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Spatial Distribution of Temperature and Moisture in Grain Bin and Grain Bin Size Effect on STR Dryer Performance in Bangladesh

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Abstract

Technical feasibility study of low cost mechanical batch dryer (STR) was carried out at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh during 30 April to 05 May, 2015 in order to investigate effectiveness of using at farmers' level as alternative to sun drying. The detail technical parameters e.g., spatial distribution of temperature and moisture content, drying rate, drying capacity, drying efficiency and germination test related to paddy drying were analyzed. Three treatments based on grain bin size i.e. 300, 400 and 450 kg of paddy as S300, S400 and S450, respectively, were selected and three replications of each treatment were conducted for the STR dryer performance study. The temperature profile of STR dryer proved that hot air uniformly distributed throughout the dryer, and the paddy dried uniformly and reached at desired moisture level (less than 12%) in between three to five hours. The drying rate i.e. moisture removal rates of the STR dryer were 11.3, 12.2 and 15 kg/hr for the treatments of S300, S400 and S450, respectively. The drying capacities of the STR dryer were 75.0, 88.9 and 121.6 kg/hr/batch for treatments of S300, S400 and S450, respectively. The drying efficiency (73.1%) of treatment S450 was found highest than that of others due to higher energy use efficiency. The dryer performance was also found satisfactory in terms of seed quality.

Key words: Low cost dryer, Drying capacity, Drying efficiency.

1. Introduction

Drying is the process to reduce the moisture from grain to a safe level for storage and handling following harvesting. It is a critical step for maintaining grain quality and minimizing storage and processing losses. Paddy is usually harvested at grain moisture content (MC) between 22 to 28% (wet basis) and parboiled paddy contains about 35% moisture. Any delays in drying, incomplete drying, or uneven drying will result in qualitative and quantitative losses.

Improper drying paddy/high moisture grain will cause heat buildup from respiration of microorganisms and grain itself, low thermal diffusivity of grain and increased temperature accelerate mold growth. Mold damage the grain. Some grain mold pathogens produce compounds (mycotoxins) that can be toxic to farm animals, wildlife, or humans. High moisture also reduces the rate of grain germination and vigor due to respiration of grain, mold and insects activities. It causes the loss of nutrition and flavor due to reduce starch and sugar content and increased fatty acid.

Sun drying is a traditional and common practice in Bangladesh where paddy is exposed to sun and wind in the yard or field. Sometimes, farmers leave the harvested paddy in the field for drying before threshing. Some peoples use roads and highway to dry paddy. There is no control on drying rate. This increases losses by birds and decreases quality by addition of foreign materials. Farmers faced problem in paddy drying mainly in Boro and Aus season. During this time heavy rainfall occurs due to effect of monsoon. Moreover, paddy seed of Aman season also affected due to foggy weather in the northern region of Bangladesh. Safe moisture content of stored paddy is very important for germination, and seed viability which can be attained by improved drying technology.

Drying of paddy needs to take as first priority in small traders and farmer's level in wet season. Proper drying is essential to maintain seed quality. Paddy

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seed will lose seed vigor in higher grain temperature over 43°C during drying. The deterioration of the seed vigor in rice crop accounted for 20% of the yield losses (Shenoy *et al*., 1988). Improper drying will accelerate insect and disease infestation during storage period. BRRI estimated a national yield loss of 10-15% due to all diseases (Bayes, 2003). Farmers sow seed two to three times of actual requirement due to lack of good quality seed. The practice of mechanical dryer would be an alternative to sun dry.

However, uniform temperature throughout the drying bin is important for drying the grain uniformly. No study investigated before to understand spatial distribution of temperature and moisture in the drying bin. Moreover, selection of optimal drying bin size is important for increasing drying efficiency and reducing drying time. Therefore, an attempt was taken to investigate those issues for selecting proper size of dryer for small farmers and traders. The present research deals with the following specific objectives:

- To study spatial distribution of air temperature and moisture content inside of the STR dryer;
- To investigate the technical performance of STR dryer; and
- To study the effect of STR dryer on seed quality.

1. Materials and Methods

2.1 Experimental site and Materials

The performance evaluation of selected STR dryer was conducted at the workshop of Department of Farm Power and Machinery, Bangladesh Agricultural University (BAU), Mymensingh. The performance study of STR dryer was conducted during 30 April to 5 May, 2015 for paddy (variety BRRI dhan28). The paddy samples were collected from BAU farm.

