Comparison of rotary dryer with conventional fixed bed dryer for paddy drying, milling quality and energy consumption

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Abstract: Operation of a rotary dyer (RD) was compared with conventional fixed bed dryer (FBD). Drying time, trends of moisture content and specific energy consumption for water evaporation were investigated for drying of Iranian paddy cultivar. Rice milling qualities such as husking, milling recovery (MR) and head rice yield (HRY), were studied. Results showed that, using FBD decreased drying time 8% and saved energy 6.78% respectively. Specific energy consumption in RD was 10.48 MJ per one kilogram of removed water and it was 6.82% more than FBD. Paddy moisture contents and temperatures differences at top and bottom layers of FBD were 2% and 6°C, respectively. High thermal stress in low layers of FBD increased grains cracking chance in milling process. The type of dryer did not have significant effect on dehusking process, but MR and HRY were 2.7% and 7.6% respectively more when paddy dried with RD.

Keywords: paddy, drying, rice milling, energy saving, rotary dryer

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1 Introduction

Rice is one the main food sources of the world's people. The FAO reported, nearly 161 million hectares were under cultivation of rice with the total yield of 679 million tons in the world in recently years. It ranked after wheat and barley at third place in Iran (Anonymous, 2015). Rice paddy needs to several processes for supplying as white rice in the market. The final quality of white rice is influenced by dying and milling process. Drying as one of the main and of necessity processes has critical effect on the quality of final product. Harvested paddy must be dried for storage or milling processing. In the international level, it was reported that paddy must be dried to moisture content about 13% (w.b.) for long storage. Also, for optimum head rice recovery in milling process the moisture content of paddy should be within the range of 10% to 13% (w.b.) (Teter, 1987; Tirawanichakul et al., 2004). For suitable milling results, it was recommended that the moisture content of Iranian paddy decrease below 10% (w.b.). (Shaker and Alizadeh, 2002; Sadeghi and Nassiri, 2010). Conventional batch type dryers generally used for paddy drying. High energy consumption and longtime period are the major concern in paddy drying. Rice physical characteristics and milling machines affected on rice milling losses (Bhattacharya 1980). Using high temperature in paddy

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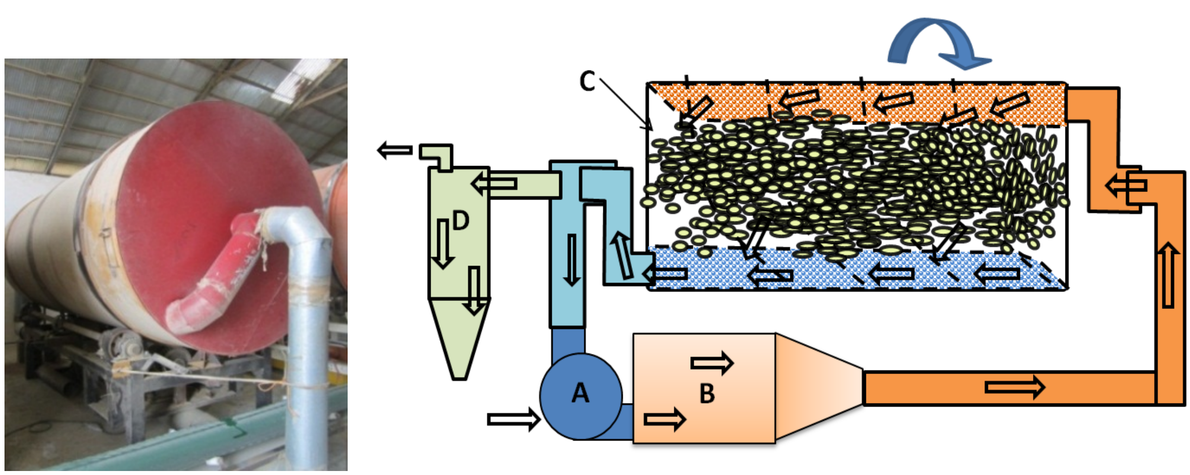
drying for long time decreased mechanical strength and increased kernel physical damages (Basunia and Abe, 1998; Siebenmorgen et al., 2005). The most important rice milling quality indicators are total rice yield, head rice yield and degree of milling (Pan et al., 2011). It was reported that, paddy drying must be uniform and smooth with low temperatures in order to reach the best quality in with rice. Using the temperature range of 30°C-40°C in paddy drying caused to produce maximum head rice yield in milling process (Soleymani, 1998; Brooker et al., 1992; Omar and Yamashita, 1987). In fixed bed dryer (FBD), increasing the dryer temperature, up to 55°C did not have adversely effect on white rice breakage and color, but increasing the temperature above 60°C caused to observe more cracked grain in the milled rice (Bakker et al., 1983). Paddy drying in temperature more than 50°C increased 50% breakage in compare with sun drying in Thailand (Wongpornchai et al., 2004). Energy use and efficiency of a commercial, cross-flow dryer were measured when drying rough rice across a range of ambient conditions and drying air temperatures.

