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Performance Evaluation of Reversible Air Flow Drying in Circulating Dryer

Dai-Chyi Wang [1] and Yeun-Chung Lee [2]

***Abstract*—**In Taiwan, rice is harvested with high moisture content (above 27%) and must be immediately dried for storage and processing. Circulating dryers are common for drying newly harvested wet paddy rice. On the way of drying, the air blows horizontally in one-way direction when the rice moving through the drying section. It causes a great moisture deviation if the grain is always dried unilaterally in each cycle.

In this study, a bidirectional ventilation drying device was designed. The hot air passed through the experimental group and the controlled group in drying tube (150mm diameter) under the same temperature and wind speed. For both groups, each heating cycle lasts for 10 minutes as it does in traditional dryer. For experimental group, the direction of ventilation was reversed after heating for 5 minutes. After the sample was heated for 10 minutes, the ventilation was stopped and the sample weight was measured. Each sample was well-stirred, still and tempered in a sealed drying tube. When the moisture content decreased to 15%, the samples were sealed for 24 hours before they were milled and polished. Broken rice was separated and the head yield rate was measured.

The results showed that there was no significant difference in drying rate between two groups. However, to compare with the traditional one-way ventilation, the bidirectional model presents well-distributed heat that decreases broken rice and thus yields better drying quality.

***Keywords*—**Circulating, bidirectional flow, drying, rice.

I. Introduction

TAIWAN is affected by the ocean-type climate. Rice harvesting period often encounters typhoons or rainy season. The rice moisture content is still high and must be immediately dry for storage or processing. The government counseled township farmers' association to set up the drying center, equipped with circulating dryers of various capacities. The individual farmer transports the newly harvested wet rice directly to the drying center for drying [1].

Circulation type dryer is widely used in Asia's rice industry. It has the advantages of being free from the influence of natural climate and the limitation of field of solar drying, thus improves the rice quality and reduces manpower. Kerosene is burned in circulation type dryer to heat the air. The hot air flow through wet rice in the dry section and draw out by the rear exhaust fan into the dust room. There are also the circulation type dryers which burn rice husk as heating energy. In addition to reducing the cost of fossil fuels, they also solve the environmental problem of rice husk. [2].

Dai-chyi Wang [1] is with the Department of Mechanical Engineering, De-lin Institute of Technology, New Taipei City, 23654 TAIWAN (corresponding author's phone: +886-937952503; e-mail:dcwang@dlit.edu.tw).

Yeun-Chung Lee [2], is with the Department of Bio-industrial Mechtronics Engineering, National Taiwan University, Taipei City, 10617 TAIWAN. (e-mail:yclee@ntu.edu.tw)..

II. REFERENCE REVIEW

Circulation type dryer is designed with the model of grain drying and tempering. The whole drying process is executed by several continuous cycles of batch drying and tempering state. So that the rice can redistribute the moisture inside the grain after each drying cycle to obtain high efficiency of drying. [3] The appearance of a type of circulating dryer is shown in Figure 1.

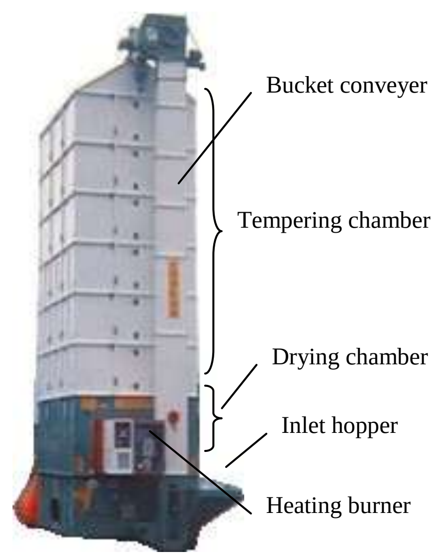


Fig.1 Circulation type dryer

Wet rice was lift by bucket conveyer from the hopper to the top of dryer. The upper part of the six-storey is the tempering chamber and the lowest layer is the drying chamber. Most of the wet grain are stored in the tempering chamber and sink toward drying chamber by gravity. Screw conveyor draw the rice of bottom into bucket conveyer and lift to top of tempering chamber and a cycle of drying is completed.

