

Development of a Commercial Scale Vibro-Fluidized Bed Paddy Dryer

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ABSTRACT

The objectives of this research were to design, construct and test a prototype of vibro-fluidized bed paddy dryer with a capacity of 2.5–5.0 tons/h. Experimental drying conditions were: air flow rate 1.7 m³/s (1.9 kg/s), bed velocity 1.4 m/s, average drying air temperature 125–140°C, residence time of paddy approximately 1 minute, bed height 11.5 cm, fraction of air recycled 0.85 (1.6 kg/s) and vibration of intensity 1 (frequency 7.3 Hz and amplitude 5 mm.). It was found that moisture content of paddy was reduced from 28 to 23 % d.b. at a feed rate of 4821 kg/h. Electrical power consumption and average diesel oil consumption were 9646 W and 17.6 l/h, respectively. Specific primary energy consumption was 6.15 MJ/kg-water evap. Electrical power of blower motor and vibrator motor was 55 % as compared to electrical power of blower motor used in fluidized bed drying without vibration. For operation of 12 hours/day and 90 days/year, paddy drying cost was 1.50 baht/kg-water evap. (fixed cost 0.50 baht/kg-water evap. and operating cost 1.00 baht/kg-water evap., US\$ 1 = 40 baht).

Key words : drying cost, head rice yield, paddy, rice whiteness, vibro-fluidization

INTRODUCTION

Soponronnarit and Prachayawarakon (1994) studied drying of high moisture content paddy using fluidization technique. The factors, which affected paddy quality after drying and energy consumption, were investigated. The experimental conditions were as follows: drying air temperature 100–150°C, specific air flow rate 0.13–0.33 kg/s-kg dry matter and initial moisture contents of paddy 28.4–40 % d.b. The result showed that drying rate increased with specific air flow rate and/or temperature of drying air. Energy consumption decreased when specific air flow rate increased or fraction of air recycled increased. The

suggestions to obtain good paddy quality were: drying air temperature should not be higher than 115°C and moisture content of paddy after drying should not be lower than 24–25 % d.b. (mainly considered in head rice yield and rice whiteness qualities). The study and development of paddy using fluidization technique was continued and succeeded in 1996, a prototype of fluidized bed dryer was constructed. The commercial fluidized bed dryers with capacities of 5 and 10 tons/h were constructed and had been sold since the beginning of 1996. The conditions of paddy drying were as follows: drying air temperature in range of 120–150°C, drying air velocity approximately 2–2.3 m/s and fraction of air recycled approximately 0.8.

Rysin and Ginzburg (1992) studied food product drying using vibro-fluidization technique. It was found that vibration intensity ($A\omega^2/g$) should be lower than 3.3. The suitable values of vibration intensity and amplitude were 1.5–2.0 and 5–10 mm, respectively. Ringer and Mujumdar (1982) designed a chart, which provided to aid in the selection of the operating parameters of drying by using vibro-fluidization technique (the ratio of drying air velocity to minimum fluidization velocity and vibration intensity not more than 1.1 and 3.3, respectively.). Han *et al.* (1991) studied the residence time distribution and drying characteristics of a continuous pilot-plant vibro-fluidized bed dryer. Wheat particles and BYN (trade name Biyanning, a medication for rhinitis) were used as testing materials. Operating variables in the study included vibration intensity, mass flow rate of air, material feed rate, inlet air temperature, and particle size. The flow of particles in the dryer was considered as plug flow. From the results, it was found that vibration intensity was the most significant factor affecting particle mean residence time, particle diffusion and constant drying rate. As vibration intensity increased, mean residence time decreased and drying rate increased.

From the past research, it can be concluded that the appropriate operating conditions of paddy drying using fluidization technique to obtain good paddy quality were as follows: moisture content of paddy after drying not lower than 23 % d.b., bed height of 10–15 cm, drying air temperature not higher than 150°C. For drying using vibration fluidization technique, it was recommended that vibration intensity and amplitude should be in range of 1.0–3.3 and 5–10 mm, respectively, and low frequency should be used to avoid the deterioration of vibration system.

According to the success of producing the commercial fluidized bed paddy dryers which have been sold in Thailand and exported to various

countries and the requirement to reduce electrical power of blower motor, the objectives of this research are therefore to design, construct, and test a commercial-scale vibro-fluidized bed paddy dryer with capacity of 2.5–5 tons/h (suitable for rice mill), expecting that it can reduce electrical power of blower motor by applying vibration technique with fluidization technique.