2.2 STR dryer

STR dryer is a low cost batch dryer developed by Centre for Agricultural Energy and Machinery, Nong Lam University, Vietnam and Japan International Research Center for Agricultural Sciences (JIRCAS). A schematic view of the dryer is shown in Fig. 1 (b). This dryer consists of two perforated concentric cylinders with grains inside the annular space. Air is passed from the inner cylinder through walls with bottom and top closed to dry the grains inside the annular space. An axial flow blower is used to suck the hot air from the stove (*Chula*) through steel pipe and force the air radially through perforated bins [Fig. 1(a)]. The dimension (40 cm dia x 114 cm height) of inner bin was fixed and outer bin was adjusted according to sample size. The blower (40 cm x 40 cm) was used to suck hot air from heat source and passing through the inner bin. A stove (36 cm diameter × 40 cm length) was used as a heat source. Locally available rice husk briquette was used as fuel in a portable locally made stove.

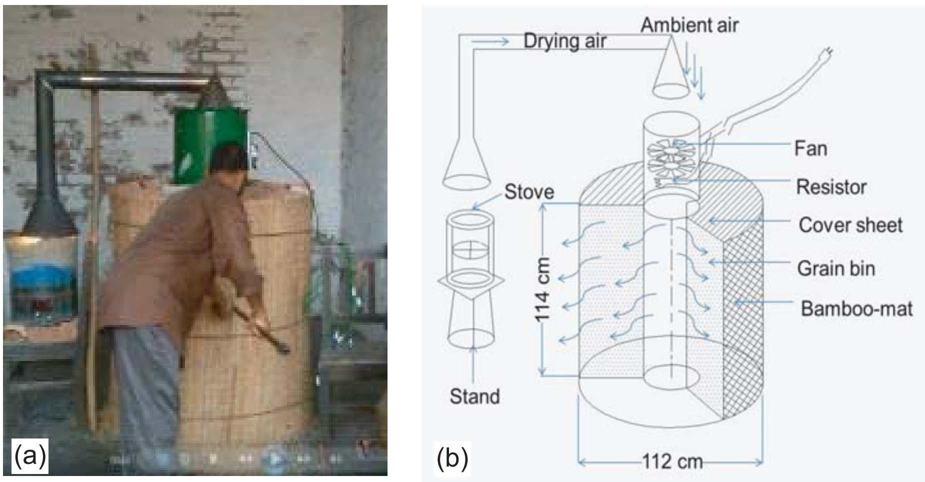

Fig. 1: STR dryer (a) Photographic view and (b) Schematic view

2.3 Experimental set-up

At first, inner bin of STR dryer was set up in the suitable position at the workshop of Farm power and Machinery, BAU. The outer grain bin was fixed around the inner bin with the help of GI wire as per required volume of grain. Then eight *K type* thermocouples were set up in different points of the dryer to get the temperature reading in real time during drying operation (Fig. 2). The thermocouples' positions were varied with sample size of paddy. The paddy grains were delivered in the annular space of the dryer in such a way so that equal amount of paddy contained in all sides. The axial flow blower was set up on the top of the inner bin of the dryer and a polythene cover was used to protect hot air leaking from the paddy of the dryer. A stove was placed in one side of the grain bin and firing was done using rice husk briquette. Then the hot air supply channel was fixed with the help of bamboo stand which was tied by GI wire.

The experiment was conducted with three treatments and three replications. The sample sizes of treatments were 300, 400 and 450 kg named S300, S400 and S450, respectively. To determine the spatial distribution of temperature eight sensors were used in vertical and horizontal axis namely $T_{m,0}$, $T_{m,1}$, $T_{m,2}$, $T_{m,3}$, T_t, T_b, $T_{m,4}$ and $T_{m,5}$, respectively (Fig. 2). The sensor Tm0 was set up in the center point of inner bin. $T_{m,1}$, $T_{m,2}$, $T_{m,3}$, $T_{m,4}$ and $T_{m,5}$ sensors were set up at the distance of 26, 32, 38, 44, and 50 cm, respectively for 450 kg; 25, 30, 35, 40 and 45 cm, respectively for 400 kg; 24, 28, 32, 36 and 40 cm, respectively for 300 kg from the center line of inner bin. The top (T_t) and bottom (T_b) sensor were set up middle and 6 cm apart from upper and bottom surfaces of the grain bin. The distance of sensors varies with the varying of sample size of paddy. The hot air temperature inside grain pile was measured using a digital thermometer (Model- VOLTCRAFT K101, accuracy: ± 1°C). The air velocity through the blower was measured by using a digital anemometer [Model- RS 212-578 AM 4201, accuracy: ± (2% + 0.2 m/s)], at the suction and delivery point of the blower. The inlet area of the blower measured and air flow rate also calculated during operation.

