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Radio Frequency Drying Kinetics of Paddy Grain

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ABSTRACT

The drying characteristics of a paddy grain (NLR 33 892) were studied using Radio Frequency Dryer (RFD). The drying chamber of the RFD consisted pair of electrodes of size 75 cm X 55 cm and a grain holding cell of 36 L X 25.5 W X 5.5 H, cm^3. The cell was filled with grain for three levels of bed thickness (2, 3 and 4 cm) to study the drying and drying rate curves. The weight of the drying grain was recorded at every 1 min interval to calculate the moisture loss. The obtained data was plotted and analyzed for moisture loss and drying rate. It was observed that the drying curve followed the falling rate period for all the bed thickness experiments conducted in Radio Frequency drying. The longest time of drying 9 min was observed in the experiment where the grain bed thickness was 3 cm whereas the shortest time of drying 6 min was observed in the experiment where the grain bed thickness was 4 cm.

Key words: Drying curve, Drying rate, Radio Frequency dying, Paddy.

Paddy, one of most important cereal crop in the world, is a staple food source for more than a half of the world's population. India has produced about 102.54 million tonnes of paddy during the year 2013-14 (Anonymous, 2014) and is expected to increase. Drying is an important unit operation that reduces the moisture content from a higher level to a predetermined level. Though a number of drying methods and technologies exist, lack either in time saving or in quality of end product. Therefore, there is an increasing demand for the new technologies in drying process to avoid the problems such as, non-uniform heating, slow rate of drying and low quality aspects of milling and cooking.

The application of Radio Frequency for drying is a novel heating technique which rises temperature volumetrically, penetrated deeply in bulk product with low energy consumption. Radio Frequency involves the transfer of electromagnetic wave energy directly into the product, therefore inducing volumetric heating due to frictional interaction between molecules (Akaranuchata *et al.,* 2012, Wang *et al.,* 2011 and Wang *et al.,* 2013). As polar molecules (water) in the material continually arrange in a line and reorient themselves to change electric field, then friction is formed and causes heat within conductive materials, called Polarization (Piyasene *et al.,* 2003). The essential advantage of Radio Frequency heating resides in the generation of heat within the material to be heated is much more rapid and energy efficient in comparison with more conventional heating techniques (hot air, infrared, *etc*).

Keeping the advantages of Radio Frequency drying and its associated higher quality grain, the research work is taken to study the drying curves of Radio Frequency dried paddy grain at different bed thickness.

MATERIAL AND METHODS

The fresh type paddy grain (NLR 33 892) sample of 25 kg was procured from Agricultural College Farm, Bapatla. The Radio Frequency drying experiments were conducted at laboratory of Monga Strayfield Pvt. Ltd. Pune, Maharashtra, India.

A 6-kW, 27-MHz Radio Frequency system (Model: SO-06 B) was used to dry the paddy grain as shown in Plate 1. A control panel was used to start/stop of the machine and to control the electrode gap manually. The applicator part of the machine was provided with a window to open and close to facilitate to place the paddy sample in between two electrodes of the applicator. The plastic container (36 L× 25.5 W×5.5 H, cm^3) was used as sample holder and was used to place the paddy sample in applicator to conduct drying experiment at different grain bed thicknesses between two electrodes as shown in Plate 2.

The moisture content of paddy grain was determined by hot air oven method (ASAE 1982). The experiment was conducted with different grain bed thickness of 2, 3 and 4 cm to find out the effect of bed thickness of drying of paddy grains in between two electrodes. The weight, temperature of grain and relative humidity at each grain bed thickness was noted before and after drying. The moisture loss was recorded after every 1 min interval of exposure of the paddy grain to Radio Frequency waves at 130 mm of electrode gap. The weight loss during successive readings was recorded as moisture loss. Thus obtained data was used in plotting the drying curves and was used for further analysis. The experiments were conducted in duplicate to confirm the experimental results. The Radio Frequency drying was continued till it reaches to equilibrium moisture content.