There are several punched baffles in dryer section (Fig. 2) to guide the rice passes by gravity through the gap of the separator and the hot air flow through the punched baffle toward the material in the gap of the separator. The capacity of a dryer is 20~ 30 tons, the current type is even up to 100 tons and more than 15 meters in height [4].

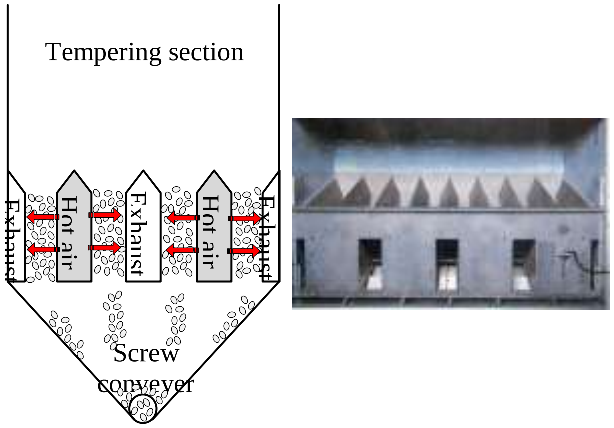


Fig. 2 Drying section in circulation type dryer

According to grain layer thickness, type of grain drying model is divided as thin layer and thick layer. Thin layer drying model, which is based on single grain thickness, is established to further develop other drying system model. The general application range of thick layer drying is above 15-20 cm of the grain depth up to 6 meters.

Wang et al. [5] applied computer simulation to describe the transferring of heat and moisture between grain and air during drying period. Wang et al. [6] developed the SAPGD software to simulate the drying properties of several major grains and also provide 3D simulations results for thick layers of drying as shown in Fig. 3. Chen et al. [7] established a layer-type drying model and verified simulation results with the experimental drying. The drying simulation provides an important reference for designing and operation of the dryer.

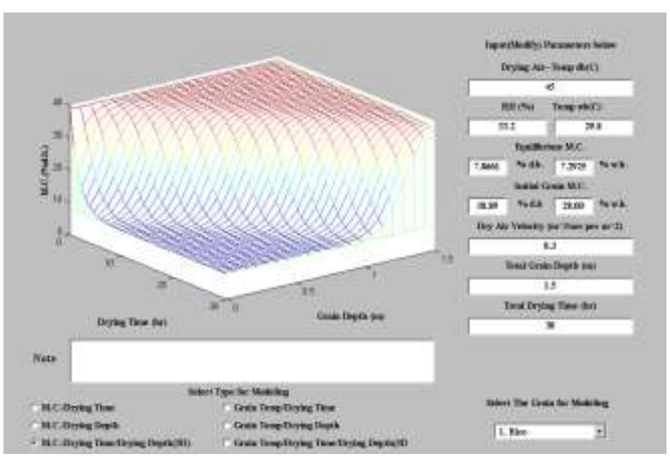


Fig. 3 Simulation results of drying software SAPGD (2004)

The paddy rice passes through the drying section by gravity in current dryer, hot air flows through the rice from single direction. In each cycle, rice grain is only dried with one side that will lead to uneven drying results. Uneven moisture distribution and grain contraction stress is found in grain. It is likely to cause internal cracks in brown rice and results in broken rice in the process of polishing.

The purpose of this study is to design a reversible ventilation system and drying device to simulate circulating drying, and to test the drying rate as well as the rice broken rate after one-way and bidirectional ventilation drying. Finally, the drying quality of both types will be compared.

III. MATERIALS AND METHODS

In this study, a bidirectional ventilation drying device is designed as shown in Fig.4, including a heating box, an air inlet tube, and a drying bin. Air is heated in the heating box which is controlled in constant temperature. The flowing direction of hot air in drying bin is controlled by the combination of PVC pipes and parts.