Thermal energy for water removing in paddy drying changed from 6900 to 9670 kJ kg^{-1} (Billiris and Siebenmorgen, 2014). In a study, Two local cultivars of paddy (long and medium grain size) were dried in thin layer by three different methods included indirect active solar dryer, mixed-mode active solar dryer and continuous dryer, at three temperature levels of 35°C, 45°C, and 55°C (Nassiri and Etesami, 2013). Drying temperature significantly influenced on head rice yield and the specific energy consumption, so that the lowest ratio was obtained at 35°C. Considering low specific energy consumption and drying time duration, continuous dryer acted more efficient than others (Nassiri and Etesami, 2013). Objective of this paper was to compare paddy drying, milling quality and energy consumption between a horizontal rotary dryer (RD) and a conventional FBD.

2 Materials and methods

This research was conduct in Zare brothers milling factory in Sanger city, Gilan province, Iran. A RD was compared with a conventional FBD in the same capacity (Figure 1). RD had 4 m length and 2 m diameter with 3000 kg paddy capacity. Also, FBD had 5 m length, 2 m width and 1 m depth (Figure 2). Paddy height in FBD was 0.7 m. Capacity of FBD was the same RD. Air flow rate in new RD and conventional FBD was 0.02 and 0.15 m^3 s^{-1} m^{-2} respectively. Ambient relative humidity range was 60%-85%. Iranian long grain paddy *Ali Kazamei* was used in this research. The grain moisture content presented in this paper as percent and wet basis (% w.b). Paddy with initial moisture content of 13% dried to 8% for milling process.



A: Blower B: Furnace C: Bin dyer and paddy D: Dust Cyclone

Figure 1 New rotary dryer (RD)

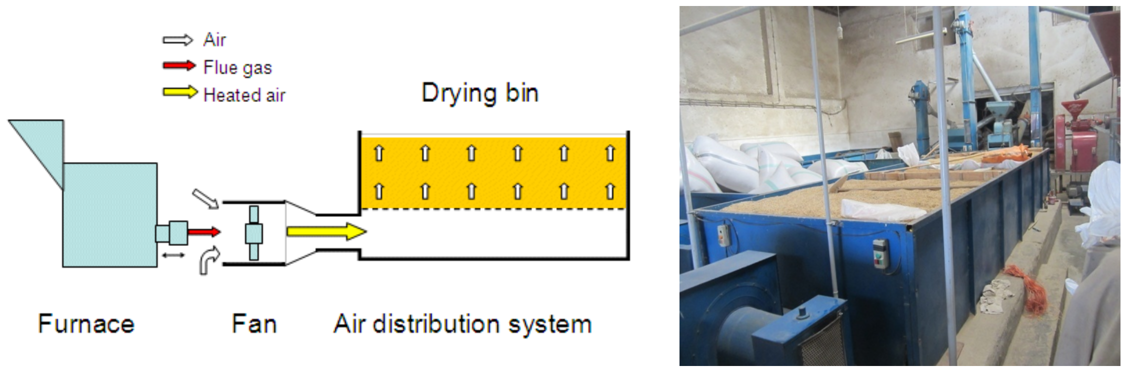


Figure 2 Conventional fixed bed dryer (FBD)

Drying air temperature for RD and FBD was 35°C-40°C and 30°C-40°C, respectively. Paddy moisture content was recorded in 3 hours intervals and drying process finished when three record were the same. Paddy moisture content and air temperature were measured by portable grain moisture meter (G-won GMK 330) and digital thermo meter (Lutron TM903-Taiwan), respectively. Besides, in conventional FBD temperature and moisture content of grains were measured in difference layers (low, middle and top). Grain temperature and moisture content were measured using thermocouple (K type) and portable grain moisture meter, respectively. Energy consumption (EC_T) calculated by thermal and electrical energy summation in each experiment as following equations (Sarker et al., 2014):

$$EC_T = EC_{el} + EC_{th} \tag{1}$$

Where EC_T is the total energy consumption(J), EC_{el} is the electrical energy consumption(J), EC_{th} is the thermal energy consumption(J).

