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Effects of Discharge Fan on the Drying Efficiency in Flat-bed type Dryer

Jafar Hashemi, Reza Tabatabaekoloor, and Toshinori Kimura

Abstract**—**The study of interaction among the grain, moisture, and the surrounding space (air) is key to understanding the grain-drying process. In Iran, rice (mostly Indica type) is dried by flat bed type dryer until the final MC reaches to 6 to 8%. The experiments were conducted to examine the effect of application of discharge fan with different heights of paddy on the drying efficiency. Experiments were designed based on two different configurations of the drying methods; with and without discharge fan with three different heights of paddy including; 5, 10, and 15 cm. The humid heated air will be going out immediately by the suction of discharge fan. The drying time is established upon the average final MC to achieve about 8%. To save energy and reduce the drying time, the distribution of temperature between layers should be fast and uniform with minimum difference; otherwise the difference of MC gradient between layers will be high and will induce grain breakage. The difference of final MC between layers in the two methods was 48-73%. The steady state of temperature between the two methods has saved time in the range of 10-20%, and the efficiency of temperature distribution increased 17-26% by the use of discharge fan.

Key words**—**FBT Dryer, Final MC, Discharge Fan.

I. Introduction

RICE has hygroscopic properties if it is moved from one environmental to another; the grain can lose or gain moisture from the surrounding environment. Farmers all over the world have increased the production of rice by adopting modern technology and efficient management techniques. However, quality and quantity losses still occur at the pre- and post harvest phases, when many factors influence the ultimate quality of grains. In the milling process, the grain will be broken by two causes namely; cracked kernels and non-uniformity in the final moisture content (MC). Cracked kernel is mainly affected by the drying method, which may break rice during husking and whitening processes [1]. A part of artificial crack caused by thermal stress, rapid drying, moisture sorption, and high MC gradients in the drying process. Thermal stresses usually occur during the heating period and become smaller afterwards. Velupilla et al. [2] reported that the reduction in whole kernel yield was dependent on both the rice lot and the percentage of fissured kernels. Paddy kernels that experience large moisture differences between their interiors and exteriors are prone to breakage. Conditions most favorable for stress cracking occur when the grain is subjected to high temperature and non-uniform drying rates. The second factor that results in breakage is varying of final MC of paddy after drying. This factor completely related to the height of paddy in the flat bed dryers that causes breakage during milling process due to machine strength. It might be supposed that MC of paddy at lower part of the flat bed dryer reaches to finishing MC level but the upper parts due to low temperature still is high [1].

It is important to note that the problem becomes more critical when the height of paddy increases. In deep bed drying, all the grains are not fully exposed to the same conditions and the drying air conditions change with both time and position [3]. However, it can be noticed that if the final MC has varied in the paddy layers, subsequently it could break paddy during the milling process. To overcome this problem normally millers have increased the drying time that the difference reduces to a minimum and it results in higher crack in kernels. This problem motivated us to investigate the approach of uniform final MC in different layers of paddy by using a discharge fan to transfer the humid heated air and assessing this method at different height of paddy when the final MC reaches about 8% (w.b.). In order to do that we examined the effect of application of discharge fan with different height of paddy on the drying efficiency that meets the requirements for high quality, homogeneity of temperature and final MC in the paddy layers to obtained high milling recovery and reduce the costs.

II. Materials and Methods

A. Materials

Rough rice, harvested in 2005 (Belepatna, Indica variety) and kept in the storage at 5^{o}C with about 14% MC (w.b.) has been used in this study. In the experiment time, the Paddy was rewetted by adding certain amount of water, sealed in double-layer plastic bags, and stored in a refrigerated warehouse at 5°C for 10 days until the moisture content reached to about 24% (expressed on wet basis, unless stated otherwise) to imitate the conditions of fresh harvested grain [4]. The rewetted rough rice was removed from cold storage one day prior to the experiment and kept overnight in double-layer plastic bags to allow equilibration to room temperature. It can eliminated any transient heat transfer effects on the moisture desorption rates.

Figure 1 is illustrated the schematic diagram of FBT dryer and its components, which used for drying of paddy. It is comprised of a paddy chamber with dimension of $12cm \times 12cm \times 30cm$, an electric heater (1.2 kw), two axial flow type fans, thermal sensor and data recorder.