The moisture content was measured in three locations maintaining 29, 38 and 47 cm for 450 kg; 27.5, 35 and 42.5 cm for 400 kg and 26, 32 and 38 cm for 300 kg distance from the center line of inner bin during drying operation. The moisture content measurement locations named $M_{m,1}$, $M_{m,2}$ and $M_{m,3}$ were fixed considering grain thickness in the dryer. The moisture content of paddy was measured using a digital moisture meter (Model - RiceterL accuracy: ± 0.2% 105°C, measurement range 11-30% for paddy rice) after collection of paddy sample with the help of steel made auger. Data were collected in every half an hour interval.

The ambient air temperature and relative humidity were measured by using thermometer (Model- VOLTCRAFT HT-200, temperature accuracy: ± 0.8°C at 25°C, and relative humidity accuracy ± 2% RH). The performance evaluation of STR dryer in terms of moisture removal rate and drying efficiency were carried out in order to adopt in farmers and small traders' level for proper drying and safe storage of paddy in Bangladesh. Three batches of drying operation were performed in a day. One person was required to deliver fuel (rice husk briquette) every 5-10 minutes interval and another person needed for loading and unloading of paddy.

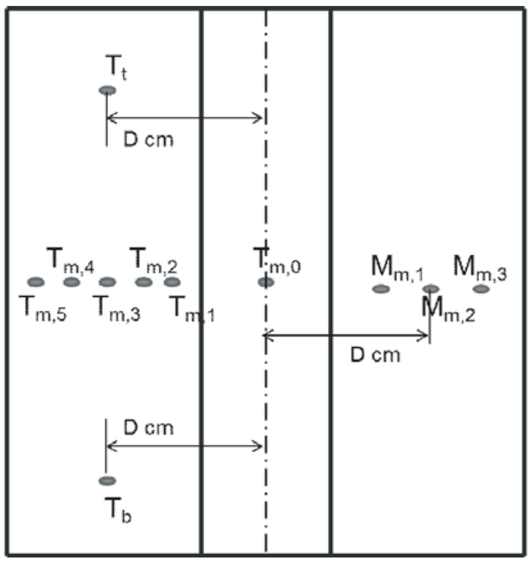

Fig. 2: Thermocouple set up of STR dryer (T-temperature sensor, M-moisture sensor, t-top, m-middle, b-bottom)

2.4 Calculation of technical parameters

The following technical parameters were calculated to determine drying capacity and efficiency of the dryer.

2.4.1 Moisture content

The amount of water in paddy grain is represented by the moisture content of the grain. At first time moisture removed from grain interior to the grain surface and then moisture evaporated from the surface to surrounding air. Moisture content is usually expressed in percent.

The quantity of moisture removed (M_w) from paddy can be found out using the relationship (Forson, 2007) as (eq. 1).

$$M_w = \frac{M_p\ (M_i = M_f)}{(100 - M_f)} \quad (1)$$

Where, M_w = the mass of water removed from wet paddy, kg; M_p = the initial mass of the paddy to be dried, kg; M_i = the initial moisture content of paddy (wet basis), %; M_f = the final moisture content of paddy (wet basis), %.

2.4.2 Drying rate

Drying rate of paddy is the ratio of mass of moisture removed by dryer and drying time of paddy (eq. 2).

$$DR = \frac{M_w}{t} \quad (2)$$

Where, DR = Drying rate, kg/hr; t = Time required for drying, hr.

2.4.3 Drying capacity

The ratio of the weight of total grain (whole and damage) in bin and time required to dry each bin is called drying capacity. The drying capacity was calculated using (eq. 3).

$$DC = \frac{M_t}{t} \quad (3)$$

Where, DC = Drying capacity, kg/hr-batch; W_t = Wet weight of total grain, kg; t = Time required for drying, hr.

2.4.4 Drying efficiency

Dryer performance was measured using drying efficiency equation as well the total energy supplied to the drying chamber and the total energy utilized by the drying chamber to remove desired moisture. The energy supplied by the heat source and the total energy output was determined in STR.

