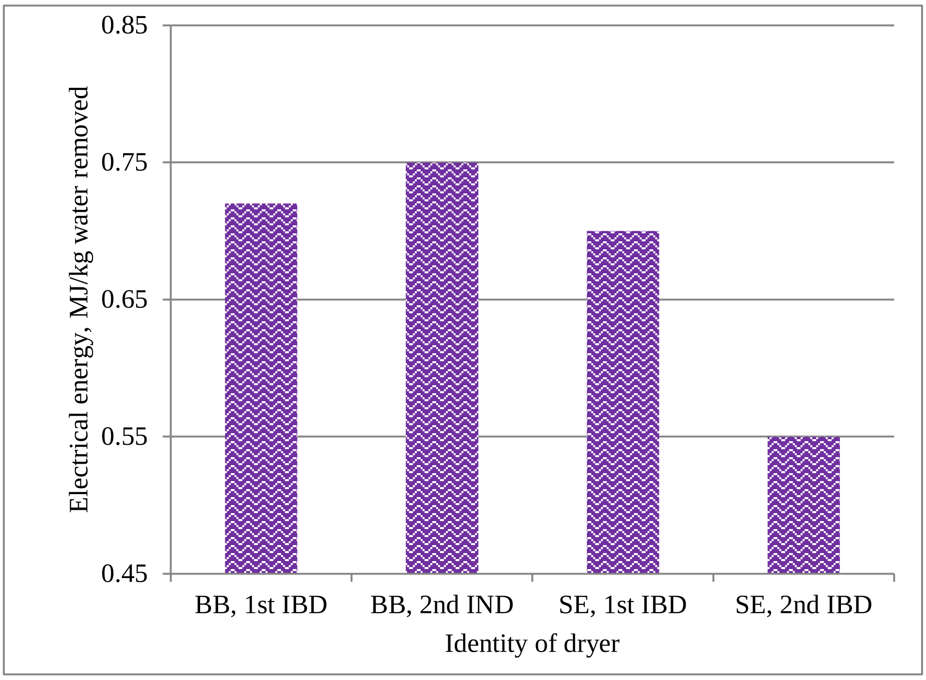


Fig. 7: Electrical energy consumption during paddy drying with inclined bed dryer in the two complexes of BERNAS. [BB: Bukit Besar, SE: Simpang Empat, IBD: inclined bed dryer]

Drying capacity and drying rate

A simple calculation revealed that drying with higher drying temperature resulted in higher drying capacity of the IBDs with same holding capacity as displayed in Table 2. However, drying rate was found almost same in three dryers except IBD no 2 of second complex because of higher air flow of 29 $m^3/s/m^2$.

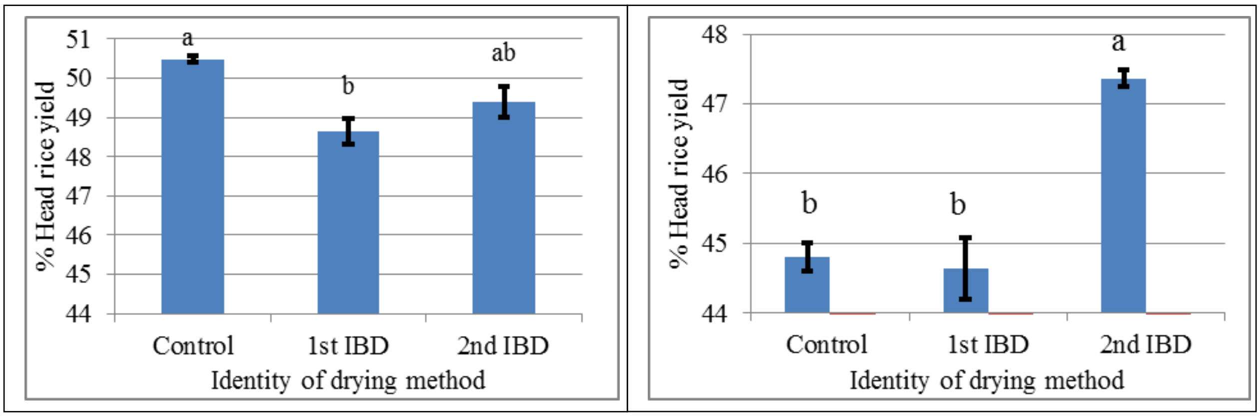
Table 2. Drying capacity and drying rate of industrial inclined bed dryers (IBDs).