Jafar Hashemi, Assistant Professor, Agricultural Machinery Department, University of Agriculture and Natural Resources, Sari, Iran. P.O. Box: 578 - & Vice chancellor of Tehran Payame Noor University (Corresponding author, e-mail: szhash@yahoo.com).

Reza Tabatabaekoloor, Assistant Professor, Agricultural Machinery Department, University of Agriculture and Natural Resources, Sari, Iran. P.O. Box: 578.

T Toshinori Kimura, Graduate School of Agriculture, Hokkaido University Kita-9, Nishi-9, Kita-ku, Sapporo, 060-8589, Japan.

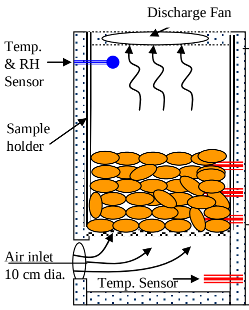

Fig. 1 The average layers temperature vs. treatments

B. Experiment Design

The experiments were carried out by two different configurations of the drying methods namely, with discharge fan (*WF*) and without discharge fan (*WOF*). In each drying method, three heights of paddy (5, 10, and 15 cm) were used and expressed by *L*, *M*, *H* in the without discharge fan and *LF, MF, HF* in the with discharge fan method. In WOF method, the heated air coming in the air plenum afterwards transfers the paddy chamber. The other method (WF), the humid heated air will be going out immediately by aid of the discharge fan suction.

Arora et al. [5] suggested that the drying air temperature should be held below 53^{o}C to minimize the effect of thermal expansion on rice fissuring. Hence, to avoid thermal stresses, the maximum temperature in the base layer was settled at 53^{o}C that is normally practiced in Iran [1]. The drying time is established upon the height of paddy to achieve the average final MC at about 8%, it was 300 min and fixed for two methods at same height of paddy. Each test was replicated three times.

C. Temperature and Humidity of Discharged Air

The temperature changes during drying at three layers of paddy depth were monitored by thermocouples linked to a computerized data logger. Three copper constant thermocouples were used in the sample holder. The first thermocouple was placed one-centimeter above the bottom layer of sample holder (T_b) and the third one was set one-centimeter below the top layer (T_t). The second thermocouple was placed at mid layer between above mentioned layers (T_m). The temperatures of ambient air and drying air entering the dryer were also measured. All data were recorded at 15 min intervals of first hours then 30 min intervals of the remained time.

D. Moisture Content and Drying Rate

The moisture content of samples were measured before and after drying in a hot-air oven, in which 5 g of rough rice were dried in a convection oven for 72 hours at 105^{o}C, [6]. The drying rates of top and base layer are indicated with dR_t and dR_b, respectively. The difference of drying rate between two layers (base and top) is a representative of uniformity of final MC in FBT dryer that was computed and expressed by $dR_{(b-t)}$.

$$dR_{(b-t)}\% = \frac{dR_{(b-t)WF} - dR_{(b-t)WOF}}{dR_{(b-t)WF}} \quad (1)$$

Where $dR_{(b-t)WF} = dR_{(b-t)}$ with discharge fan method
$dR_{(b-t)WOF} = dR_{(b-t)}$ without discharge fan

E. Statistical Analysis

An experiment data were classified into four sections as follows:

1- Final MC in different layers (Bottom-FMC_b, Middle-FMC_m , Top- FMC_t, Average- FMC_a)

2- Drying Rates (Top–dR_t, Middle-dR_m, Bottom–dR_b, Difference rate-$dR_{(b-t)}$, Average-dR_a)

3- Temperatures Distribution in different layers (Bottom-TD_b, Middle-TD_m, Top-TD_t, Average- TD_a).

The statistical analysis was performed as a two-factor experiment in completely randomized design (CRD) for every section that mentioned above. The analysis of variance (ANOVA) was applied to determine the standard errors associated with the height of paddy and drying methods (Table I).

