Pakistan J. Agric. Res. Vol. 27 No.4, 2014

PERFORMANCE EVALUATION OF CROSS-FLOW RICE DRYERS

Munir Ahmad*, Asif Ali Mirani**, Hafiz Sultan Mahmood**, Tanveer Ahmad** and Muhammad Azhar Saeed**

ABSTRACT:- A considerable amount of rice grains is wasted every year in Pakistan because of unavailability of postharvest drying and processing technologies. About 70% of the rice produced in the country is dried through sun heat. which is one of the major causes of reducing head rice recovery during the milling operation. Recently, cross-flow rice dryers have been adopted in the rice milling industry of the country. The heat source of these cross-flow dryers can be a gas or rice husk. This study focussed on the performance evaluation of cross-flow rice dryers with both gas and rice husk heat sources. The experimental results indicated that drying air temperature of the gas-fired and rice husk-fired dryers was 54° and 66°C, respectively. However, the average air flow rate was 6.24 and 2.60 m^3s^{-1} of gas-fired and rice husk-fired cross-flow dryers, respectively. The drying rate of gas-fired dryer was 2.0 percentage point h^{-1}, whereas the drying rate of rice husk-fired dryer was 1.0 percentage point h^{-1}. The drying costs of gas-fired and rice husk-fired dryers were about Rs. 0.21 and 0.16 kg^{-1}. The overall performance of the gas-fired dryer was satisfactory, while that of the rice husk-fired dryer can be improved by incorporating an appropriate heat exchanger.

Key Words: Rice Drying; Cross-Flow Dryers; Rice Husk-fired; Gas-Fired; Economics; Pakistan.

INTRODUCTION

Rice is an export commodity of Pakistan and was grown on 2.57 m ha during 2011-12. Its annual production was about 5.6 m t (GoP, 2013). For better head rice recovery, the rice is usually harvested at 21 - 23% moisture content (Beeny and Ngin, 1970; Igathinathane et al., 2008; Jittanit et al., 2010). At this moisture content, it can be held safely for 24 h (Jittanit et al., 2010). Therefore, the harvested rice should be dried as quickly as possible to prevent damage caused by microbial growth (bacteria, yeasts, fungi, etc.) in wet grains. Wet grains, if held more than 24 h, may develop odours, off-flavour, attain yellowish kernels and may even become contaminated with aflatoxins (Juliano, 1993). This will result in poor quality and will not be suitable for national and international markets.

At the time of harvest, there may be significant difference in moisture content of rice grains between the most matured and the least matured kernels on one plant. Variations up to 20% in moisture content between the grains from the most matured panicles and the least matured panicles are common (Chau and

* Central Secretariat, Pakistan Agricultural Research Council, Islamabad, Pakistan.
* Agricultural and Biological Engineering Institute, National Agricultural Research Centre, Islamabad, Pakistan.
Corresponding author: drmunir.abei@hotmail.com

Kunze, 1982).The maximum head yield of medium and long grain varieties was obtained at 21-23% and 18-20% harvesting moisture content, respectively.

The cross-flow dryers are most popular in the United States of America (Brooker et al., 1992). The drying air temperatures for the cross-flow dryers are in the range of 35°-40°C. In general, the amount of moisture removed from rough rice per pass in a cross-flow dryer should be limited to 1-2 percentage point on wet basis(w.b.).

For concurrent-flow rice dryers, the drying air temperature is 65°-175°C and thus is substantially higher than in cross-flow dryers (Bakker-Arkema et al., 1983). To maintain the quality of rice, the maximum amount of moisture to be evaporated in a concurrent-flow drying pass is 1.5-2.0% (w.b.). The time period during which the moist rice is subjected directly to the hot drying air should be limited to 15-20 s and the rice temperature in the tempering zones should not exceed 43°C. Other mechanical dryers have also been investigated as an alternative. New types of dryers are now being developed; for example, spouted, fluidised bed and conduction drum dryers (Noomhorm et al., 1994). A fluidised bed dryer was developed for first stage drying of paddy in which they predicted a drying cost of about US $ 80 t^{-1} removal of water and studied the energy consumption, quality and throughput rates of the fluidised bed drying system (Soponronnarit and Prachayawarakorn, 1993). This has now been commercialised in Thailand.

