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DEVELOPMENT OF A FULL-SCALE CONDUCTION HEATING ROTARY DRYER FOR ACCELERATED DRYING AND STERILIZATION OF HIGH MOISTURE ROUGH RICE

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Abstract

A full-scale conduction heating rotary dryer was designed and constructed at the Dep. of Agric. Mech., Fac. of Agric. Mansoura Univ. The dryer was tested, examined and evaluated for accelerated drying and sterilization of high moisture rough rice (Giza 176) at the Rice Mechanization Center experimental farm of the Agric. Eng. Res. Institute, Kafr El-Shiekh Gov. branch.

Dryer performance through field experiments and calculation of parameters proved the applicability of the dryer for rapid drying and sterilization of high moisture rough rice down to 17-18%. Heat treatment of rough rice corresponding to 80% led to a significant improvement in grain physical quality and milling potential.

The heat-treated grain exhibited a marked reduction in grain broken percentage approached 30-35% in comparison with the naturally dried grain . The reduction in grain broken percentage was attributed to the increase in grain hardness and the reduction in grain crack percentage. The average thermal efficiency of the dryer was determined to be 68.5% and the required heat energy for removing 1 kg of water from rice was about 3681.69 kJ. In general, the dryer showed a good mechanical and thermal performance and proved to be practical.

INTRODUCTION

Rice is not only among the most important crops in Egypt but also world wide. The planted area of rice in Egypt was 1,137,000 feddan in 1972, and production was 2.533, 545 tons. In 1997, the planted area of rice increased to 1,400,000 feddan. However, due to the breeding of high yielding varieties and the application of mechanical harvesting, the production increased nearly by 95% and reached 4,930,000 tons.

In spite of this increase in production, losses almost always take a great toll of the potentially available supply because of poor handling and processing techniques. Advances in processing can therefore greatly augment any development in the technology of rice production.

Recently, in Egypt, rice harvesting has been mechanized by the use of combine harvesters, which enable large quantites of high moisture grains to be harvested in short time. The almost universal use of the combine harvester, coupled with increased yield, has made it difficult for milling companies to dry all the grains in few weeks during and shortly after harvest. Drying capacities in most miling companies are still insufficient to cope with the drying demand for the large quantity of harvested grains received during this short period.

On the other hand, the delay in processing the high moisture grain resulted in rapid qualitative deterioration and high quantitative losses. A real solution to this problem will consist of either avoiding drying delays or extending the safe storage period of high moisture paddy by conditioning the grain or stopping its rapid deterioration during this period. Accelerated heating of high moisture rough rice for partial drying and inactivating the fungi may prove to be innovating by the use of practical conditioning method. However, evaluation of this approach must include detailed investigations of the time-temprature history of the grain during the process as well as the determination of the operational characteristics of the applied system and the changes in grain quality that may take place.

Lapp (1973) initiated laboratory scale experiments beginining in 1972 using fine textured sand and steel balls approximately 0.91 mm in diameter to investigate the feasibility of obtaining moisture removal from rape seed. In initial drying trials sand to grain moisture ratio (SGMR) of 2.5:1, 5:1 and 8:1 with sand heated approximately to 32C were used. The residence time of the samples in a bench type drum dryer was about 2 min. Trials with initial moisture content of rape seed at 19,17 and 16%, yielded moisture content after drying of 13.3, 12.0 and 9.30% respectively. Initial laboratory success led to further investigtions resulted in the construction of proto-type dryer.

Jindal and obaldo (1986) developed a rotary dryer using high temperature conduction heating by burning the rice husk. The dryer was tested for the disinfestation and rapid drying of high moisture paddy. The result showed that the heating surface temperature within the range of 100-180 ^{o}C could be used for continuous drying and sterilization of high moisture paddy to suppress fungal growth and respiration rate during temporary storage.

Chakraverty and Devadattam (1987) ,developed a continuous rice bran stabilizer. The conduction drying of rice bran was carried out at drying surface temperature of 105, 110, 115, 120 ^{o}C for 10, 20 and 30 min. The dry conduction heat treatment at a rice bran temperature of 110 ^{o}C for 20 min was taken as optimum to keep the free fatty acids (FFA) of the treated bran below 10% for 60 days when stored in sealed polyethylene bags at storage temperature of 18-45 ^{o}C and relative humidity of 62-98%.