TABLE I
ANALYSIS OF VARIANCE FOR TEMPERATURE, FINAL MC, DRYING RATE, AND ENERGY CONSUMPTION

Temperature	*df*	TD_b		TD_m		TD_t	
		MS	F_c	MS	F_c	MS	F_c
Height of paddy	2	17.2	234.1^{**}	109.9	52.28^{**}	180.9	197.73^{**}
Drying method	1	4.9	66.19^{**}	35.26	16.76^{**}	52.5	57.37^{**}
Height & method	2	20.8	282.82^{**}	134.1	63.72^{**}	213.5	233.30^{**}
Error	6	0.07		2.1		0.92	
Final MC	*df*	FMC_b		FMC_m		FMC_t	
		MS	F_c	MS	F_c	MS	F_c
Height of paddy	2	2.31	0.33^{ns}	2.31	8.29^{**}	14.93	156.63^{**}
Drying methods	1	0.529	0.02^{ns}	0.529	1.90^{ns}	5.522	57.94^{**}
Height & methods	2	2.89	0.65^{ns}	2.89	10.35^{*}	18.96	198.96^{**}
Error	6	0.19		0.28		0.1	
Drying rate	*df*	dR_t		dR_b		$dR_{(b-t)}$	
		MS	F_c	MS	F_c	MS	F_c
Height of paddy	2	0.66	57.69^{**}	0.01	0.32^{ns}	0.54	288.84^{**}
Drying method	1	0.298	25.94^{**}	0.004	0.22^{ns}	0.235	126.00^{**}
Height & method	2	0.84	73.53^{**}	0.01	0.67^{ns}	0.70	376.04^{**}
Error	6	0.01		0.02		0.002	

^{ns} Not significant, * Significant at level of 5%, **Significant at level of 1%, MS: Mean Square, F_c: Calculated F

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III. Results and Discussion

A. Temperature Distribution

Drying air temperature is critical in grain drying processes. The comparison means of statistical results was indicated that there is no significant difference between layers in the 5 cm height of paddy at two drying methods (Table 1). The combined effect of heights and drying methods has significant effect ($P < 0{\cdot}05$, $P < 0{\cdot}01$) on temperature distribution at 10 cm height of paddy in the base and top layers. As shown in the Table 2, the efficiency of discharge fan on the uniformity distribution of temperature between layers is about 1-5% in the base layer, 2-17% in mid layer and 3-22% in top layer. It could be elucidated that the difference in the temperature becomes more uniform in mid and top layer by using of discharge fan.

Figure 2 shows that there is a difference between the temperatures of layers. With the elapse of time, it becomes close together but it takes more time. This large difference might produce the crack in the kernels. To avoid developing the crack, distribution of temperature between layers could be fast and uniform with minimum difference. Some researchers ([7] & [8]) showed that the temperature of the entire kernel increases rapidly (within 2 to 3 min) to the temperature of drying air when drying in a thin layer fashion. The uniform temperature might be caused in uniformity of MC distribution inside kernels, resulting in high yields of full kernels [9]. The maximum differences between layers were occurred after 30- 40% of time passed in all treatments. Afterwards the difference was declined until the top layer reached to steady state. It can presume that the height of paddy and discharge fan has been strongly affected on the distribution of temperature in the paddy layers. The required time to reach maximum temperature for base layer was lower than those mid and top layers. In this case, it is impossible to finish the drying process because it could produce the major difference of MC between layers.

Consequently, the final MC has been extremely decreased (about 8-6%). If the final MC of paddy were decrease 8-6%, the color of rice will change from transparent to opaque and the whitening degree is increased from the standard level [1]. The steady state condition has had close relation with the height of paddy especially in the commercial FBT dryers. With the increase of paddy height, the average time to reach the steady state was also increased (about 10% for all treatments). In the 15 cm height of paddy, the top layer reaches to steady state after 80% and 100% of drying time passed in the with and without discharge fan, respectively. It was saved 20% of drying time at critical condition. The discharge fan can diminish drying time through the faster transfer of top layer to steady state conditions (Table 3).

B. Uniformity of Final MC

No significant difference was observed in the 5 cm between two methods and three layers but the difference of final MC was found between the two methods in the 10 and 15 cm drying cycles (Table 1). With increase of paddy heights, non-uniformity of final MC between layers increased and the function of discharge fan will be seriously appeared. As heated air enters a bed of high-moisture paddy sample, it picks up moisture from the wet grains and becomes humid and warm. Most of this exchange of heat and mass occurs as the air passes through a few centimeters of the grain bed. The majority of the drying takes place in the drying zone and it moves through the grain in direction of the airflow that is commonly known as the drying front [3].