In Pakistan, about 30% of the rice mills are using both mechanical as well as traditional sun drying techniques, whereas the rest are completely dependent on sun heat (Tabassum, 1987). During sun drying of rice, dust and dirt from the surroundings get mixed with the grains (Mondal and Malek, 1996). These extraneous materials accelerate deterioration by permitting an increase in moisture content and fungal contamination. Secondly, the alternate loss and absorption of moisture may cause development of internal cracks in the rice kernels (Grist, 1965; Srinivas and Bhashyam, 1985), which reduce the head rice yield significantly during the milling operation. Sun-checking is a very common phenomenon during traditional sun drying which accounts a considerable loss of quality. Sun drying is still largely practiced technique and needs improvement through introduction of suitable dryers.

Different mechanical dryers have been used by the Pakistani rice industry, but no scientific study was conducted to evaluate their performance. Therefore, this study was focussed on evaluating the performance of cross-flow rice dryers with gas-fired and rice husk-fired heat sources, which have already been adopted by the rice industry in Pakistan. The results would provide useful information to rice growers and milling industry.

MATERIALS AND METHOD

Cross-Flow Rice Dryer

The cross-flow rice dryer (commonly known as G.T. dryer) has been adapted by the rice processing industry in the Punjab, Pakistan since 2000. This dryer is called a cross-flow dryer because the air flows about 90° to the flow of rice (Figure 1). It is has inner and outer bins with perforated walls (Table 1). The drying air is forced in the inner bin by an axial flow fan operated by an electric motor, from where the heated air is forced through the rice grains outwards carrying the moisture from drying material. The rice grains flow vertically downwards under the force of gravity, whereas a screw conveyer moves rice grains from bottom to the top of the dryer. This process continues until the desired moisture content of the rice grains is achieved. The heating source of drying air for this dryer can be a gas, rice husk or diesel. In this study, only the gas-fired and rice husk-fired heating systems were evaluated.

Methodology and Instrumentation

The drying trials were conducted from November 28 to December 5, 2008 at District Sialkot. During this testing period, two cross-flow dryers

