Continuous Drying of Paddy in Two-Dimensional Spouted Bed

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ABSTRACT

An industrial–scale prototype of spouted bed paddy dryer with a capacity of 3,000 kg/h was constructed and tested. The prototype was shown to be a desirable feature of spouted bed as well as capability of continuous drying and offering consistent results through the testing period. Experimental results showed that the prototype performed well on moisture reduction and milling quality. Head rice yield and whiteness were not significantly changed regardless of using inlet air temperature up to 146°C. At present, feed rate is limited to not exceed 1,000 kg/h and thermal energy consumption is relatively high, i.e. in range of 5.9-8.6 MJ/kg water evaporated. This could be attributed to using of improper blower. The relative results of increasing air velocity and pressure should be studied.

Key words : drying, grain, spouted bed

INTRODUCTION

The combination of two distinct hydrodynamic categories, a pneumatic transport in the spout which allows intensive heating and moisture evaporation and a falling bed in the downcomer which processes tempering of particles, is the main feature of the spouted bed. It is clear that a major part of the drying takes place in the spout and the moisture redistribution in the grain kernel takes place in the downcomer without significant moisture removal. The influence of the continuous movement of particles between the spout and the downcomer leads to a uniform moisture content and bed temperature. The substantial short period of the movement in the spout allows for high inlet air temperature without damaging the grains. To overcome the limitations of conventional cylindrical-conical spouted bed, Mujumdar (1984) proposed the two-dimensional spouted bed which the scaling – up can be achieved.

Kalwar *et al.* (1991), Kalwar and Raghavan (1993 a, b) studied drying of grains in two – dimensional spouted bed with draft plates using soybean, wheat, corn and shelled corn. It was found that thin layer drying of grains yielded to Page's equation was in very well agreement with observation data and two constant parameters of equation correlated with bed geometry and operating parameters. The circulation of particles strongly depended on the entrance height, spout width and slant angle. It increased with the increase in all of these parameters. It was also illustrated that the drying rate was significantly influenced by grain circulation rate.

The effect of bed height on drying rate was

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also reported by Tulasidas *et al.* (1993). The results indicated that the moisture ratio (MR) and the apparent diffusion coefficient increased with the decrease in bed height. Page's model of which two parameters related to the bed height was found a good description of the drying kinetics. The milling of paddy in terms of head rice yield and drying characteristics were investigated by Nguyen *et al.* (1998 a, b). A triangular spouted bed was proposed in their experiments. The result of head rice yield was satisfactory as long as the moisture content was above 17.6 % dry basis regardless of using high temperature up to 160°C.

Although extensive research has already been done on the spouted bed technique, the past effort has focussed on laboratory scale spouted bed dryer with particular emphasis on batch drying of agricultural food product. However, none of these works is introduced to the grain drying industry. In order to serve the commercial rice mill which continuous paddy drying is favorable, there is a need to enhance the capacity of spouted bed dryer.

The objectives of this research are therefore to design and construct an industrial–scale prototype of continuous spouted bed paddy dryer, and then test in a rice mill.