TABLE II
THE COMPARISON RATE OF TEMPERATURE DIFFERENCE BETWEEN TWO DRYING METHODS (*WF* & *WOF*)

Heights of paddy	5 cm	10 cm	15 cm
Rate of difference in base layer (%)	0.87	1.86	5.29
Rate of difference in mid layer (%)	2.26	7.46	17.13
Rate of difference in top layer (%)	3.42	12.53	22.2
Percentage difference (base –top)	16.9	25.8	23.7

TABLE III
COMPARISON OF TEMPERATURE DISTRIBUTION AND TIME SPENDING IN 3 PADDY LAYERS

Drying methods	Without discharge fan			With discharge fan		
Treatments	L	M	H	LF	MF	HF
1st- Bot. reach to 50°C (min)	30	90	105	15	45	60
1st- Time ratio (%)	10%	30%	35%	5%	15%	20%
1st –Max difference (°C)	10	17	18	10	19	17
2nd–Top reach to steady (min)	120	240	300	90	180	240
2nd - Time ratio (%)	40%	80%	100%	30%	60%	80%
2nd –Max difference (°C)	4	8	8	4	8	4
3rd –steady state (min)	180	60	0	210	120	60
3rd –Time ratio	60%	20%	0%	70%	40%	20%

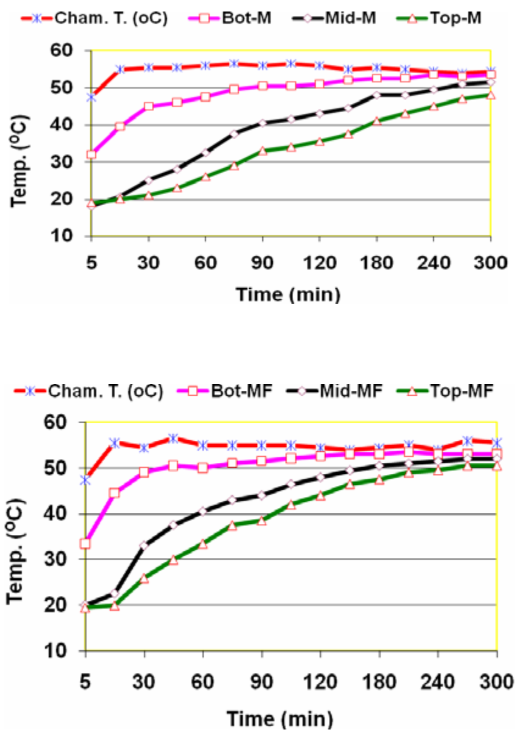

Fig. 2 Temperature of paddy layers vs. drying time with 10 cm height in two methods (M, MF)

With passing of drying time the MC of base layer decrease faster until the MC reaches to EMC range. The discharge fan has not more effect to removal the MC on the base layer.

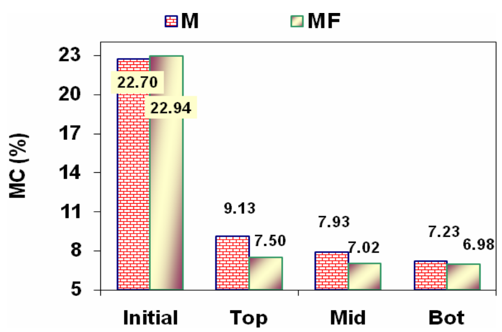

Fig. 3 Comparison of MC between layers at 10 cm heights of paddy in two methods

It is interesting to note that the bottom layer has exceptional situation. Almost crack could occur in the base layer due to over drying. The faster moisture removal, the greater moisture gradient created because the surface dries quicker than the inner part of the kernel [10]. The moisture and temperature gradients prevalent within the kernel cause expansion and contraction in the grain leading to development of internal stresses. Internal stresses due to combination MC and temperature gradients causes fissure and results in easy breakage [11] & [12].

As shown in Fig 3, the maximum difference of final MC between layers occurs in the 15 cm without discharge fan, which was 5.19%, whereas the minimum was 0.31% in the 5 cm paddy height with discharge fan. The discharge fan will avoid the appearance of the difference in the mid and top layer before drying front reached them. As a result, with increasing the height of paddy, the sample was non-uniformly dried and the final MC in the mid and top layers was significantly different. The percentage of difference between two methods was 48-73% that could be considered as discharge fan role in the drying efficiency for uniformity of final MC.