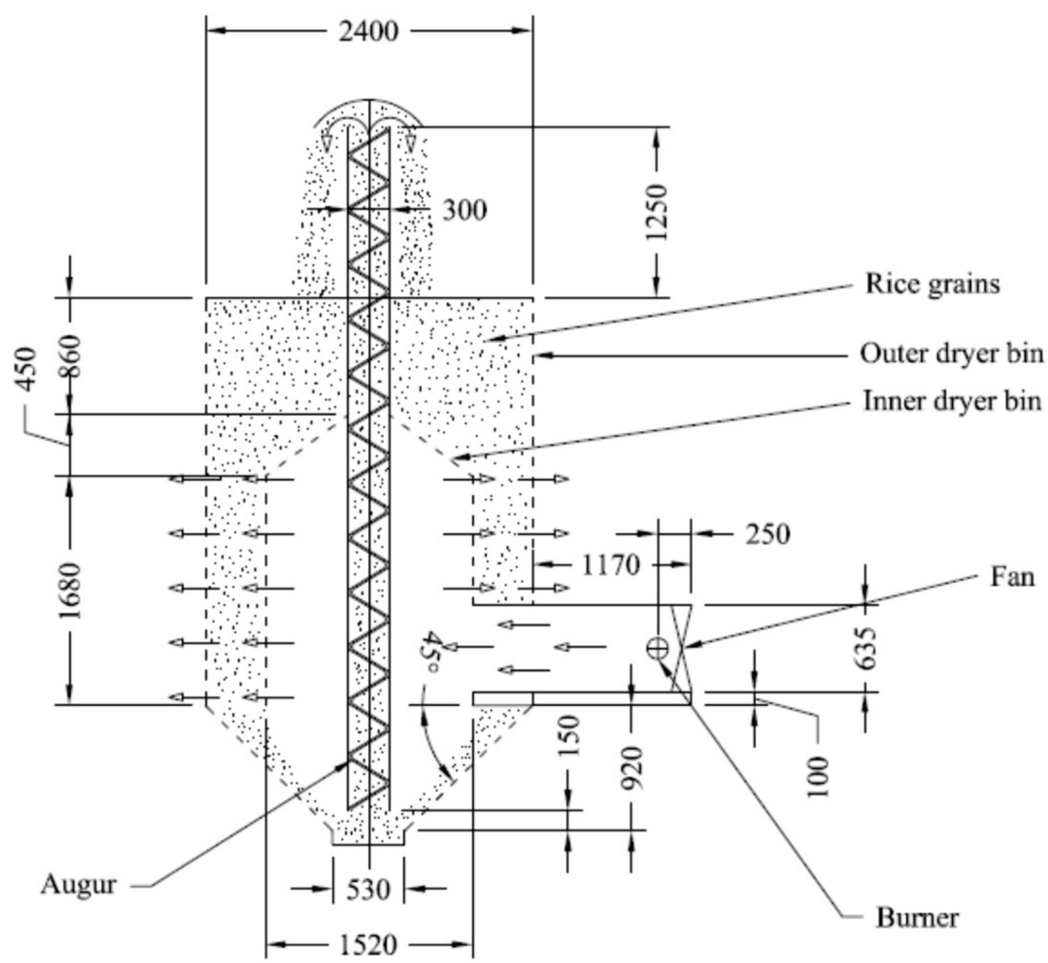

Figure 1. A cross sectional view of a cross-flow rice dryer (dimensions in mm)

Table 1. Specifications of the cross-flow dryer

Description	Specifications
Power of electric motor (kW)	18
Overall height of the dryer (mm)	5160
Overall width of the dryer (mm)	2400
Outer diameter of the grain holding bin (mm)	2400
Outer diameter of the inner bin (mm)	1520
Volume of rice grain holding bin (m^3)	11
Paddy holding capacity of the bin assuming the density of paddy about 520 kg m^3 (t)	5.6
Gas consumption (m^3 h^{-1})	0.4
Rice husk consumption (kg h^{-1})	30
Electricity consumption (kW h^{-1})	7
Moisture removal rate for gas-fired dryer (percentage point h^{-1})	2
Moisture removal rate for rice husk-fired dryer (percentage point h^{-1})	1

were evaluated: a gas-fired dryer and a rice husk-fired dryer (Figures 2 and 3). Five and three tests were conducted, respectively to evaluate the performance of the gas-fired rice and the rice husk-fired dryers.

The data regarding air flow rate, moisture content of paddy, temperature and relative humidity of ambient air, drying air and exit air were recorded at the beginning of these tests and then after every 30 min till the end of the test period. The amount of electricity and gas consumed during the tests was measured for gas-fired dryer. Similarly, the amount of electricity and rice husk consumed during the tests was also measured for rice husk-fired dryer.

A T-type digital thermometer was used to measure ambient, drying and escaped (exit) air temperatures from the rice grains. The moisture content of the paddy was measured using a Dickey-John Multigrain moisture meter (accuracy ± 0.5 %) with easy calibration method. The relative

Figure 2. A typical view of the gas-fired cross-flow rice dryer

Figure 3. A typical view of the rice husk-fired cross-flow dryer

humidity of the ambient, drying, and the escaped (exit) air from the paddy was measured with a MANNIX digital Sling Psychrometer Thermo-Hygrometer (Model SAM990DW; temperature accuracy ±1°C; relative humidity accuracy ± 4%). The air velocity through the inlet of the fan was measured using a Velometer and then the air flow rate was predicted using the cross sectional area of the airflow duct.

RESULTS AND DISCUSSION

Performance of the Gas-Fired Cross-Flow Rice Dryer

The data revealed that the loading capacity of this dryer for rice grains was about 5.6 t and the average airflow rate was 6.2 m^3s^{-1} (Table 2). On average, the moisture content of the rice grain was 19.1%, which was dropped to 15.7% in 1.7 h. This gave the drying rate of about 2.0% h^{-1}.Tumambing (1995) evaluated small-scale grains dryers of 2-3 t loading capacity with drying air temperature ranging from 40° to 50° C. The drying time was 12 h for a batch of paddy. International Rice Research Institute (IRRI) conducted paddy drying experiments in Philippines using 6 t capacity dryers to bring moisture content down from 20% to 14 % (Halos et al., 1983). The drying time of the dryer was 6 h and the air suction rate was 0.16 $m^3 s^{-1}$.