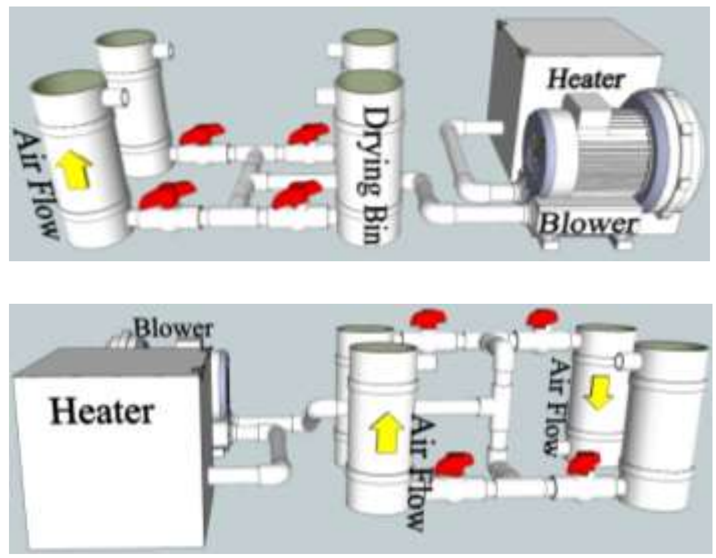
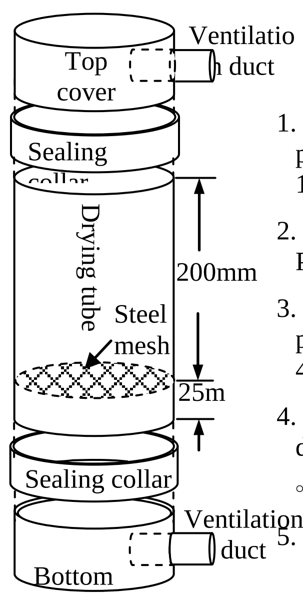


Fig. 4 Illustration of bidirectional ventilation drying device



1. Drying tube: PVC pipe, nominal diameter 150mm.
2. Top / bottom cover: PVC pipe, 95mm in length.
3. Ventilation duct: PVC pipe, nominal diameter 40mm, 50mm in length.
4. Steel mesh: Coil diameter 0.4mm,13 mesh/in 。
5. Sealing collar: Soft

Fig. 5 Illustration of sample drying bin

The drying bin is designed as shown in Fig. 5, adopted from Chen [8] and Wang [9]. Drying tube is manufactured with PVC pipe of Nominal diameter 150mm. A steel mesh is clamped and fasten between 200mm dry section and 25mm base pipe. The top and bottom covers, with a gas-tight collar, were able to join to the sample drying tube to keep airtight, and were easily reassembled. There is a ventilation duct on both the top and bottom of each sample drying bin which is able to connect with a 1.5" PVC T joint and thus forms a serial drying bin system.

The air temperature in ventilation inlet duct was controlled at 55℃. The heating time of each heating cycle was 10 minutes. After heating for 5 minutes, the PVC ducts of experimental group were rearranged, as shown in Fig. 4, to reverse the hot air direction for 5 minutes. The air flow direction of control group remained upward flowing. The ventilation was stopped after 10 minutes of drying, and the drying bins were turned over and rotated to mix the sample well. After fully mixed, drying bins were kept static and sealed to simulate the tempering process in circulation type dryer. The rice sample weight was measured after each heating cycle with an electronic scale (JENQ JYI JYW-6KG / 0.1g, shown in Fig. 6).

Precision electronic scale (AND GF-600)

Electronic scale (JENQ JYI JYW-6KG/0.1g)

Fig. 6 Electronic scale

Fig. 7 hot-wire anemometer (LUTRON YK-2005AH)

Fig. 8 Coffee grinder

Fig. 9 Oven (YOUNG CHENN Model CON-545SD)

The air flow of each drying bin was measured with hot-wire anemometer (As shown in Fig. 7) and adjusted with PVC valve, so that the air flow rate in all drying bins were the same. The moisture content of rice sample was determined with ASAE Standard S352.2 (YOUNG CHENN Model CON-545SD, as shown in Fig. 9). The sample was ground to powder with coffee grinder (BRAUN KSM2, as shown in Fig. 8) and dried in a constant temperature oven. The sample weight was measured with a precision electronic scale (AND GF-600, as shown in Fig. 6).