Location	Dryer ID	Bed Area (m × m)	Hold up (kg)	Drying capacity (ton dry paddy/hr)	Drying rate (kg water/hr)
Bukit Besar Kedah	IBD no 1	10.72 × 2.92	15000	0.656	94
	IBD no 2	10.72 × 2.92	15000	0.660	90
Simpang Empat, Perlis	IBD no 1	10.29 × 3.05	15000	0.740	95
	IBD no 2	10.29 × 3.05	15000	1.030	121

Product quality assessment

Head Rice Yield

The percentages of head rice yield (HRY) obtained from the IBDs of both the complexes under drying conditions mentioned in Table 1 are depicted in Figure 8 and Figure 9. Significant difference ($P<0.05$) in the head rice yield between the two IBDs of Simpang Empat was achieved while HRY did not vary between two IBDs of Bukit Besar. However, head rice yield obtained from control samples did not differ so much. It occurred due to drying the samples under shed drying and for longer drying time upto three days. This might lead to breakage of kernels. However, the head rice yield obtained from the IBDs of Bukit besar complex was comparatively higher (1-4%) than those of Simpang Empat complex. Almost same initial moisture content paddy dried using higher temperatures by IBD degraded head rice yields which were similar with the previous findings [25]. Moreover, as viewed in the Figure 4 and Figure 5, non-uniform drying due to higher temperature and lower air flow for very thick paddy bed (1.0 m) caused over drying of the bottom layer paddy which led to breakage of grains and thus ultimately decreased the head rice yield. Further studies are needed to select the optimum drying temperature, tempering time, air flow and reasonable bed thickness for drying paddy using inclined bed dryer to achieve better quality rice for drying of various initial moisture content paddy, which are usually found to be varied from season to season even from day to day at times.



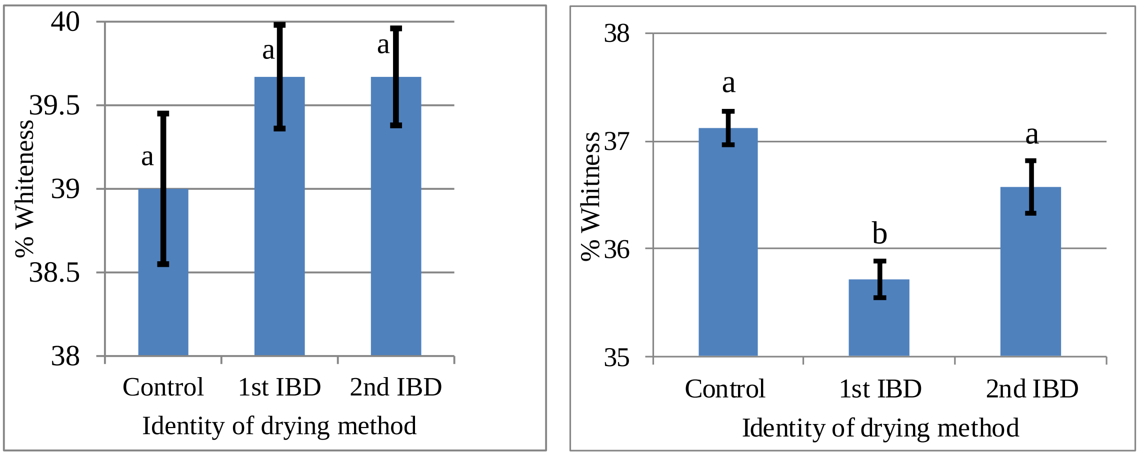
a. Bukit Besar

b. Simpang Empat

Fig. 8: Comparison of head rice yield obtained from different drying line of the two complexes of BERNAS. [IBD is inclined bed dryer, [a-d] The test values: Same letters for the different drying methods in each figure mean that the values are not significantly different ($p > 0.05$)].