On average, the ambient, drying and exit air temperatures were 25°C, 54.1°C and 27°C, respectively, whereas the average relative humidity of the ambient, drying and exit air was 33.9%, 13.3% and 93.1%, respectively (Table 3) The moisture take-off during these tests was 224.6 kg in 1.7 h (Table 2). About 5 batches of rice grains can be processed daily, which indicates the daily drying capacity of this dryer is about 25 t. This depicts that more than 600 t rice can be dried per month using this dryer keeping in view the dryer constraints and repair and maintenance period.

Data also revealed that wet-bulb depression was the difference between the dry bulb temperature of drying air and the wet bulb temperature of ambient air (Table 4), whereas the temperature drop of the drying air was the difference between the dry bulb temperature of the drying air and dry bulb temperature of the exit air. Drying efficiency was the ratio of the temperature drop of the drying air and the wet-bulb depression of the drying air. The temperature drop of the drying air, wet-bulb temperature of the drying air and wet-bulb depression of the drying air were 27.0°C, 25.5°C and 28.5°C, respectively. On average, the drying efficiency of the cross-flow dryer was 94.7%, which was quite reasonable. Therefore, the gas-fired cross-flow dryer was reasonably efficient and was suitable for rice drying. The quality of dried rice looked good.

Performance of a Rice Husk-Fired Cross-Flow Dryer

It was revealed from data that on an average, 5.6 t of rice grains were loaded in this dryer (Table 2). The average air flow rate of rice husk-fired dryer was 2.6 m^3s^{-1}, which was 2.4 times less than the average air flow rate (6.2 m^3s^{-1}) of gas-fired dryer. This was because the dust and soot in the flue gases of the rice husk-fired

Table 2. Grain loaded, air flow rate, drying time, moisture content, and moisture take-off for rice drying using gas-fired and rice husk-fired dryers

Test No	Quantity of grain loaded (t)	Air flow rate (m^3 s^{-1})	Drying time (h)	Moisture content (%)		Moisture take-off (kg)
				Initial	Final	
Gas-fired cross-flow dryer						
1	5.6	6.4	1.3	18.0	15.0	197.6
2	5.6	6.3	1.5	19.8	16.0	253.3
3	5.6	6.0	2.0	19.8	16.2	240.6
4	5.6	6.2	1.5	18.5	15.5	198.8
5	5.6	6.3	2.0	19.5	16.0	233.3
Average	5.6	6.2	1.7	19.1	15.7	224.6
Rice husk-fired cross-flow dryer						
1	5.6	3.4	3.0	17.8	14.0	247.4
2	5.6	1.6	3.0	17.8	15.0	184.5
3	5.6	2.7	3.0	17.5	14.5	196.5
Average	5.6	2.6	3.0	17.7	14.5	209.5

Table 3. Relative humidity and temperatures of air for rice drying using gas-fired and rice husk-fired dryers

Test No	Relative humidity (%)			Temperature (°C)		
	Ambient air	Drying air	Exit air	Ambient air	Drying air	Exit air
Gas-fired cross-flow dryer						
1	30.8	13.0	92.5	26.2	53.7	26.5
2	25.5	12.1	91.2	28.1	56.6	28.3
3	49.0	15.0	95.7	21.5	52.5	27.3
4	29.0	12.5	92.0	25.0	54.0	27.0
5	35.0	14.1	94.0	24.0	53.5	26.0
Average	33.9	13.3	93.1	25.0	54.1	27.0
Rice husk-fired cross flow dryer						
1	44.8	20.5	95.3	24.3	80.3	42.0
2	45.2	22.0	98.6	23.3	58.0	18.0
3	48.3	25.0	99.7	23.6	60.0	30.0
Average	46.1	22.5	97.9	23.7	66.1	30.0

furnace blocked the screen of the inner bin of the dryer and restricted the area for air flow. Therefore, rice husk-fired furnace must have the heat exchanger so that the flue gases should be vented directly to environment without passing through rice grains. On average, the rice husk-fired dryer took 3h to drop the moisture content of rice grains from 17.7% to 14.5%. This indicates that the drying rate of rice husk-fired dryer was 1.07% h^{-1}, which was half the drying rate of gas-fired dryer. On average, the rice husk-fired rate was 30 kg h^{-1}.