MATERIALS AND METHODS

Drying studies were conducted in an industrial-scale prototype of spouted bed paddy dryer with a capacity of 3,000 kg/h as shown in Figure 1 and 2. The dryer consisted of a vertical rectangular chamber 0.6 m in width, 1.45 m in height and 2.1 m in length. Front and both side walls of the drying chamber were made of glass to visualize the grain flow patterns. The slanting base plates were inclined at 60 degrees. The air entrance width was 0.04 m. Two vertical plates (0.62×2.1 m) were centrally installed to accommodate a spout width of 0.06 m. The entrance height was held constant at 0.10 m for all tests. The air was heated by a diesel oil burner. Paddy was continuously fed into the hopper by an elevator before being automatically fed to the drying chamber. With sufficient air velocity, the paddy traveled upward
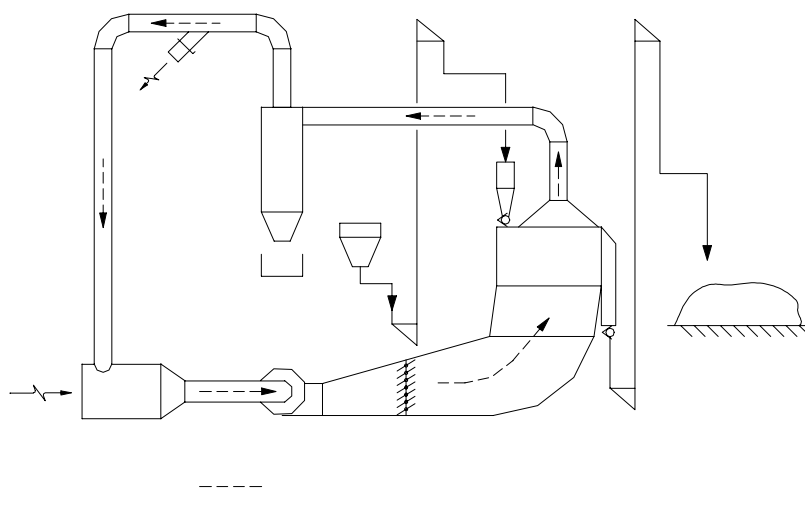

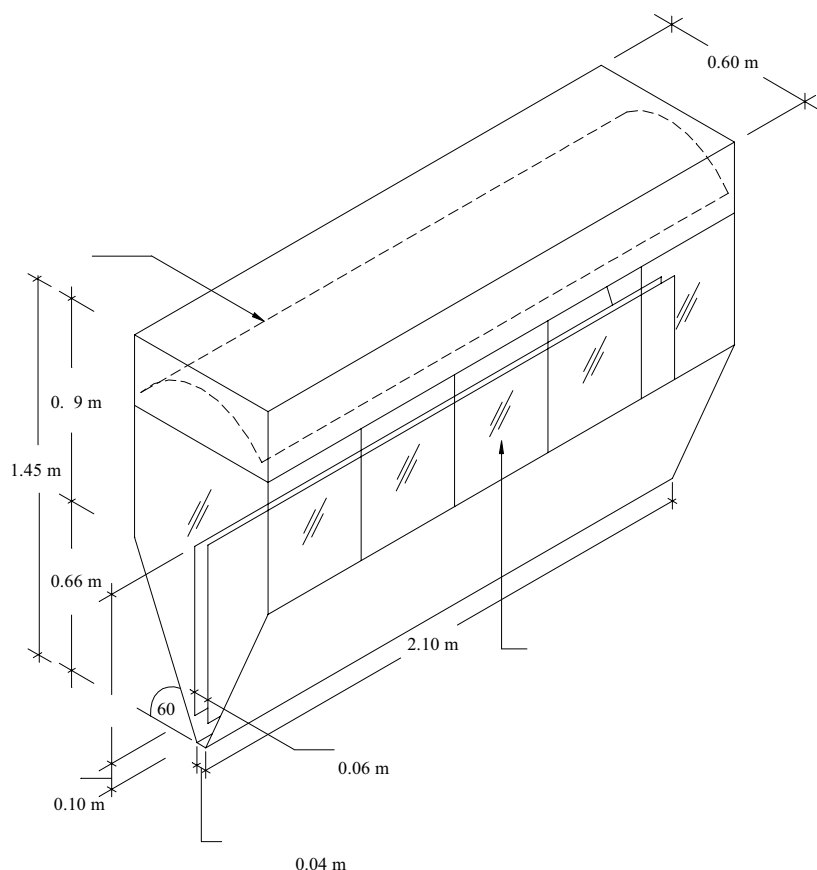**Figure 1** Schematic diagram of continuous souted bed dryer.

Figure 2 Dimensions of the drying chamber of continuous spouted bed dryer.

through the draft channel and further flowed forward before raining back onto the downcomers. The hot air leaving the chamber was discharged into a cyclone and some portion of it was recirculated to the combustion chamber. The air recirculation ratio was in the range of 60-70%. Air and paddy temperatures were measured by K-type thermocouples connected to a data logger with an accuracy ±1°C and a thermometer, respectively. The pressure across the bed and air velocity were determined by a U-tube manometer and a hot air anemometer with and an accuracy±4%, respectively. The samples were taken for measuring moisture content, head rice yield and whiteness at ten minute intervals for periods of 80 minutes.