Based on the efficiency of power plants for conversion of the thermal to the electrical energy, the following equation was used to calculate the initial thermal energy consumed to produce the electrical energy (Firouzi et al., 2017; Sarker et al., 2014)

$$EC_{el} = 2.6P \times t \tag{2}$$

Where P is the electrical motors power in the dryer (kW), t is the experimental time (h).

Thermal energy consumption (EC_{th}) calculated by following equation:

$$EC_{th} = V \times eq \tag{3}$$

Where V is the volume of natural gas consumed (m^{-3}), eq is the energy equivalent of Iran liquefied natural gas (36 MJ m^{-3}) (Anonymous, 2014). A volumetric counter (diaphragm gas meter) was used for measuring gas volume consumption. The total specific energy consumption (SEC) was determined as the ratio of summation of electrical and thermal energy divided by the amount of water removed from initial paddy at the end of drying process (Sarker et al., 2014). The mass of evaporated water calculated by following equation (Billiris and Siebenmorgen, 2014; Jittanit et al., 2010; Soponronnarit and Chinsakoltanakorn, 1986):

$$m_w = \frac{m_r \times (MC_i - MC_f)}{100 - MC_f} \tag{4}$$

Where m_w is the mass of evaporated moisture (kg), m_r is the mass of paddy dried (kg), MC_i is the Average of initial paddy moisture content (%), MC_f is the Average of final dried paddy moisture content (%). Besides, in each experiment, energy consumption for drying 1 kg of paddy (EC_{kg}) calculated using Equation 1 as following equation (Motevali et al., 2011):

$$EC_{kg} = \frac{EC_{el} + EC_{th}}{W_p} \tag{5}$$

Where W_p is the initial weight of paddy before drying (kg).

Milling quality contains husking (RH), milling recovery (MR) and head rice yield (HRY) are the most important indices to assess the milling quality of rice (Pan et al., 2011). These attributes were evaluated in this study.

About 1.5 kilograms of dried paddy were collected from each dryer and then stored in sealing in polyethylene packages for 1 day for further quality testing. The moisture contents of the dried samples before the milling tests were 8%-9%. Three rice samples from each dryer were used for the quality determination.

150 g sample of dried and cleaned paddy was dehusked with a Satake testing husker (THU-35A) and the bran was removed with a laboratory friction type rice whitener (McGill Miller, USA) running for 45 seconds. Head rice yield was separated by the laboratory rotary sieve Satake test grain grader (TRG 05B). Percentage of rice husking (*RH*), milling recovery (*MR*) and head rice yield (*HRY*) were calculated by following equations (Tajaddoditalab et al. 2013, Soleymani 1998):

$$RH = \frac{Weight\ of\ brown\ rice}{weight\ of\ dried\ paddy} \times 100 \quad (6)$$

$$MR = \frac{Weight\ of\ head\ rice\ and\ broken\ rice}{weight\ of\ dried\ paddy} \times 100 \quad (7)$$

$$HRY = \frac{Weight\ of\ head\ rice}{weight\ of\ dried\ paddy} \times 100 \quad (8)$$

All experiments were done triplicate and data analyzed using T-student method in 5% probability.

3 Results and discussion

Results of T-student test and mean comparison for drying time and energy consumption presented in Tables 1 and 2, respectively.

Table 1 T-student test of time and energy consumption for paddy drying

Variable	df	t-value	Std. Dev. (RD)	Std. Dev. (FBD)
Drying time	4	3.58*	0.58	0.29
Specific energy consumption	4	11.99**	0.0894	0.0733

Note:** Significant difference (level 1%);* Significantly difference (5% level).