MATERIALS AND METHODS

A vibro-fluidized bed paddy dryer with capacity of 5 tons/h was fabricated by Rice Engineering Supply Co., Ltd. and tested at Thanyakanwangtaphet Rice Mill, Suphanburi province, Thailand. The unit comprised of a diesel burner and combustion chamber, a backward curved blade centrifugal fan driven by a 7.5 kW motor, 0.6 × 2.1 × 1.2 m drying section, and 0.6 × 2.1 m perforated steel sheets with 0.5 mm thickness and 1.1 cm diameter hole. The vibration systems comprised of cams, coil springs, watch springs, 1.5 kW vibrator (frequency of 7.3 Hz, vibration intensity of 1 and vertical amplitude of 5 mm), hopper, rotary feeder, rotary discharger, recycle air pipe and cyclone, the details as shown in Figures 1(a) and 1(b).

During drying, paddy samples before and after drying were kept every 20 minutes to investigate moisture and test quality. Before testing of paddy quality, paddy samples were blown with ambient air until moisture content decreased to approximately 14 % w.b. The positions for temperature and air velocity measurement were shown in Figure 1(a). Temperatures were measured by a thermocouple, type k, connected to a data logger with an accuracy of ± 1°C. Air velocities were measured by a hot wire anemometer with an accuracy of ± 4 % and electrical power was measured by a clamp-on meter with an accuracy of ± 0.5 %.

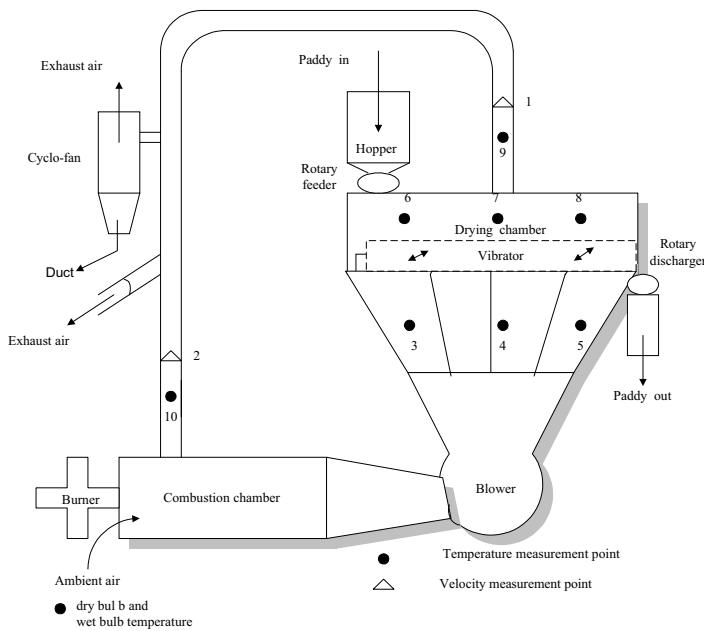


Figure 1(a) Diagram showing a vibro-fluidized bed paddy dryer.

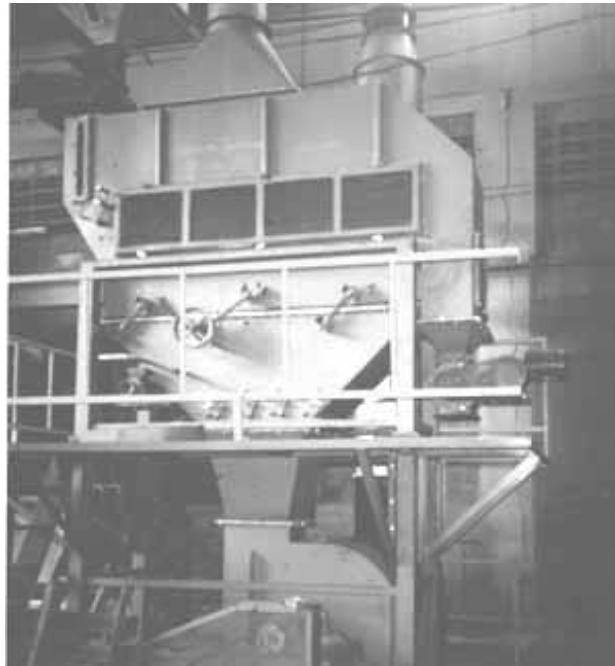


Figure 1(b) Photograph showing a vibro-fluidized bed paddy dryer.