Moisture contents were determined by a hot air oven at temperature of 103°C for 72 hours. Head rice yield was determined according to the method of the Rice Research Institute and the whiteness was measured by Kett meter.

RESULTS AND DISSCUSSION

Paddy Motion in Spout and Bed Shape

Paddy starting from the base of the bed first accelerated from rest to a peak velocity, and then decelerated until it again reached zero velocity at the top of the fountain and fell down to both of downcomers. The proper air distribution at the entrance allowed uniform flow of paddy through

2.1 m length of the drying chamber. However, the spouting was observed intermittent occurrence. It took 1-2 seconds after sending the paddy through the draft plate in order to build up pressure before starting the next pass. This could be attributed to the improper fan performance, and resulted in low bed pressure drop (1225 Pa) and low inlet air velocity (10 m/s). Figure 3 presented bed shape of both downcomer sides that were nearly symmetrical achieved by positioning the draft channel to the center of the drying chamber.

Drying efficiency and milling quality

  The seven experiments were carried out and the results were summarized as in Table 1. To observe how the dryer performed in terms of moisture content reduction, milling quality and energy usage, feed rate of paddy and the inlet air temperature had been varied from one experiment to another.
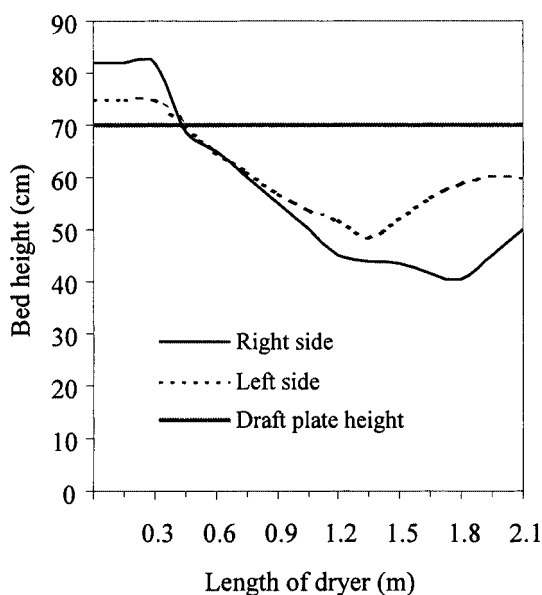

Figure 3 Variation of bed height with length of dryer. (feed rate, 1000 kg/h; hold-up, 210 kg)

Moisture Content: Cycle time strongly affected the moisture distribution throughout the paddy in the downcomer and number of turns of paddy flowing through the draft channel as reported by Tulasidas *et al.* (1993). This allowed for consequent partial tempering in the downcomer and heating and moisture removal in the draft channel. However, it was impractical to record cycle time in these experiments. Thus for studying the drying kinetics, it was convenient to define a mean residence time in the dryer (t_m) by the equation:

$$t_m = \frac{hold - up}{feed\ rate} \qquad (1)$$

  In test no. 1 as in Table 1, it seems likely that moisture reduction was not satisfactory. Even high inlet temperature of 185°C was applied, the moisture content was decreased around 3.4% dry basis (from 31.9% dry basis to 28.5% dry basis). It was also noticed that the air temperature declined close to grain temperature at the exit. It was probably due to non-matching between current airflow rate (0.74 m^3/s) and high feed rate (3100 kg/h). Therefore, feed rate of next experiments was limited to not exceeding 1000 kg/h. The results showed that the prototype performed well on the reduction of paddy moisture. Furthermore, the final moisture content appeared to be consistent through an operating period. In overview, the paddy was dried from the range of 20-30.3% dry basis to 14.4-21.5% dry basis. Figure 4 indicated that the moisture content at the dryer exit was rather consistent.