Fig. 10 Rice husker

Fig.11 Polishing machine

Sample weight of 15% moisture content was calculated from the initial moisture content. The drying process was stopped when the moisture content decreased nearly to 15% and the samples were stored for 24 hours. After that, the samples were kneaded for three minutes to simulate the transport squeezing effect of the cycling process to separate the rice grains from the branches. The paddy was husked by Impeller Husker (As shown in Fig. 10) and polished by a sample polishing machine shown in Fig. 11. (McGill No. 2 Miller, Seedburo Co., USA) The whiteness was set on scale of 2 and the rice flow on 3. After polishing, 300g of polished rice sample was placed in sorting machine to separate the broken rice, as shown in Fig. 12, (Satake, the angle was set on 0 degrees, and the time on 3 minutes). The rice broken rate was derived from the weight ratio of broken rice separated from the sample.

Fig. 12 Broken rice sorting machine (Satake)

IV. RESULT AND DISCUSSION

The internal diameter of ventilation duct and drying tube is 40.1mm and 157mm. The air velocity in ventilation duct for batch 0722, 0721, 0720 are 5.0, 4.7, 4.3 m/s respectively, and are 0.33, 0.31, 0.28 m/s., if converted into the air velocity in drying tube. They are similar to the ventilation speed in current circulation dryer.

Three batches of newly harvested were collected from the Xiluo farmers' association (0720) and Wujie farmers' association (0721, 0722) and stored in refrigerator. Samples were tempered in room temperature and stirred intermittently 24 hours before test. The moisture content of the three batches of samples was measured as 0720 (23.7%), 0721 (26.7%), 0722 (26.9%).