C. Drying Rate

The drying rate is high initially due to the faster evaporation of free water and it will be gradually reduced during the drying by reduction of MC. The statistical analysis shows that the heights and drying methods did not affect the drying rate in the base layer and had same trend for both methods (Table 1). The thermal energy entering through the dryer is first absorbed by the base layer, heats up and accelerates the drying rate, then goes to other layers. Thereafter, there is a linear drop in drying rate with the reduction in MC. Therefore, high drying rate and low final MC values in the base layer region are expected. By using of discharge fan, the difference between 5 and 10 cm was not significant but in the without discharge fan it has significant difference at level of 0.05. It can be interpreted that the maximum effect of discharge fan on the drying rate will be appeared in the 10 cm.

The trend of drying rate obtained from this experiment is in agreement with the results presented by Bala [3]. The drying rate was steady from initial MC to equilibrium MC level and thereafter there was linear reduction in drying rate when the drying time increased. The linear reduction in drying rate can be observed with reduction in MC of the grains. These results also concur with the work presented by. Mossman [13] who reported that it is possible to add an additional fan and increase the static pressure to uniform distribution of airflow supports this result. The report indicates that for a well-designed system a second fan could increase bin-drying capacity by 25% to 35%. Moreover, by increasing the height of paddy, the evenness of final MC becomes less and the difference of drying rate curve is steeper when the height increased.

The difference in drying rate between base and top layers ($dR_{(b\text{-}t)}$) has very meaningful effect on the uniformity of final MC. With increasing of $dR_{(b\text{-}t)}$, the variation of the final MC, which is produced by non-uniform distribution of temperature will be increased. Consequentially, the milling recovery will be decreased. Therefore, with lower value of $dR_{(b\text{-}t)}$, the paddy bulk could be dried uniformly and fewer broken would be resulted in milling stages.

Figure 4 shows the difference of $dR_{(b\text{-}t)}$ between two drying methods which compared together as percentage point of $dR_{(b\text{-}t)}$. It was expected that the percentage of $dR_{(b\text{-}t)}$ in 15 cm should also be more than 5 and 10 cm but it happened inversely due to the height of the paddy, the blower ability and discharge fan efficiency. Percentage of $dR_{(b\text{-}t)}$ for the two methods in different heights were; 49%, 74%, and 47% for 5, 10, and 15 cm, respectively. The maximum difference happened in 10 cm height of paddy, and it decreased at about 27% for 15 cm.

It is predictable that by increasing paddy height more than 15 cm, the grain resistance will be increased subsequently, the percentage of $dR_{(b\text{-}t)}$ will be decreased. It is interesting to note that the blowing of blower is fixed rather than increasing efficiency; the airflow rate of discharge fan should be increased. This shows that, every discharge fan has a peak ability to defeat the static pressure of paddy height.

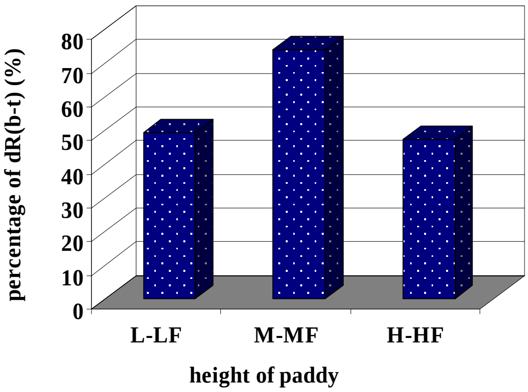

Fig. 4 Percentage of $dR_{(b-t)}$ in two methods

IV. Conclusion

It could be elucidated that the difference in the temperature becomes to more uniform in mid and top layer by using of discharge fan. The difference of steady state in the temperature between the two methods has saved time in the range of 10-20% and efficiency of temperature distribution increased 17-26% by the use of discharge fan. The maximum percentage point of MC was removed in the 5 and 10 cm drying cycle with discharge fan and the minimum percentage point of MC occurred in the 15 cm due to maximum paddy height. The percentage of difference between two methods was 48-73% that could be considered as discharge fan role in the drying efficiency for uniformity of final MC. By increasing the height of paddy, the percentage of difference of the drying rate will be increased and to obtain more uniform final MC, the drying time should be increased. Percentage of $dR_{(b-t)}$ for the two methods in different heights were; 49%, 74%, and 47% for 5, 10, and 15 cm, respectively. By using of discharge fan the temperature and moisture distribution in the paddy layers become almost uniform. This is an advantage of discharge fan and can accordingly provide more economic energy utilization and will provided premium quality, with high values of head-rice yield and whiteness.

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