Bonifacio et al., (1990) developed a rotary mechanical dryer utilizing rice hulls, coconut husks, and other agro-waste fuel that are readily available on the farm for a rapid drying of high moisture paddy. The dryer has the following characteristics: (1) It employs direct conduction heating of grain which makes drying possible even at humid condition; (2) It has a high throughput capacity and less power requirement per unit size; (3) It employs practical drying strategies which minimize sprouting and/or spoilage of the paddy; (4) It dries paddy with a better milling recovery and storability as a result of partial gelatinization and disaffection of grain; and (5) It is easy to fabricate with the use of locally available construction materials.

Younis et al., (1993) designed a mechanical dryer employing sand as heat transfer medium. However, it involved heating the sand in a bucket then manually pouring the heated sand and grains in the rotating drum and, finally, manually sieving the hot sand and dried grain. This caused heat loss and was not practical for the farmers in bulk grain drying.

Iqbal et al., (1996) developed a continuous-flow grain dryer employing heated sand as heat transfer medium. The machine performed well in drying, separating, recirculating hot sand and delivering dried grain. Results of the drying experiments conducted with the equipment showed that initial sand temperature of 120 ^{o}C residence time of 21.818 sec and high moisture content of grain selected (28%) were the optimum values for efficient drying of shelled maize.

The present study aims to develop a full-scale rotary dryer for accelerated drying and sterilization of high moisture rough rice. The operational performance of the dryer and the grain quality changes are to be evaluated.

MATERIALS AND METHODS

Rough rice used for the experimental work was a short grain variety (Giza 176) which was harvested from the experimental farm of the Rice Mechanization Center (R.M.C) at Meet El-Dyba, Kafr El-Sheikh Governorate during 1997 rice harvesting season.

Equipment and test condition

1. Structure of the full scale rotary dryer with helical flights

Based on the results obtained from the one pitch experimental heating unit (El-Sahrigi et al., 1999) a full-scale conduction heating rotary dryer with a capacity of 1-1.5 ton/h. was designed and constructed in the workshop of the Agric. Mech. Dept. Faculty of Agric. Mansoura univ.

For economic purposes, the heating source used for this dryer was changed to a butane gas instead of electricity used in the one pitch experimental unit. The structure details of the full-scale rotary dryer are shown in Figures 1 and 2 as follows:

A. Rough rice feeder

The feeder assembly consisted of a hopper for loading the grain, a screw conveyor welded to the rotating shaft at the bottom of the feeding hopper for maintaining the desired grain feed rate, and spout for preventing the grains from discharge direclty into the screw conveyor.

B. Rotary heating cylinder

The rotary heater was basically a cylinder (0.6 m diameter and 6.2 m long) constructed with a 3 mm thick mild steel sheet and divided into 3 connected parts for maintenance and repair purposes. The cylinder served as a heat exchanger for drying and sterilization of high moisture rough rice. It had a helical spiral welded to the inside wall and it was fixed from both sides by a two 70 mm iron bar riding on four ball bearings two at each side of the cylineder. Double sprocket, and chain drive assembly powered using 1.0 KW electric motor were employed for rotating the cylinder. A discharge spout and chuts were also used for unloading the dried grains. The horizontal travel of the grains in the heat exchanger was affected by the helical flights. As the heating cylinder rotated, the flights pushed and conveyed the grain causing it to slide, roll or tumble along the inner wall of the heated cylinder. The helical flight also served as an additional heating surface aside from providing grain agitation and transport. Using an electric inverter connected to the electric motor, the cylineder rotational speed could be changed.

C. Heater housing and heating method

the butane gas was used as a heat energy source for heating process as mentioned before. The heater housing was formed of 1.5 mm thick mild steel shute with gross dimensions of 6.2 m long, and 0.8 m diameter. The outside surface of the heater housing was insulated using 50 mm thick fiberglass insulation material and enclosed with another mild steel sheet, in the lower portion of the cylinder, a six meter long gas pipe divded into three equal parts each two meters in length were installed and enclosed with one mm perforated mild steel sheet. A temperature control system was used to provide a cylinder surfce temperature from 75 to 150^{o}C and a digital butane gas gage was installed into the discharge portion of the gas pipe in order to record the butane gas consumption of the drier.