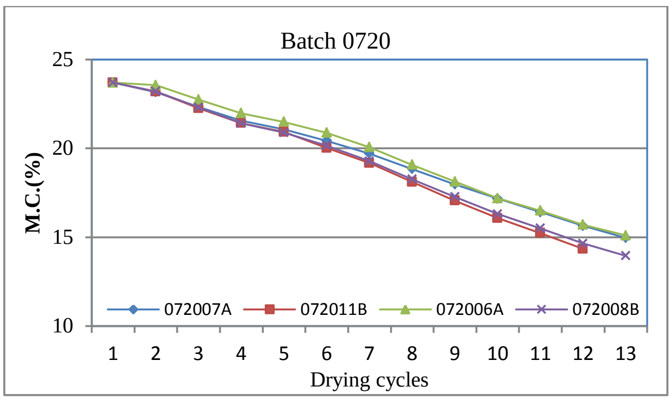


Fig. 13 Moisture content variation for batch 0720 drying

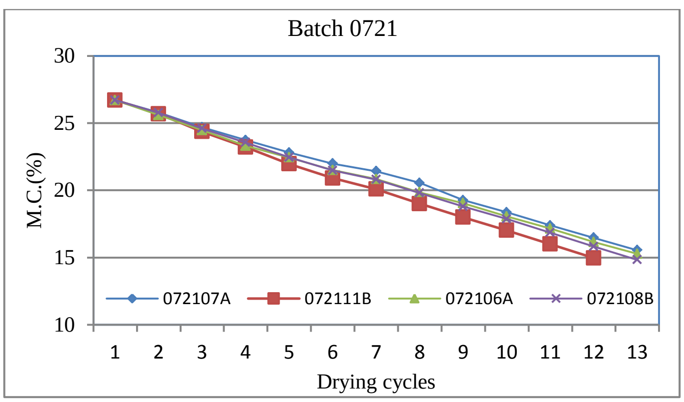


Fig. 14 Moisture content variation for batch 0721 drying

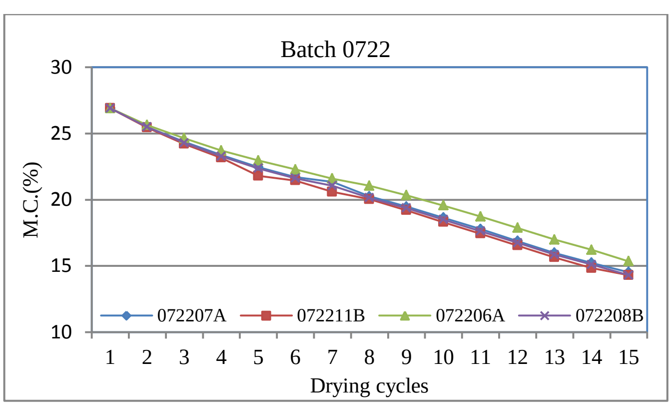


Fig. 15 Moisture content variation for batch 0722 drying

The sample lot number is the code of the source sample (4 digits) plus the barrel number of the drying bin (two digits). The English letter A stands for the bidirectional ventilation test group and B stands for the one-way ventilation control group. The variation of moisture content for each drying test is shown in Fig. 13~15. The difference in moisture content is not significant, and the difference in drying time is only one hour, indicating that the control of wind speed is fairly uniform among the four drying bins. The trend of moisture content in the middle of drying slightly slowed to the original drying rate, because the experimental process suspended in midnight. The effect of suspended drying on the drying efficiency is worthy of further study.

Both the moisture content and the drying rate of the sample were calculated. The results are shown in Table 1. The air velocity in ventilation duct is 4.3m/s (0720 batch), 5.0m/s (0721 batch), 4.7m/s(0722 batch). The drying rate is affacted by hot air flowrate, so the average drying rate of batch 0720 is the lowest and batch 0721 is the highest.

Table 1 The drying rate of sample drying test

Lot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	AVG	STD
072007A	0.53	0.83	0.79	0.49	0.64	0.72	0.87	0.86	0.81	0.76	0.78	0.68			0.73	0.12
072011B	0.51	0.93	0.85	0.50	0.90	0.85	1.07	1.06	0.98	0.84	0.89				0.85	0.19
072006A	0.14	0.82	0.77	0.48	0.61	0.81	0.99	0.94	0.94	0.70	0.80	0.60			0.72	0.24
072008B	0.49	0.89	0.90	0.52	0.73	0.87	1.02	1.00	0.96	0.80	0.86	0.69			0.81	0.17
072107A	0.92	1.10	0.94	0.94	0.81	0.57	0.87	1.29	0.90	0.98	0.92	0.92			0.93	0.17
072111B	1.01	1.32	1.15	1.24	1.07	0.81	1.08	1.01	0.97	1.03	1.03				1.07	0.14
072106A	1.12	1.11	1.17	0.86	0.94	0.67	0.99	0.81	0.98	0.91	0.99	0.88			0.95	0.14
072108B	0.94	1.16	1.05	1.10	0.98	0.68	0.99	1.01	0.93	1.01	1.04	0.98			0.99	0.12
072207A	1.43	1.10	0.99	0.93	0.75	0.35	1.10	0.78	0.84	0.86	0.91	0.90	0.75	0.71	0.88	0.24
072211B	1.46	1.24	1.04	1.37	0.35	0.85	0.56	0.83	0.90	0.87	0.89	0.91	0.81	0.53	0.90	0.31
072206A	1.27	0.99	0.93	0.76	0.67	0.69	0.55	0.71	0.77	0.84	0.86	0.88	0.78	0.86	0.83	0.17
072208B	1.41	1.20	1.02	0.91	0.74	0.57	0.91	0.78	0.87	0.86	0.88	0.89	0.75	0.80	0.90	0.20

The dried sample was hulled by impeller husker. Then brown rice was milled by rice polishing machine to obtain polished rice. Sorting machine separated broken rice from 300 g of polished rice sample. The rice broken rate was determined and the experimental results of each batch are shown in Table 2.