Whiteness of rice

The whiteness of milled rice from the paddy dried with IBDs did not exhibit much difference among them as presented in Figure 9. Although the whiteness of rice was degraded slightly when the paddy was dried at higher temperature in case of Simpang Empat dryers in which the values fell in the range of 35-37 but the range, is still within the acceptable limit as per rice trade quality. Longer drying time up to three days of the control samples dried by shed drying might lead to non-enzymatic browning of paddy which could be the cause of lesser degree of whiteness.



a. Bukit Besar b. Simpnag Empat

Fig. 9: Comparison of whiteness of rice obtained from different drying lines of two complexes of BERNAS. [IBD is inclined bed dryer , [a-d] The test values: Same letters for the different drying methods in each figure mean that the values are not significantly different ($p > 0.05$)].

Milling recovery, milling degree and transparency of rice

The target of milling industry is to improve the quality of final product through increasing head rice yield and finally maximizing milling recovery at reasonable milling degree and transparency acceptable for the traders and for the consumers finally. In this context, the results obtained from the IBDs as presented in Table 3, are still within the range of acceptable values by the traders and consumers. In the rice industry, degree of milling and transparency of 80-100 % and 1.1 to 1.7 % , respectively are acceptable. Higher milling degree might be reason of lowering of milling recovery and whiteness as well in rice sample obtained from IBDs of Bukit Besar complex.

Table 3: Comparison of milling recovery, milling degree and transparency of rice obtained from inclined bed dryer (IBD) of the two complexes of BERNAS

Name of complex	Drying line	% Milling recovery	% Milling degree	% Transparency
Bukit Besar, Kadah Malaysia	Control	*65.34 ± 0.50^a	90 ± 0.58^a	1.68 ± 0.03^a
	1st IBD	66.36 ± 0.60^a	89.75 ± 0.75^a	1.48 ± 0.06^b
	2nd IBD	66.68 ± 0.60^a	90 ± 0.41^a	1.75 ± 0.05^a
Simpnag Empat, Perlis Malaysia	Control	67.64 ± 0.36^a	76.5 ± 0.29^b	1.90 ± 0.0^a
	1st IBD	66.60 ± 0.36^b	88.25 ± 0.95^a	1.50 ± 0.07^c
	2nd IBD	68.04 ± 0.20^a	71.5 ± 0.65^c	1.70 ± 0.04^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

The actual drying performances in terms of drying kinetics, energy consumption and final product quality of industrial inclined bed dryers as per usual operation in the two complexes of BERNAS are presented in this paper. In the case of both the complexes, lack of consistency in operating parameters, such as drying temperature, drying time and air flow rate among the IBDs were exhibited for drying the same kind of raw paddy. Drying capacity and drying rate of IBDs were found to be higher by 11 to 36 % and 5 to 25 %, respectively in the second complex than those of first complex for using higher drying temperature of 41-42 ^{o}C to dry almost identical paddy. In addition, thermal energy consumption was also found to be higher in second complex than first one while electrical energy consumption was lesser. In conclusion, IBDs yielded better quality rice in terms of head rice yield and whiteness and consumed less energy during drying of paddy with an average initial moisture content of 22.5-23% using 38-39 ^{o}C drying air temperature. However, further study is recommended to identify the appropriate drying temperature and air flow for optimum bed thickness for drying of a particular initial moisture content paddy to achieve better quality rice.