D. Temperature control system

The temperature control system of the cylinder surface consisted of a thermostat connected to a gas solenoid valve for stopping and connecting the gas flow to each pipe based on the required level of cylinder surface temperature. In order to reignite the gas heater, a spark plug was installed at the center of each pipe facing the gas nozzle and connected to an electric transformer with three second interval timer. The details of the temperature control system are shown in Figure 1.

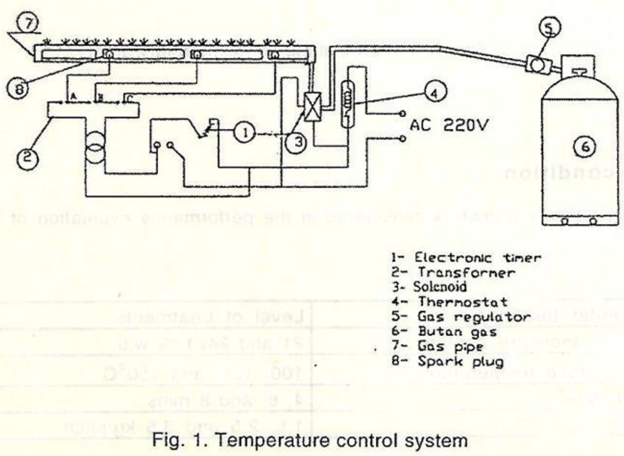
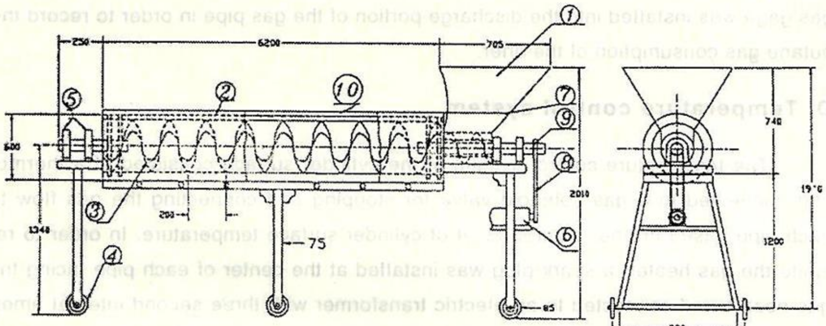


Fig. 1. Temperature control system

E. Support frame and drier mobility

The dryer support frame was constructed of 7.62 cm (3 inch) iron bars. The drying cylinder rested on six iron rollers that rotate on ball bearing and distributed in equal distances along both sides of the heated cylinder. These rollers could facilitate the cylinder movement and prevent the heat effect on its circular shape. The dryer can move by using four 25cm diameter rubber wheels fixed into both sides of the frame. Figure 2 presents the structure of the prototype rotary dryer.



1- *Hopper*
2- *Heating cylinder*
3- *Helical*
4- *Wheel*
5- *Ball bearing*
6- *Electric motor*
7- *Shatter*
8- *Chain*
9- *Sprocket*
10- *Insulation*

Dimensions in mm

Fig. 2. Overall features of the full-scale rotary dryer

2. Test condition

The drying parameters considered in the performance evaluation of the dryer were as follows:

Experimental treatments	Level of treatments
Initial grain moisture content	21 and 24±1 % w.b.
Heating surface temperature	100, 125, and 150°C
Exposure time	4, 6, and 8 mins.
Grain feed rate	1.5, 2.5 and 3.5 kg/pitch

3. Test procedure and measurements

Immediately after harvest, the average moisture content of rough rice was measured and found to be about 24±1% w. b. as determined by the drying oven method. Foreign materials, broken and unfilled grains were removed through winnowing process. Lower moisture content levels of rough rice samples could be obtained by exposing the high moisture grains to the ambient condition under shade. Rice samples were stored temporarily in a freezing room adjusted to a temperature of (-5 ^{o}C) in order to suppress fungal growth and minimize quality change. Before each experiment, rough rice samples were taken out from the freezing room and left at the ambient temperature until the initial temperature of the grains approached an equal level for all samples. Initially the cylinder rotational speed and grain feed rate were set to the levels recommended for each test condition. Conduction drying started after attaining the required heating surface temperature. After heating the grains to the required heating time, they were cooled to room temperature in wooden buckets covered with a perforated aluminum foil to allow escape of vapor during cooling process. Subsequently the grains were dried to about 14% w.b. moistuure content by spreading on nylon mats and prepared for quality evaluation tests.