Drying rate is in g/100 g bone dry matter per unit time. The average drying rate was calculated as amount of moisture transfer during drying time divided by total drying time interval (Rayaguru *et al.,* 2011).

$$DR = \frac{M_{t+dt} - M_t}{t_d} \quad .... (1)$$

Where, M_t = moisture content at a specific time (g water / g dry base),

M_{t+dt} = moisture content at t+dt (g water/ g dry base) and

t_d = drying time (min)

RESULTS AND DISCUSSION

The data obtained from the experiments conducted to dry the paddy grain of 2, 3 and 4 cm bed thickness is presented in Table 1, Table 2 and Table 3, respectively and the drying curves for the same is shown in Fig. 1. The Radio Frequency dryer took 8 min to reduce the moisture of grain from 17.38% to 7.61% when the bed thickness was 2 cm. Similarly, at 3 cm grain bed thickness, it took 9 min time to reduce the moisture content from 17.38% to 6.77% as shown Fig. 1. Similarly, at 4 cm grain bed thickness, it took 6 min time to reduce the moisture content from 17.38% to 5.72%. It is also observed from the same Fig. 1, that the drying curves of all the three bed thicknesses investigated suggested that the paddy grain continuously reduced in moisture content with respect to time of drying.

The drying rate curves were also plotted for the paddy grain dried at bed thickness 2, 3 and 4 cm and are shown in Fig. 2. The drying rate varied between to1.95 x 10^{-3} and 25.22 x 10^{-3} g/g-min; 2.70 x 10^{-3} and 31.03 x 10^{-3} g/g-min; 6.30 x x10^{-3} and 42.03 x 10^{-3} g/g-min for 2, 3 and 4 cm bed thicknesses, respectively under Radio Frequency drying. On keen observation of drying rate curve of 2 cm bed thickness the drying rate increased gradually from 1.94 x 10^{-3} g/g-min during 1st min of drying and attained a peak drying rate to 25.22 g/g-min during 4th min and later decreased to 9.70 x 10^{-3} g/g-min and evaporated the moisture content of about 90 g during drying. This indicates the temperature of the grain gradually increased during the first 4 minutes and continued to decrease. The drying rate of the 3 cm grain depth increased sharply 31.03 x 10^{-3} g/g-min during 2nd min of drying and decreased continuously to reach 2.70 x 10^{-3} g/g-min during the 9th min and evaporated moisture of about 159 g. And for the 4 cm thick bed paddy grain reached a maximum drying rate of 42.03 x 10^{-3} g/g-min during first min of drying itself and gradually decreased to 6.30 x 10^{-3} g/g-min during 6th min of drying evaporated the moisture content of about 223 g.

On observing the Fig. 2 it is found that there is a shift in the values of peak drying rates of different bed thickness of paddy grain during Radio Frequency drying. The dielectric loss factor of the paddy grain is higher at high moisture content and lower at lower moisture content (Sacilik *et al.,* 2003) i.e., higher the loss factor higher the energy converted to heat. As seen in Fig. 2 the higher drying rates were founded during the initial periods of drying and the lower rates were found in the later periods of drying. This is because of the major radio frequency energy is converted to heat energy as the value of dielectric loss factor is high at higher moisture content of paddy. It was found during experimentation that the Radio Frequency drying yielded puffed and burnt grains during the first 2 min of drying under 3 and 4 cm of grain bed thickness. This further confirmed that the high drying rates are not suitable for paddy drying. But the grain bed thickness of 2 cm showed higher rates of drying without visual damage to the grains.

Table 1. Drying rate of Radio Frequency dried paddy grain at 2 cm grain thickness.

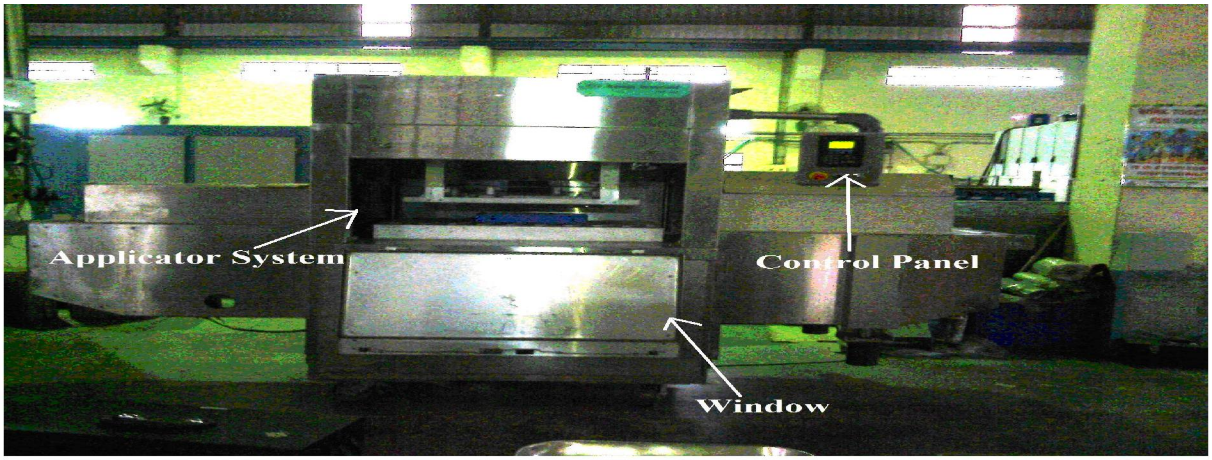
S. No.	Weight of paddy grain				Drying interval, min	Average Moisture Content, % (db)	Drying rate,g/g-min
	R1, g	R2, g	Average, g	Moisture evaporated, g			
1	1210	1210	1210	0	0	17.38	0
2	1208	1208	1208	2	1	17.19	$1.94 * 10^{-3}$
3	1196	1196	1196	12	1	16.02	$11.64 * 10^{-3}$
4	1180	1180	1180	16	1	14.47	$15.52 * 10^{-3}$
5	1154	1154	1154	26	1	11.95	$25.22 * 10^{-3}$
6	1140	1140	1140	14	1	10.59	$13.58 * 10^{-3}$
7	1128	1128	1128	12	1	9.425	$11.64 * 10^{-3}$
8	1120	1120	1120	8	1	8.649	$7.76 * 10^{-3}$
9	1110	1110	1110	10	1	7.679	$9.70 * 10^{-3}$