The drying efficiency of dryer is defined as the ratio of energy used to evaporate the moisture from the paddy to the energy input to the dryer.

$$\eta = \frac{W.L}{E_t} \quad (4)$$

Where, W = the weight of water evaporated, kg; L = the latent heat of evaporation of water, MJ/kg; E_t = total energy input, MJ.

The total energy input of dryer was measured from the sum of electrical power required by the fan and the caloric energy supplied by the burner. Fan energy was obtained from power and run hour of fan. The burner energy was calculated using amount of fuel (briquette) used and calorific value of fuel.

The total energy input calculated with the (eq. 5)

$$E_T = (M.C + Ee) \quad (5)$$

Where, E_T = Energy input, MJ; M = Amount of fuel used, kg; C = Net calorific value of fuel, MJ/kg; E_e = Electrical energy used, MJ. Considered the net calorific value of fuel (briquette) = 10.655 MJ/kg.

2.4.5 Seed germination

Seed grain requires a high proportion of individual grains with germination properties. The viability of grain is directly linked to the temperature attained by grains during drying (Kreyger, 1972). Grain temperature over 43°C for drying paddy seed will lose seed vigor. The deterioration of the seed vigor in rice crop accounted for 20% of the yield losses (Shenoy *et al.*, 1988). Seed sprouting rate or germination rate was calculated using number of seed sprout or germinate in 100 seeds.

3. Results

3.1 Spatial distribution of temperature

Figure 3.1a, b and c shows the vertical drying temperature variation at top (T_t), middle (T_{m3}), bottom (T_b), and inner bin middle ($T_{m,0}$) point of dryer during operation for different sizes of the STR dryer. The figure shows that temperature was around 30°C at the starting point of the dryer in all locations in all cases and then increased above 40°C in every location after 1.5 hour. Similar trend of temperature profile can be found for horizontal temperature distribution in Fig. 4a, b and c. There were no significant differences in temperature among the vertical locations (as mentioned in the Fig. 3) as because T_t, $T_{m,3}$, T_b sensors locations were at the same distance from the center of the inner bin from where hot air was entering into grain pile.

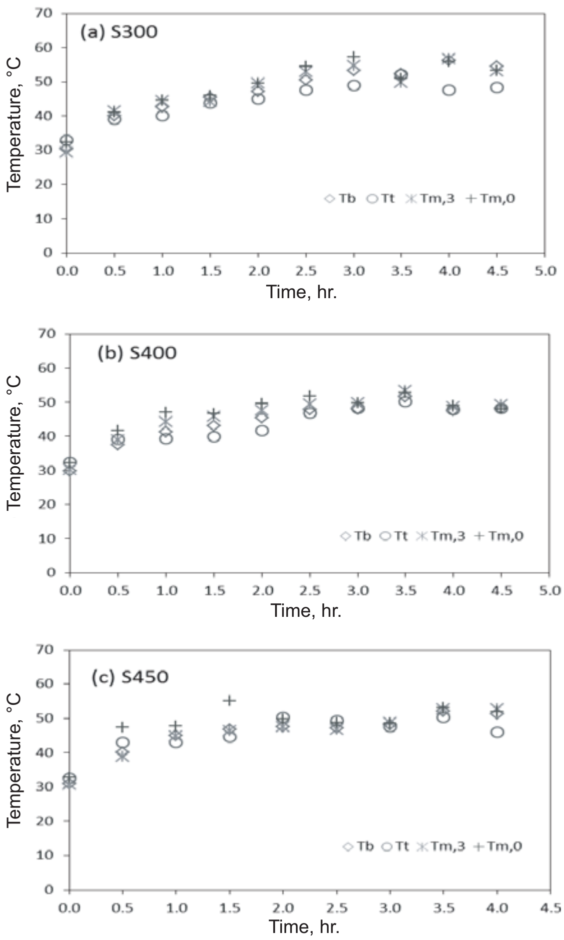

Fig. 3: Vertical air temperature distribution at different locations of STR dryer for the drying bin sizes of (a) 300 kg, (b) 400 kg, and (c) 450 kg

The temperature was varied initially among the horizontal locations because distances from the center of the inner bin were different. As for example, temperature at $T_{m,5}$ was much lower than temperature at $T_{m,1}$ after half an hour of starting drying operation (Fig. 4). After certain time depending on the size of the dryer, temperature distribution of all horizontal sensors location became almost same. Lower capacity STR dryer reached temperature equilibrium condition faster than higher capacity dryer (Fig. 4a, b and c). STR dryer of 450 kg capacity took 2 hr to reach at the same temperature level. The drying temperature increased rapidly within two hours, and then increasing rate was nearly steady or slowed down till the completion of drying. It proves that hot air temperature uniformly distributed to all over the drying section. However, variations of the temperature over the time depend on the efficiency of steady fuel supply for producing same hot air temperature which needs to be taken care of.