RESULTS AND DISCUSSION

In this research, vibro-fluidized bed dryer was tested. The paddy drying conditions were as follows: paddy feed flow rate of 4.82 tons/h, drying air flow rate of 1.7 m³/s (velocity of air in drying chamber was 1.4 m/s), fraction of air recycled of 0.85, drying air temperature in range of 125–140 °C and vibration intensity of 1 (frequency of 7.3 Hz and vertical amplitude of 5 mm). Experimental results shown in Table 1.

Moisture content of paddy and temperature in drying chamber

Figure 2 shows the values of temperature at various points of dryer. In case of average inlet air temperature of 140°C, average temperature and relative humidity of ambient air were 35°C and 66 %, respectively. It was found that average paddy temperature at drying chamber outlet was 64°C. Figure 3 shows the inlet and outlet moisture contents of paddy, the average values were 28 and 23 % d.b., respectively.

Paddy quality

In order to investigate the percentage of head rice yield, paddy samples before and after drying were kept every 20 minutes. It was found that average percentages of head rice yield of paddy samples, which were dried by ambient air, and vibro-fluidized bed dryer (in case of average inlet drying air temperature was 140°C) were 32.0 and 37.0, respectively. Head rice yield obtained from ambient air drying was approximately 5 % lower, as shown in detail in Figure 4. This resulted from high enough initial moisture content of paddy as well as from using suitable drying air temperature (140°C) within short drying period (approximately 1 minute). Consequently, partial gelatinization occurred in paddy kernel, which was the same as the results from the study of paddy drying using

Table 1 Performance of vibro-fluidized bed paddy dryer (bed height = 11.5 cm, bed velocity = 1.4 m/s, vibration intensity = 1, fraction of air recycled = 0.85 and feed rate = 4821 kg/h).

Drying air temperature (°C)	Initial moisture content (% d.b.)	Final moisture content (% d.b.)	Paddy temperature at dryer outlet (°C)	Head rice yield from ambient air drying (%)	Head rice yield from fluidized bed drying (%)	Rice whiteness from ambient air drying (%)	Rice whiteness from fluidized bed drying (%)	Specific electrical energy consumption in terms of primary energy [*] (MJ/kg-water evap.)	Specific thermal energy consumption (MJ/kg-water evap.)
125	26.8	23.7	62	33.0	32.5	42.4	42.9	0.77	5.47
133	24.1	20.7	63	35.2	37.5	41.5	41.0	0.66	4.69
140	28.0	23.0	64	32.0	37.0	42.5	41.2	0.48	3.80

* Electricity multiplied by 2.6

fluidization technique by Taweerattanapanish *et al.* (1999)

From the test of rice colour of paddy samples dried by ambient air and vibro-fluidized bed dryer, it was found that average rice whiteness were 42.5

and 41.2, respectively (according to scale of whiteness measuring instrument type Kett C-300), with approximately 1.3 difference, as shown in detail in Figure 5.

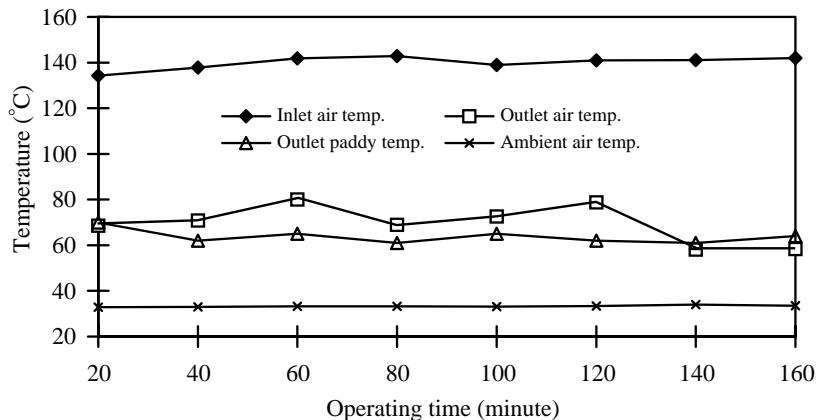


Figure 2 Temperature at various locations.

(average inlet air temperature = 140°C, vibration intensity = 1, feed rate = 1.34 kg/s, inlet moisture content = 28.0 % d.b., bed height = 11.5 cm, bed velocity = 1.4 m/s, outlet moisture content = 23.0 % d.b.)