  It should be noted that the time spent by paddy during spouting in the draft channel was less than 1 second for each pass of paddy flowing through the spout region. Consequently, almost all of residence time (9-17 minutes) was dominated by paddy in downcomer. It clearly showed that the time for heating and moisture transferring (in the spout) was substantial less compared to that of fluidized bed (1.5-2 minutes). Therefore, we believed that the moisture distributed somewhat

Table 1 Summary of the experimental results.

Description	Test no.						
	1	2	3	4	5	6	7
Feed rate (kg/h)	3,140	1,000	900	844	664	939	816
Hold-up (kg)	180	210	135	125	190	190	190
Residence time (min)	4.0	12.6	9.0	8.9	17.2	12.1	14.0
Average inlet air temp. (°C)	185	144	144	146	146	133	126
Exit grain temp. (°C)	67	71	69	67	72	72	71
Average moisture content							
BFD (% dry basis)	31.9	20.0	23.2	25.0	30.3	26.2	26.6
AFD (% dry basis)	28.5	14.4	17.8	20.4	21.3	21.5	19.9
Head rice yield							
BFD (%)	62.9	34.2	45.6	37.1	48.2	39.5	43.5
AFD (%)	64.8	33.4	42.7	39.2	48.0	36.8	45.5
Whiteness							
BFD	41.9	47.6	50.2	51.0	45.9	49.6	44.6
AFD	39.2	47.5	51.1	51.1	46.7	50.3	45.0
Drying rate (kg water/h)	83	49	41	33	49	39	46
Energy consumption (MJ/kg water evaporated)							
Heat	7.1	6.7	7.0	7.7	5.6	7.7	N/A
Electricity	0.50	0.76	0.91	1.12	0.74	1.00	0.80

AFD   =   after drying
BFD   =   before drying
N/A   =   not available
Temp.   =   temperature
Entrance height   =   10 cm (for all experiments)

uniformly throughout the grain kernel when entering the draft channel, which led to good performing of drying kinetics in the spout.

Milling Quality: As seen on Table 1, it was clear that the drying process did not affect the quality in terms of head rice yield and whiteness. There was no significant reduction in head rice yield even the paddy was dried continually until the moisture content reduced to around 18% dry basis regardless of using high inlet air temperature (up to 146°C). This was simply explained that the moisture was well distributed throughout the grain kernel during partial tempering process in the downcomer, and resulted in less stress occurring between the inner part and outer surface when passing through the spout channel. These results confirmed the conclusion obtained by Nguyen *et al.* (1998). A satisfactory whiteness result could influence by a very short period in the spout region. The head rice yield and whiteness results of some experiments were presented on Figure 5 and 6, respectively.

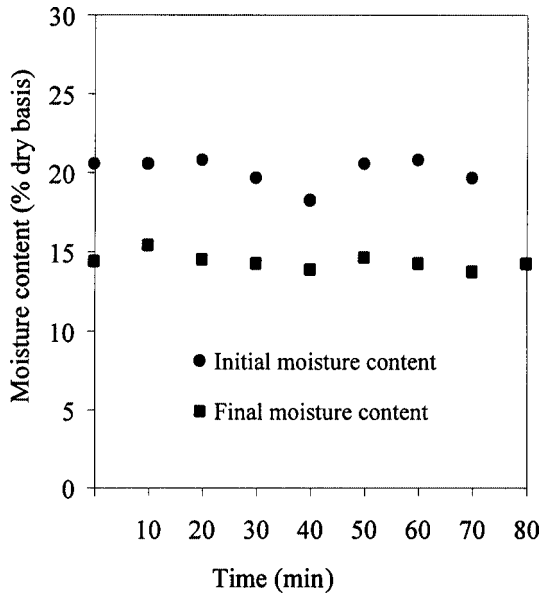Energy Consumption: Table 1 also listed the energy