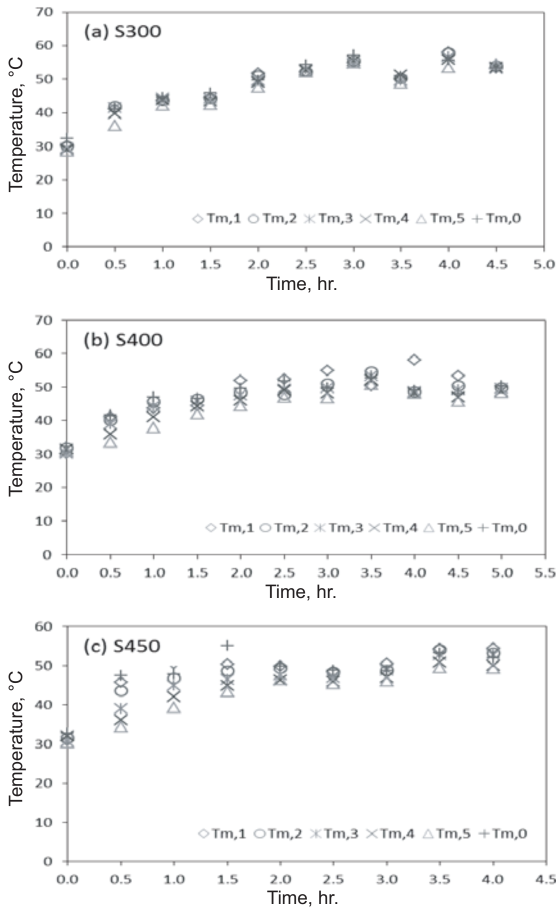

Fig. 4: Horizontal drying air temperature variation at different point of middle layer of dryer for different sample size

3.2 Spatial distribution of moisture content

The typical drying curves for three sample size (S300, S400 & S450) at middle layer of dryer are shown in Fi. 5a, b, and c. The general trend, moisture level of grain was decreased with the time.

There were no significant differences of moisture content with time among the dryer capacities. The grain was dried uniformly and reached same and desired moisture level (less than 12%) in all part of the dryer in 3 to 5 hours.

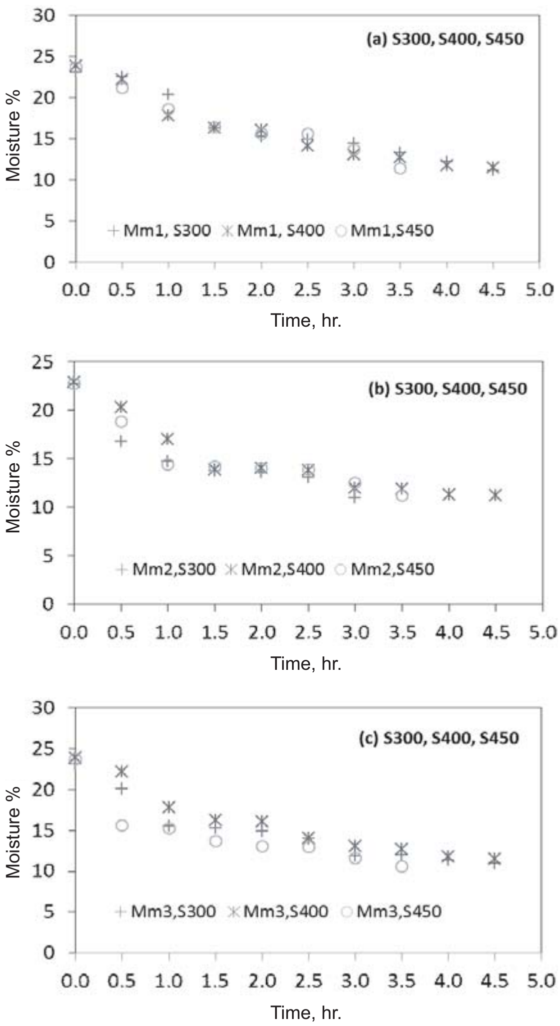

Fig. 5: Change of moisture content at different distance at middle layer from the center of dryer for the different drying bin size