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REFERENCES

1. Inprasit, C. and Noomhorm, A. (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.
2. 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.
3. Sangdao, C., Songsermpong, S. and Krairiksh, M.(2011) A continuous fluidized bed microwave paddy drying system using applicators with perpendicular slots on a concentric cylindrical cavity. Drying Technology 29, 35–46.
4. Das, I.; Das, S.K. and Bal, S. (2009) Drying kinetics of high moisture paddy undergoing vibration-assisted infrared (IR) drying. Journal of Food Engineering 95, 166–171.
5. Soponronnarit, S., Prachayawarakorn, S., Rordprapat, W., Nathakaranakule, A. and Tia, W. (2006) A superheated-steam fluidized-bed dryer for parboiled rice: Testing of a pilot-scale and mathematical model development. Drying Technology 24, 1457–1467.
6. Evin, D., Gul, H. and Tanyildizi, V. (2008) Grain drying in a paraboloid-based spouted bed with and without draft tube. Drying Technology 26, 1577–1583.
7. Jittanit, W., Srzednicki, G. and Driscoll, R. (2010) Seed drying in fluidized and spouted bed dryers. Drying Technology 28, 1213–1219.
8. www.knowledgebank.irri.org at @EbookBrowse. Training Manual Paddy Drying pdf free ebook download from www *...ebookbrowse.com/training-manual-paddy-drying-pdf-d88323894* , pp, 18, 20.
9. D. Zare D., Jayas D.S and Singh, C.B. (2012) A Generalized Dimensionless Model for Deep Bed Drying of Paddy, Drying Technology 30: 44–51.
10. Naghavi Z., Moheb A. and Ziaei-rad S. (2010) Numerical simulation of rough rice drying in a deep-bed dryer using non-equilibrium model Energy Conversion and Management 51, 258–264.
11. Sitompul, J.P.,Istadi, I. and Widiasa, I.N. (2001) Modelling and simulation of deep-bed grain drying. Drying Technology 19, 269–280.
12. V.K. Srivastava V. K. and John J. (2002) Deep bed grain drying modelling. Energy Conversion and Management 43, 1689–1708.
13. Kribs JD and Spolek GA. (1997) Drying energy conservation for deep bed barley–malt kilns. J Agri Engg. Res 68: 307–73.
14. Zare, D., Minaei, S., Mohamad Zadeh, M. and Khoshtaghaza, M.H. (2006) Computer simulation of rough rice drying in a batch dryer. Energy Conversion and Management 47, 3241–3254.
15. Naghavi, Z., Moheb, A. and Ziaei-rad, S. (2010) Numerical simulation of rough rice drying in a deep-bed dryer using non-equilibrium model. Energy Conversion and Management 51, 258–264.
16. Zare, D. and Chen, G. (2009) Evaluation of a simulation model in predicting the drying parameters for deep-bed paddy drying. Computers and Electronics in Agriculture 68, 78–87.

17. Daud, W.R.W., Sarker, M.N.H. and Talib M.Z.M. (2000) Drying characteristics of Malaysian Padi., Pertanika Journal of Science & Technology 8(1), 105–115.
18. Law, C.L.,Tasirin, S.M. and Daud, W.R.W. (2001) Batch drying of paddy in a rapid bin dryer. The 2nd Asian-Oceania Drying Conference 607–616.
19. Law, C.L.,Tasirin, S.M. and Daud, W.R.W. (2003) A new variable diffusion drying model for the second falling rate period of paddy dried in a rapid bin dryer. Drying Technology 21(9), 1699–1718.
20. Jittanit, W., Saeteaw, N. and Charoenchaisri, A. (2010) Industrial paddy drying and energy saving options. Journal of Stored Products Research 46, 209-213.
21. Wan D. Gong Y. , Jin H. , Jian Ma and Chenghua Li. (2010) Study on the moisture uniformity of paddy drying in a deep fixed-bed. World Automation Congress (WAC), 19-23 Sept.
22. Sarker M.S.H., Ibrahim M. N., Ab Aziz N. and Mohd. Salleh, P. (2012) Drying kinetics, energy consumption and quality of paddy (mar-219) during drying by the industrial bed dryer with or without the fluidized bed dryer, accepted for publication in “Drying Technology”.
23. Prakash, B. and Pan, Z. (2012) Effect of geometry of rice kernels on drying modelling results. Drying Technology 30 (8), 801-807.
24. Mossman, A. P. (1986). A review of basic concepts in rice-drying research. Critical Rev. in Food Sci and Nutr. 25(1):49-70.
25. Taweerattanapanish, A.,Soponronnarit, S., Wetcharama, S., Kongseri, N. and Wongpiyachon, S. (199) Effects of drying on head rice yield using fluidization technique. Drying Technology 17 (1–2), 345–353.