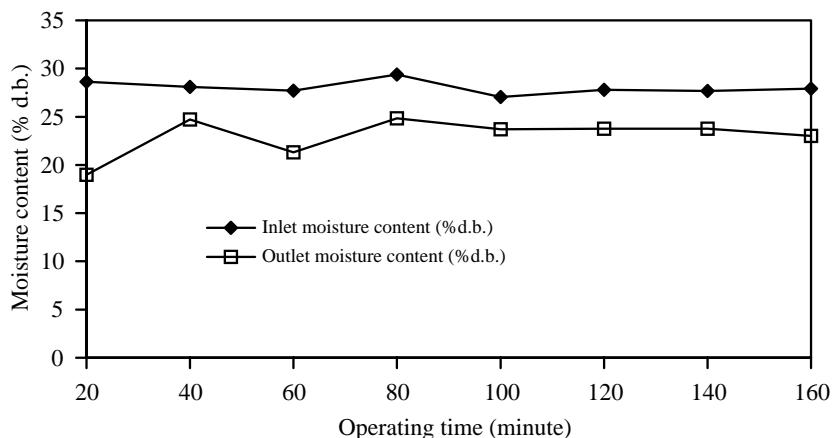


Figure 3 Inlet and outlet moisture content of paddy.

(average inlet air temperature = 140°C, vibration intensity = 1, feed rate = 1.34 kg/s, bed height = 11.5 cm, bed velocity = 1.4 m/s)

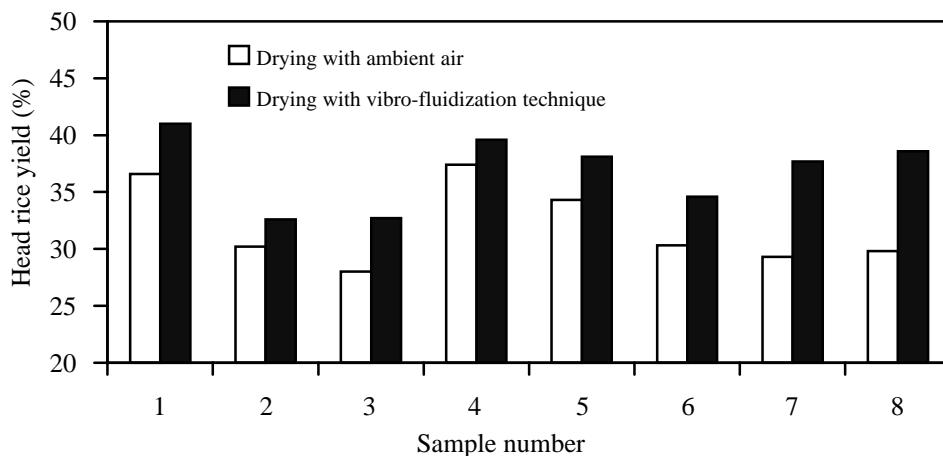


Figure 4 Comparison between head rice yield obtained from vibro-fluidized bed dryer and ambient air drying.

(average inlet air temperature = 140°C, vibration intensity = 1, feed rate = 1.34 kg/s, inlet moisture content = 28.0 % d.b., bed height = 11.5 cm, bed velocity = 1.4 m/s, outlet moisture content = 23.0 % d.b.)

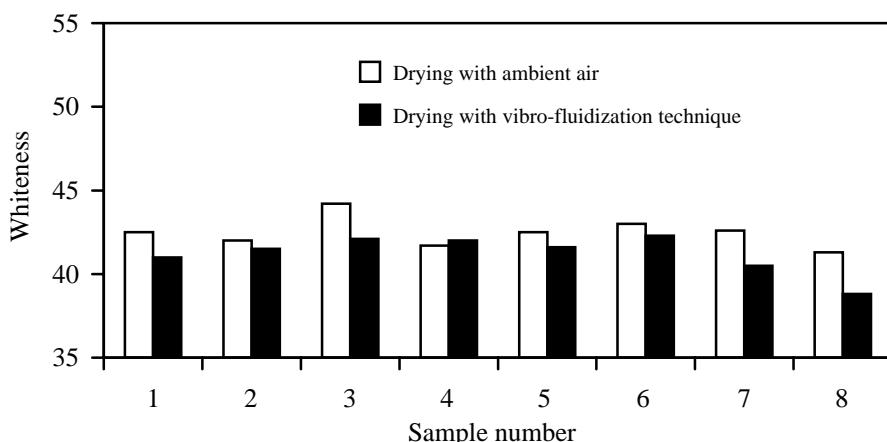


Figure 5 Comparison between rice whiteness obtained from vibro-fluidized bed dryer and ambient air drying.