3.3 Dryer performance

The STR dryer was evaluated in terms of drying capacity, moisture removal rate, drying efficiency, and physical quality of dried paddy. The paddy was dried from 23.9% to 10.4%, 22.9% to 10.6% and 21.6% to 10.7% mc. in sample size 300 kg, 400 kg and 450 kg, respectively. The higher ambient air temperature and lower relative humidity directly affected the drying time. The initial moisture content of sample size S450 is lower than sample size S300 and S400 which also affect the drying time. The resulted drying time of sample size S450 is found less than that of other sample size. The amount of removed moisture, volume flow rate of air and measured data of paddy sample are shown in Table 1.

The drying capacities of the dryer were 75, 88.8 and 121.6 kg/hr/batch for S300, S400 and S450, respectively (Table 2). The drying capacity increases with the increasing in sample size of paddy. The drying rates of STR dryer were 11.3, 12.2 and 15 kg/hr for S300, S400 and S450, respectively. The drying rate was also increased with the increasing in sample size of paddy.

The drying efficiency of S450 is greater than that of others due to higher energy use efficiency. The drying efficiency was increased with the increasing in sample size of paddy.

3.4 Seed germination and vigor

Seed sprouting test was conducted taking 400 numbers of dried paddy for sample size S300, S400 and S450 respectively (Table 3). Sprouting in S400 treatment was more than that of other sample size. The sample size S400 was dried within 24 hours period after harvesting. The sample size S300 and S450 were stored in plastic bag for 2 to 3 days with high moisture content for delay drying. The resulted sprouting rate decreases due to store with high moisture content.

Table 1: Amount of moisture removed during drying

Treatment	Hot air temp. °C mean ± std	Relative humidity, % mean ± std	Air flow rate (m^3/hr)	Initial moisture content (%)	Final moisture content (%)	Initial paddy weight (kg)	Final paddy weight (kg)	Moisture removed (kg)
S300	47.2 ± 2.4	64.7 ± 7.4	5683	23.9	10.4	300	254.7	45.3
S400	45.8 ± 4.1	71.9 ± 8.0	5683	22.9	10.6	400	345.0	55.0
S450	45.8 ± 2.9	65.5 ± 6.3	5683	21.6	10.7	450	395.1	54.9

Table 2: Performance of STR dryer

Treatments	Amount of moisture removed, kg	Drying time, hr	Drying rate, kg/hr	Drying capacity, kg/hr/batch	Total energy input, MJ	Total energy consumed, MJ	Drying efficiency, %
S300	45.3	4.0	11.3	75.0	192.7	111.0	57.6
S400	55.0	4.5	12.2	88.8	198.4	134.8	67.9
S450	54.9	3.7	15.0	121.6	184.0	134.6	73.1

Table 3: Germination rate of dried paddy sample

Treatments	% of dead seed	% of germination
S300	18	82
S400	6	94
S450	19	81

4. Discussion

Variation of temperature, relative humidity and moisture content were observed during drying period (Fig. 3, 4 and 5). There is no significant difference between horizontal and vertical dryer temperature. Therefore, uniform temperature distribution was present in the dryer. Similar results have been reported for paddy seed drying (Hossain *et al*., 2012).

The moisture removal rate (Fig. 5) decreases continuously with drying time. It is observed that time required is more in treatment S400 compared to others. The drying temperature was more in treatment S300 as higher amount fuel supplied, on the other hand the initial moisture content was less in treatment S450 as collected from the field. The resultants drying time reduced compared to others treatments. The similar results are reported on drying of Thai Hom Mali paddy (Doungporn *et al*., 2012), parboiled wheat (Mohapata and Srinivasa 2005; Kahyaoglu *et al*., 2012), garlic slices (Madamba *et al*., 1996), onion slices (Sarsavadia *et al*., 1999), egg plants (Akpinar and Bicer 2005), peach slices (Kingsly *et al*., 2007) and plum slices (Goyal *et al*., 2007).

5. Conclusions

STR was tested for Boro season (April-June 2015) at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh. Spatial distribution of temperature and moisture content of STR dryer shows that blower uniformly delivers the hot air through the grain stack and dry 450 kg of grain in less than 4 hrs. The STR dryer is to be used for its maximum capacity (half ton) for higher drying capacity and efficiency. Controlling of heat source is quite difficult since it depends on operator’s experience. Steady electricity supply is needed to operate the blower for efficient drying operation.

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