It was revealed that on average, ambient, drying and exit air temperatures were 23.7°C, 66.1°C and 30.0°C, respectively (Table 2). Whereas the average relative humidity of ambient air, drying air and exit air was 46.1%, 22.5% and 97.9%, respectively. On average, the moisture take-off during these tests was 209.5 kg in 3h (Table 2).

The overall performance of the rice husk-fired dryer was lower than the gas-fired dryer. However, it can be improved by adding the heat exchanger to the rice husk-fired furnace. The quality of dried rice in rice husk-fired dryer was also inferior to the rice dried in the gas-fired dryer.

Cost Analysis of Cross-Flow Rice Dryers

The cost of rice drying using a cross-flow dryer is the combination of the fixed and variable costs. The fixed cost includes depreciation, interest on average investment and repair and maintenance cost, whereas the variable cost includes fuel, electrical power and labour. Repair cost can be included either in fixed cost or in variable cost. In this analysis, it was included in fixed cost. The cost analysis of both gas-fired and rice husk-fired cross-flow rice dryers revealed that the fixed cost of drying of rice was Rs. 68 t^{-1} because the purchase price for both types of dryer was assumed same (Table 5). Whereas the variable cost of gas-fired dryer was Rs. 150 t^{-1}. Therefore, the total cost of drying per tonne of rice was calculated as Rs. 218, which further indicated the cost of drying of one kg of paddy to be about Rs. 0.21 using the gas-fired cross-flow rice dryer.

The variable cost of rice was Rs. 92.5 t^{-1} for rice husk-fired dryer and

Table 4. Temperature drop, wet-bulb temperature, wet-bulb depression of the drying air and the drying efficiency of the gas-fired cross-flow dryer

Test No.	Temperature drop (°C)	Wet-bulb temperature (°C)	Wet-bulb depression (°C)	Drying efficiency (%)
1	27.2	25.0	28.7	94.7
2	28.3	26.0	30.6	92.5
3	25.2	26.0	26.5	95.0
4	27.0	25.5	28.5	94.7
5	27.5	25.0	28.5	96.5
Average	27.0	25.5	28.6	94.7

Table 5. Cost analysis of a cross-flow rice dryer

(Rs.)

Parameters	Value
Purchasing price of two dryers + one bin + one elevator + one cleaner	15,00,000
Useful life (years)	15
Salvage value (10% of purchase price)	150,000
Annual fixed charges	
Depreciation	90,000
Interest on average investment (12%)	99,000
Repair and maintenance cost (1% of purchase price per annum)	15,000
Total annual fixed cost	2,04,000
Annual drying capacity of two dryers (t year^{-1}) (assumption: each dryer will operate 60 days a year, with drying capacity of 25 t day^{-1})	3,000
Fixed cost of drying rice (t^{-1})	68
Variable cost (t^{-1}) for gas-fired dryer	
Gas cost (gas consumption for one dryer is 0.4 m^{3}h^{-1} or 0.8 m^{3}h^{-1} batch or 0.15 m^{3}t^{-1}; gas rate Rs.500 m^{-3})	75
Electricity cost (consumption 7.0 kW h^{-1} or 14 kWh^{-1} batch^{-1} or 2.5 kWh t^{-1} or Rs.25 t^{-1} @Rs.10kWh^{-1})	25
Labour cost	50
Total variable cost	218
Total (fixed + variable) cost of rice drying	0.21
Cost of drying of rice (kg^{-1})	150
Variable cost (t^{-1}) for rice husk-fired dryer	
Rice-husk cost (Rice husk consumption t^{-1} is 14 kg and rice husk price was Rs.1.25 kg)	17.5
Electricity cost (same as for gas-fired dryer)	25
Labour cost	50
Total variable cost	92.5
Total (fixed + variable) cost of rice drying	160.5
Cost of drying rice (kg^{-1})	0.16

the total drying cost of rice was calculated as Rs. 160.5 t^{-1}. The cost of drying of one kg of rice using rice husk-fired cross-flow dryer was predicted as Rs. 0.16. This showed that rice drying cost of rice husk-fired dryer was 24 % less than that of the gas-fired dryer.