Table 2 Mean comparison for drying time and energy consumption

Variable	Mean (RD)	Mean (FBD)	Difference
Drying time (min)	17.17	15.83	1.34
Specific energy consumption ($MJ.kg^{-1}$ water removed)	10.48	9.81	0.67

For drying time and specific energy consumption, significant differences were observed at 5% and 1%, respectively (Table 1). Mean comparison showed that using FBD caused drying time to reduce 7.80% (Table 2). The reason of less drying time in FBD was suitable aeration. Besides, FBD was in a chamber whit environmental warmer than RD during drying process, so the process was faster than RD. Energy analyzing during all process indicated that, energy consumption for paddy drying in RD was 572.63 MJ ton^{-1}. It was 6.8% more than FBD. Also, specific energy consumption for water evaporation in RD was found 10.48 MJ kg^{-1}. It was about 6.82% more than FBD. Specific energy consumption for removal water in drying process is a function of paddy moisture content. If the paddy had more initial moisture content, specific energy consumption at the first step was less than final step. It means that specific energy consumption had reverse relationship with paddy moisture content. In accordance with the researches, specific energy consumption for water evaporation in paddy drying changed in the range of 2.84-5.31 MJ kg $water^{-1}$ (Jittanit et al., 2010; Soponronnarit and Chinsakoltanakorn, 1986; Billiris and Siebenmorgen, 2014). Differences between specific energy consumption of dryers that studied in this research with previous researches were mostly contributed to the differences between moisture reduction ranges. Although, the drying time in FBD was a little less than RD but paddy moisture content variation was similar in two types of dryer (Figure 3). Generally, differences between moisture variations in dryers were about 5% during drying process. More ventilation in FBD increased drying speed in comparison with RD. Besides, environmental temperature beside of FBD was little higher than RD and it helps to speedup drying process.

If the paddy initial moisture content is about 12%-13% drying process would be finished after 12 hours for both dryers. Researchers reported that paddy drying in high thermal stress caused to break kernel and increase losses (Sarker et al., 2014; Bakker et al., 1983; Wongpornchai et al., 2004).

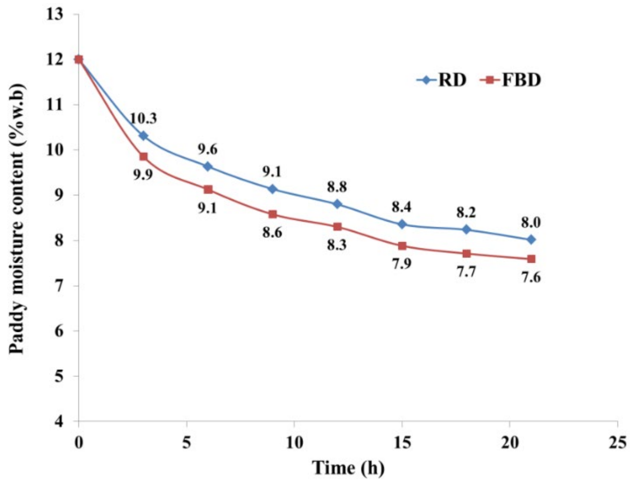


Figure 3 Paddy drying curves in RD and FBD

The moisture changes trends at difference layers (bottom, middle and top) of FBD showed in Figure 4. Paddy moisture content decreased from 12% to 8% after 9 hours in low layer while it happened after 15 hours in top layer. During the drying of top layer, over drying happened in bottom layers and rice cracking chance increased. Similar results were observed in the other researches (Sarker et al., 2014; Latifi, 2011).

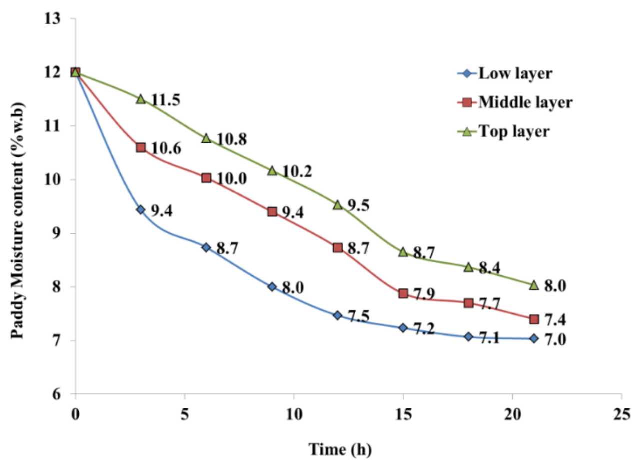


Figure 4 Paddy moisture content trend at different layers of FBD

The temperature variation of Furnace and paddy layers in FBD showed in Figure 5.