Table 2 The experimental results of rice broken rate test

Group (Note1)	Lot No.	Dried rice weight (g)	Brown rice weight (g)	Polished rice weight (g)	Rice broken rate (%)	Average (%)
A	0720 07A	1621	1311.1	908.6	20.58	21.8
	0720 06A	1610	1302.3	908.5	22.96	
B	0720 11B	1602.4	1301	900	Failed	24.85

	0720 08B	1594.3	1274.7	906.7	24.85	
A	0721 07A	1299.3	1068.2	759	26.92	27.94
	0721 06A	1297.2	1064.5	760.6	28.97	
B	0721 11B	1291.6	1061.7	781	31.16	32.88
	0721 08B	1290.7	1061.6	757.1	34.59	
A	0722 07A	1448.8	1193.1	948.5	22.65	24.07
	0722 06A	1350	1110.7	874.6	25.49	
B	0722 11B	1450.6	1193.9	951.7	24.80	24.8
	0722 08B	1466.8	1208.7	914.2	Failed	

Note 1: A group is the drying test batch of bidirectional ventilation, B group is of one-way ventilation.

Note 2: The air velocity in the drying bin is 0.33 (0721 lots), 0.31 (0722 lots), 0.28 (0720 lots) m/s

The effect of hot air flow rate on drying quality is shown in Table 3. The higher hot air velocity can increase the drying rate, but lead to a negative effect on the broken rice rate. The higher drying air flow resulted in increased grain shrinkage stress and increased broken rice rate. The standard of broken rice size in this experiment may be different from that in industry. Therefore, it should not be compared with the rate of broken rice of drying industry. However, it can provide a reference value for the condition control of the drying rate. When the drying rate is more than 0.9%, there will be a significant increase in broken rice rate. Therefore, the drying rate is controlled below 1% to meet the requirement of low broken rice rate.

Table 3 Effect of hot air flow rate on drying quality

Test batch	Drying air velocity (m/sec)	Mean drying rate (%/Hr)	Mean rice broken rate (%)
0720	0.28	0.78	22.80
0721	0.33	0.98	40.41
0722	0.31	0.88	25.54

Due to operational error, two test lots failed. There are 10 batches of experimental data, as shown in Figure 16. The rice broken rate of one-way ventilation is slightly higher than the bidirectional ventilation. Since the drying rate also affect the rice broken rate, the experimental data rearranged in different ventilation ways as shown in Table 4. Obviously, the way of ventilation affect significantly on drying quality. The average broken rice rate with one-way ventilation was 28.85%, which is significantly higher than that of bidirectional ventilation 24.59%.

Table 4 Average rice broken rate of two test groups

Ventilation type	Average rice broken rate (%)
One way	28.85
Bidirectional	24.59

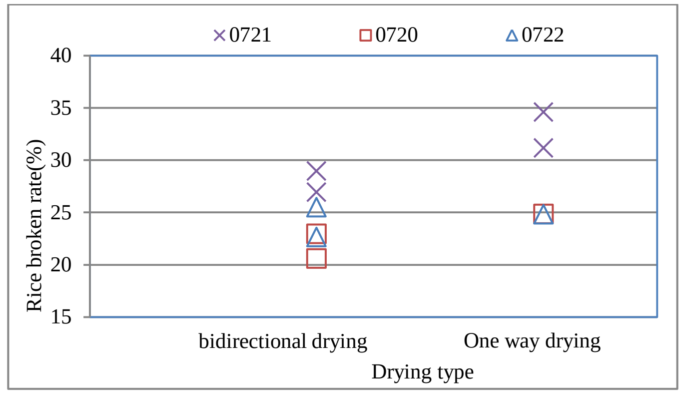


Fig. 16 Effect of drying type on rice broken rate

According to the operation process of this experiment, the definition and drying parameters in this study is different from industry. Although the broken rice rate in this study should not be compared with the industry, the experimental data can still result in the conclusion that the broken rice rate with bidirectional ventilation is lower than the traditional one-way ventilation.

V. Conclusion

According to the analysis and comparison of the experimental data, the higher hot air speed will increase the drying rate, but results in the higher rice broken rate. This phenomenon is due to the high rate of drying, resulting in increased grain shrinkage internal stress.

Drying with bidirectional ventilation of hot air obtains a better quality of drying, because that the rice broken rate is less. Since the bidirectional ventilation can get a more uniform direction of the vapor escape, the shrinkage stress of grain kernel will be more uniform. The distribution of internal stress is more uniform and results in less rice grain cracking.

To sum up, the circulation type drying with bidirectional ventilation can get better drying quality and lower rice broken rate.

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