(average inlet air temperature = 140°C, vibration intensity = 1, feed rate = 1.34 kg/s, inlet moisture content = 28.0 % d.b., bed height = 11.5 cm, bed velocity = 1.4 m/s, outlet moisture content = 23.0 % d.b.)

Specific energy consumption

In using vibro-fluidized bed dryer, total electrical power consumption was 9,646 W, divided into electrical power consumption of each component as follows:

1. Blower = 55.0 %
2. Vibrator = 10.4 %
3. Rotary feeder = 6.4 %
4. Rotary discharger = 7.1 %
5. Elevator = 13.0 %
6. Burner = 8.1 %

The result from the test of dryer showed that average primary energy consumption was 723.1 MJ/h, of which 87.6, MJ/h was primary energy in terms of electrical energy (multiplied by 2.6) and 635.5 MJ/h was primary energy in terms of thermal energy. Drying rate was 117.6 kg/h. Total average specific primary energy consumption was 6.15 MJ/kg-water evap., nearly the same value as that in case of paddy drying using fluidization technique without vibration. Electrical power of blower motor and vibrator motor was 55 % as compared to electrical power of blower motor used in paddy drying using fluidization technique without vibration Soponronnarit *et al.* (1998).

Cost analysis

The fabrication cost of vibro-fluidized bed dryer was 450,000 baht including labour cost and installing cost (US\$ 1 = 40 baht). Salvage value was defined at 10 % of fixed cost. Others costs were based on the results of testing dryer as follows: drying capacity 4.82 tons/h, initial and final moisture contents of paddy 28 and 23 % d.b., respectively. The dryer could evaporate water with a rate of 189.4 kg/h and the operating time of dryer was 90 days/year. The cost analysis was divided into two cases as follows: 1) In case of operating time of dryer 12 hours/day and 2) In case of operating time of dryer 24 hours/day. The results from cost analysis were as follows:

1) In case of operating time of dryer 12 hours/day: The total drying cost was 305,015 baht/year which was divided into fabrication cost 100,131 baht/year, diesel consumption cost 170,726 baht/year, electrical power cost 16,070 baht/year, maintenance cost 20,000 baht/year and salvage value 1,913 baht/year. Therefore, it was found that total drying cost was 59 baht/ton of paddy (1.50 baht/kg-water evap.) of which 19 baht/ton of paddy (0.5 baht/kg-water evap.) was fabrication cost and 40 baht/ton of paddy (1 baht/kg-water evap.) was operating cost.

2) In case of operating time of dryer 24 hours/day: The total drying cost was 49.5 baht/ton of paddy (1.25 baht/kg-water evap.) of which 9.50 baht/ton of paddy (0.25 baht/kg-water evap.) was fabrication cost and 40 baht/ton of paddy (1 baht/kg-water evap.) was operating cost.

CONCLUSION

In this research, a commercial-scale vibro-fluidized bed paddy dryer was tested. The operating conditions were as follows: paddy feed rate 4.82 tons/h, paddy bed height 11.5 cm, drying air flow rate 1.7 m³/s (1.9 kg/s), drying air velocity through bed 1.4 m/s, fraction of air recycled 0.85 and vibration intensity approximately 1 (frequency 7.3 Hz and amplitude 5 mm). In case of using average inlet air temperature of 140°C, it can be concluded as follows:

- 1) Vibro-fluidized bed dryer could reduce moisture content of paddy from average 28 % d.b. to 23 % d.b. Paddy temperature at drying chamber outlet was average 64°C.
- 2) The average percentage of head rice yield of paddy samples dried by ambient air, was 32. For paddy samples dried by vibro-fluidized bed dryer, the average percentage of head rice yield was 37, which was 5 % higher than that dried by ambient air.

3) The rice whiteness of paddy which dried by ambient air and vibro-fluidized bed dryer were approximately 42.5 and 41.2, respectively, according to scale of whiteness measuring instrument type Kett C-300.

4) Total average specific primary energy consumption was 6.15 MJ/kg-water evap.

5) Electrical power of fan motor and vibrator motor was approximately 55 % of the case of drying by fluidization technique without vibration.

6) From drying cost analysis, in case of operating time of dryer 12 hours/day (90 days/year), the total cost of drying was 59 baht/ton of paddy (1.50 baht/kg-water evap.) of which 19 baht/ton of paddy (0.5 baht/kg-water evap.) was fabrication cost and 40 baht/ton of paddy (1 baht/kg-water evap.) was operating cost (US\$ 1 = 40 baht).

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