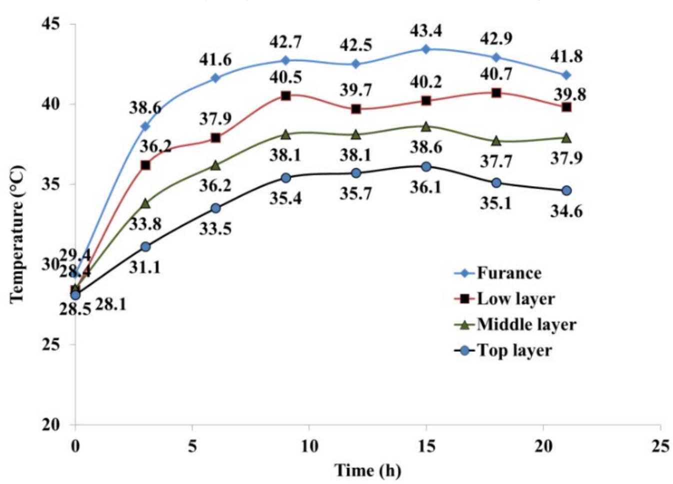


Figure 5 Temperature changes of Furnace and paddy at different layers of FBD

As it would be expected, Furnace temperature changes was more than paddy layers temperature in the dryer. It was changed between 30°C-43°C.

The temperature difference between top and bottom layers in FBD was 4°C-6°C. Non-uniformity of thermal stress increased the chance of milling losses for paddy in lower layers. It has been reported by the other researchers (Khostaghaza et al., 2002; Soleymani, 1998). Results of T-student test and mean comparison of milling quality has been shown in Tables 3 and 4.

Table 3 Result of T-test for milling quality of dried paddy

Evaluation parameters	df	T value	Std. Dev. (FBD)	Std. Dev. (RD)
Milling recovery	4	* 3.83	1.08	0.54
Husking	4	n.s 3.35	1.18	0.22
Head rice yield	4	** 5.25	1.38	0.99
White rice breaking	4	* 4.30	0.97	2.77

Note: ** Significant difference (1% level) * Significant difference (5% level) n.s. No significant difference (5% level)

Table 4 Mean comparison of milling quality parameters of dried paddy

Evaluation parameters	RD	FBD	Difference
Milling recovery (%)	66.69	64.02	2.67
Husking (%)	82.79	83.09	0.30
Head rice yield (%)	44.91	37.33	7.58
White rice breaking (%)	32.67	39.98	7.31

Results of the rice quality evaluation show that RD has significant effect on milling recovery, head rice yield and white rice breaking compared to FBD (Table 4). Type of dryer did not have significant effect on paddy husking. Means comparison results showed that the milling recovery 2.7% improved in RD in comparison with FBD. In this research, the range of paddy milling recovery was 64% to 66%. Literature review and scientific sources reported that milling recovery has direct relation to cultivar and paddy moisture content (Reid et al., 1997; Tajaddoditalab et al., 2013). In this research, Light husks, straw and dust exited from dryer during drying process in RD and paddy was cleaner before milling process. Also, milling recovery in RD was more than in FBD. Comparison of means (Table 4) showed that type of drying did not have effect on paddy husking percentage. Paddy husking was about 83%, for two types of dryer. Some milling parameters such as milling recovery, paddy husking effected by cultivar and final rice moisture content (Fan et al., 2000; Latifi, 2011; Heydari et al., 2010). Using of RD caused to increase head rice yield up to 7.58% and decrease white rice breaking after milling process to 7.31%, in comparison with FBD. Uniformity in drying process and distribution of thermal stress in RD caused to less kernel cracking and more head rice yield in whitening process. While in FBD, high thermal stress in lower layers during drying process, decreased head rice yield. Although in this research drying air temperature was about 43°C but Adversely effect of high temperature on rice breaking was proved in previous research, it was more intense in temperature higher than 60°C (Fan et al., 2000; Bakker et al., 1983; Kiyanmehr et al., 2001).

4 Conclusion

Drying time was a little faster in FBD and saved energy than RD, but milling quality parameters such as milling recovery and head rice yield were improved when paddy dried by RD. The type of dryer did not have significant effect on husking process, but employing RD for paddy drying caused to increase HRY 7.6%. According to advantage of RD in uniform drying of paddy and suitable milling process, so it can be developed for paddy drying.

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