Figure 4 Comparision of moisture content be-
tween before and after drying. (inlet air
temp., 144°C; feed rate, 1000 kg/h;
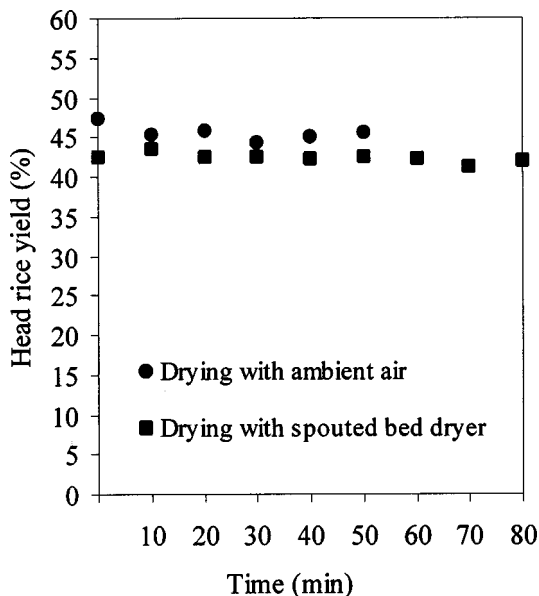hold-up, 210 kg; t_m, 12.6 min)

Figure 5 Compaison of head rice yield between
drying with ambient air and drying with
spouted bed dryer. (inlet air temp.,
144°C; feed rate, 900 kg/h; hold-up, 135
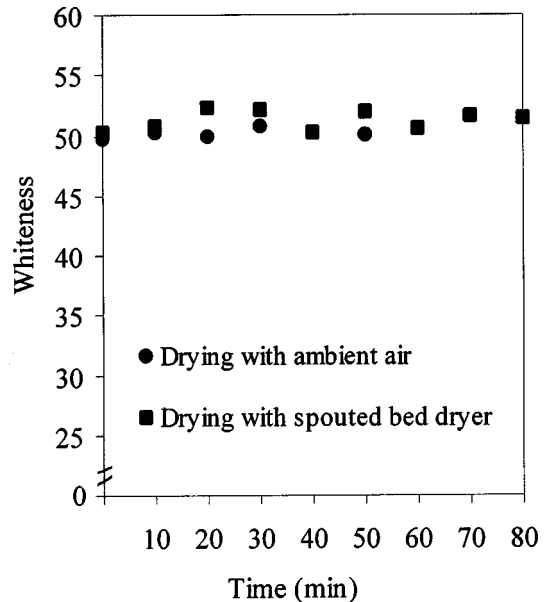kg; t_m, 14 min)

Figure 6 Comparison of whiteness between dry-
ing with ambient air and drying with
spouted bed dryer. (inlet air temp.,
144°C; feed rate, 900 kg/h; hold-up, 135
kg; t_m, 14 min)

consumption of all experiments. Thermal energy
consumption was relatively high, i.e. in range of
5.94-8.66 MJ/kg water. It was believed that this
corresponds to two general causes. First, low
moisture content paddy (20-30% dry basis) was
dried which consequently caused relatively
difficulty in water removal. Second, paddy
circulation through the draft channel was
intermittent which lead to poor drying kinetic in the
spout region. In additional, the existing fan
efficiency was about 20%. If fan efficiency achieved
to around 45%, the average electricity of 0.5 MJ/kg
water evaporated could be saved from the
experimental result, average of 0.9 MJ/kg water
evaporated.

Feed rate: Enhancing the paddy feed rate could be
achieved by replacing the existing fan with a proper
one performing at higher air flow rate and pressure.

As a consequence, the grain circulation on the other hand the rate of paddy entrained from the downcomer into the spout region would be improved. However, increase of feed rate with unchanging of dryer volume resulted in the decrease of residence time. Fortunately, gaining the higher grain circulation rate could compensate this and hence the increase in the ratio of the spouting period and the tempering period in downcomer should lead to enhancing of moisture reduction ability.

CONCLUSION

The prototype was shown to be a desirable feature of spouted bed as well as capability of continuous drying and offering consistent results throughout the testing periods. With assisting of tempering process in downcomer, the drying kinetics in the spout performed well, and resulted in satisfactory moisture reduction. No significant change in head rice yield was observed even the moisture content was reduced to 18% dry basis, nevertheless, using high inlet temperature up to 146°C. The whiteness was also acceptable. Finally, to overcome the problems of low feed rate (<1000 kg/h) and high thermal energy consumption, the influence of enhancing those of air flow rate and pressure should be studied.

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