It is thus concluded that the drying rate of gas-fired dryer was 2.0 percentage point h^{-1}, whereas the drying rate of rice husk-fired dryer was 1.0 percentage point h^{-1}. The low drying rate of rice husk-fired dryer was because of low air flow rate. The reason for low air flow rate was because the dust and soot in the flue gases of the rice husk-fired furnace blocked the screen of the inner bin of the dryer and restricted the area for air flow. Therefore, it was proposed that a heat exchanger should be incorporated in a rice husk-fired furnace so that the flue gases should be vented directly to environment without passing through rice grains. Consequently, it will improve the drying rate of rice husk-fired dryer. The average loading capacity of both was 5.6 t per batch. The drying cost of gas-fired cross-flow dryer was Rs.0.21 kg^{-1} as compared with the rice husk-fired cross-flow dryer, which was predicted as Rs. 0.16 kg^{-1}. The performance of the gas-fired rice dryer was found satisfactory for drying rice at mill level. However, the rice husk-fired dryer can be improved by incorporating a heat exchanger in its furnace. The quality of dried rice in rice husk-fired dryer was also inferior to the rice dried in the gas-fired dryer.

LITERATURE CITED

Bakker-Arkema, F.W., C. Fontana, R.C. Brook, and C.M. Westelaken.1983. Concurrent flow rice drying. Drying Technol. 1: 171-191.

Beeny, J.M., and C.S. Ngin. 1970. Multipass drying of paddy (rice) in the humid tropics. J. Agric. Engg. Res. 15: 364-374.

Brooker, D.B., F.W. Bakker-Arkema, and C.W. Hall. 1992. Drying and storage of grains and oilseeds. Anavi Book, Van Nostrand Reinhold, New York. 450p.

Chau, N.N., and O.R. Kunze. 1982. Moisture content variation among harvested rice grains. Trans. ASAE, 25: 1037-1040.

GoP, 2013. Agriculture, Pakistan Economic Survey 2012-13. Ministry of Finance, Government of Pakistan, Islamabad. p.17.

Grist, D.H. 1965. Rice. Longmans, Green and Co. Ltd, 4th edn, London. 548 p.

Halos, L.S., Y.W. Jeon, and C.W. Bockhop. 1983.Design and performance of a multi-purpose dryer using non-conventional energy sources. Paper presented at the 33rd Annual Convention of the Philippines Society of Agricultural Engineers, held in Philippines.

Igathinathane, C., P.K. Chattopadhyay, and L.O. Pordesimo. 2008. Moisture diffusion modelling of parboiled paddy accelerated tempering process with extended application to multi-pass drying simulation. J. Food Engg. 88: 239-253.

Jittanit, W., N. Saeteaw, and A. Charoenchaisri. 2010. Industrial paddy drying and energy saving options. J. Stored Products Res. 46: 209-213.

Juliano, B.O. 1993. Rice in human nutrition. FAO Food and Nutrition Series No. 26. Rome. p.165.

Mondal, K.A.M.S.H., and M.A. Malek. 1996.Traditional paddy drying in Bangladesh and associated problems. In: Champ, B. R., E. Highley, and G. I. Johnson (eds.). Grain drying in Asia. Proc. Intern. Conf. held at the FAO Regional Office for Asia and Pacific, Bangkok on October 17-20. p. 332-335.

Noomhorm, A., K. Premakumar, and H.T. Sabarez. 1994. Design and development of a conduction drier for accelerated drying of peanuts. Food Engg. 21: 411-419.

Soponronnarit, S., and S. Prachayawarakorn. 1993. Maintaining quality, maximising throughput and minimising energy consumption in fluidised bed drying. In: Naewbany, J.O. (ed.). State of the art of the grain industry in ASEAN: A focus on grain handling and processing. Proc. of the15th ASEAN Technical Seminar on Grain Post-Harvest Technology held at Singapore on September, 8-11 1992.

Srinivas, T., and M.M. Bhashyam.1985. Effect of variety and environment on milling quality of rice. Rice grain quality and marketing, IRRI, Manila, Philippines. p. 51-59.

Tabassum, M.A. 1987. Some aspects of Basmati paddy drying in Pakistan.M.Engg Thesis No.AE-87-25.Asian Institute of Technology, Bangkok.

Tumambing, J.A. 1995. Small-scale grain dryers. In: Champ, B.R., E. Highley, and G.I. Johnson. (eds.). Grain drying in Asia. Proc Intern. Conf. held at the FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, 17-20 October, 1995. p. 186-197.

(Received July 2014 and Accepted November 2014)