Table 2. Drying rate of Radio Frequency dried paddy grain at 3 cm grain thickness.

S. No.	Weight of paddy grain				Drying interval, min	Average Moisture Content, % (db)	Drying rate,g/g-min
	R1, g	R2, g	Average, g	Moisture evaporated, g			
1	1740	1740	1740	0		17.38	0
2	1734	1734	1734	6	1	16.98	$4.05 * 10^{-3}$
3	1686	1690	1688	46	1	13.875	$31.03 * 10^{-3}$
4	1650	1648	1649	39	1	11.24	$26.31 * 10^{-3}$
5	1630	1624	1627	22	1	9.757	$14.84 * 10^{-3}$
6	1614	1606	1610	17	1	8.61	$11.47 * 10^{-3}$
7	1602	1593	1597	13	1	7.767	$8.77 * 10^{-3}$
8	1594	1587	1590	7	1	7.295	$4.72 * 10^{-3}$
9	1588	1582	1585	5	1	6.9235	$3.37 * 10^{-3}$
10	1584	1578	1581	4	1	6.6535	$2.70 * 10^{-3}$

Table 3. Drying rate results of Radio Frequency dried paddy grain at 4 cm grain thickness.

S. No.	Weight of paddy grain				Drying interval, min	Average Moisture Content, % (db)	Drying rate,g/g-min
	R1, g	R2, g	Average, g	Moisture evaporated, g			
1	2234	2234	2234	0		17.38	0
2	2156	2153	2154	80	1	13.2	$42.03 * 10^{-3}$
3	2108	2104	2106	48	1	10.655	$25.22 * 10^{-3}$
4	2066	2064	2065	41	1	8.5005	$21.54 * 10^{-3}$
5	2042	2043	2042	23	1	7.318	$12.08 * 10^{-3}$
6	2020	2026	2023	19	1	6.2935	$9.98 * 10^{-3}$
7	2009	2014	2011	12	1	5.6895	$6.30 * 10^{-3}$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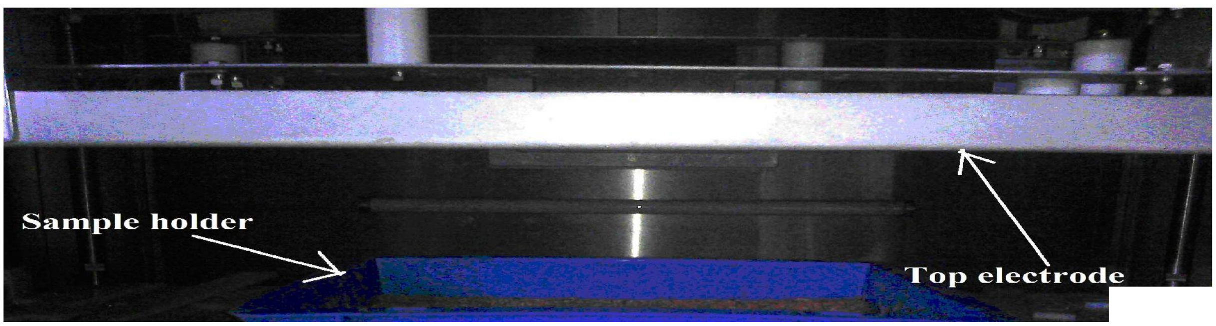
Sample holder
Top electrode