The following measurements were conducted during conduction heating drying and sterilization process:

1. Grain miosture content determination

The moisture content of the heat treated rough rice samples was measured by the standard drying oven method using 25 g sample placed in air oven at 130^{o}C for 16 h. as given by *AOAC (1990)*.

2. Temperature distribution along the cylinder

The remote-type infra red spot thermometer model (HT-II) was used for measuring the surface temperature of the rotated cylinder in order to investigate the temperature distribution and fluctuation along the cylinder length.

3. Electricity and gas consumption measurement

An electric counter was used to measure electricity consumption of the full-scale dryer motor in kW during the drying experiments. The gas flow meter model (RX-3500) was used for measuring gas consumption in m^3.

4. Thermal effieciency calculation of the full-scale rotary dryer

In order to evaluate the overall performance of the full-scale rotary dryer, the thermal efficiency was determined from actual drying tests, which was calculated using the following relationship (Jindal and Reyes 1987).

$$\eta_t = (Ww \times Lh / Q) \times 100 \quad (1)$$

where:

η_t = thermal effeciency, %.

Ww = water evaporated from grains, kg.

Lh = latent heat of evaporation of water, kJ/kg

Q = total power consumption, kJ.

The latent heat of water vaporization was taken 2456 kJ/kg as an average value and the calorific value of butane gas was taken 45600 (kJ/kg).

Tests to Evaluate Grain Quality

The quality evaluation parameters for this study may be assessed as follow

1. Fungal colony counts.
2. Crack percentage.
3. Grain rigidity test.
4. Physical soundness of kernels.
5. Whiteness degree of milled rice.

Operation of the full-scale dryer

A. residence time of rough rice into the dryer cylinder

The relationship between residence time of grain inside the dryer heating cylinder and its rotational speed can be estimated using the following equation:

$$Tr = N/V, \text{ min} \quad (2)$$

where:

Tr = residence time of grain inside the heating cylinder, min.

N = Number of cylinder spiral pitches.

V = cylinder rotational speed, rpm.

B. required grain feed rate

The required grain feed rate can also be calculated using the following equation:

F = W X V, kg/min. ---------------------------- (2)

where:

W = required grain weight per pitch, kg

V = cylinder rotational speed, rpm

RESULTS AND DISCUSSION

Performance of the full-scale rotary dryer

The operation of the full-scale rotary dryer was carefully checked before actual heating and drying tests. Several adjustments were required for achieving a smooth mechanical operation. Based on the calibration results, it was possible to regulate the cylinder surface temperature in a close range by monitoring the temperature of the cylinder using the remote-type infra red spot thermometer. Figure 3 shows the temperature distribution at different points along both sides of the cylinder surface.

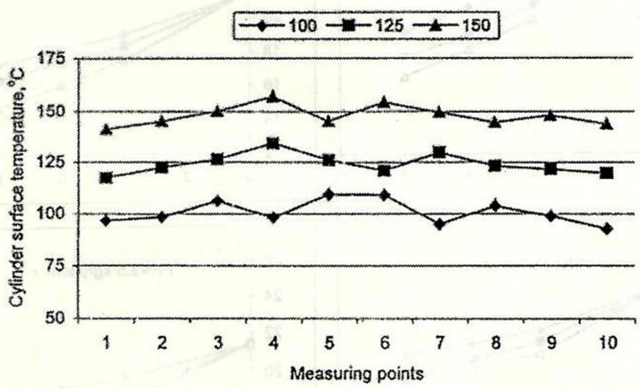


Fig.3. Measured cylinder surface temperatuure of the full-scale rotary dryer at various points along the axial length.

1. Moisture removal from grain during conduction heating

Figure 4 illustrates the change in grain moisture content as related to the exposure time using the full-scale dryer for different grain initial moisture content and feed rates. The drying experiments clearly showed rapid mositure removal from the grain especially at higher heating surface temperature and long exposure time.

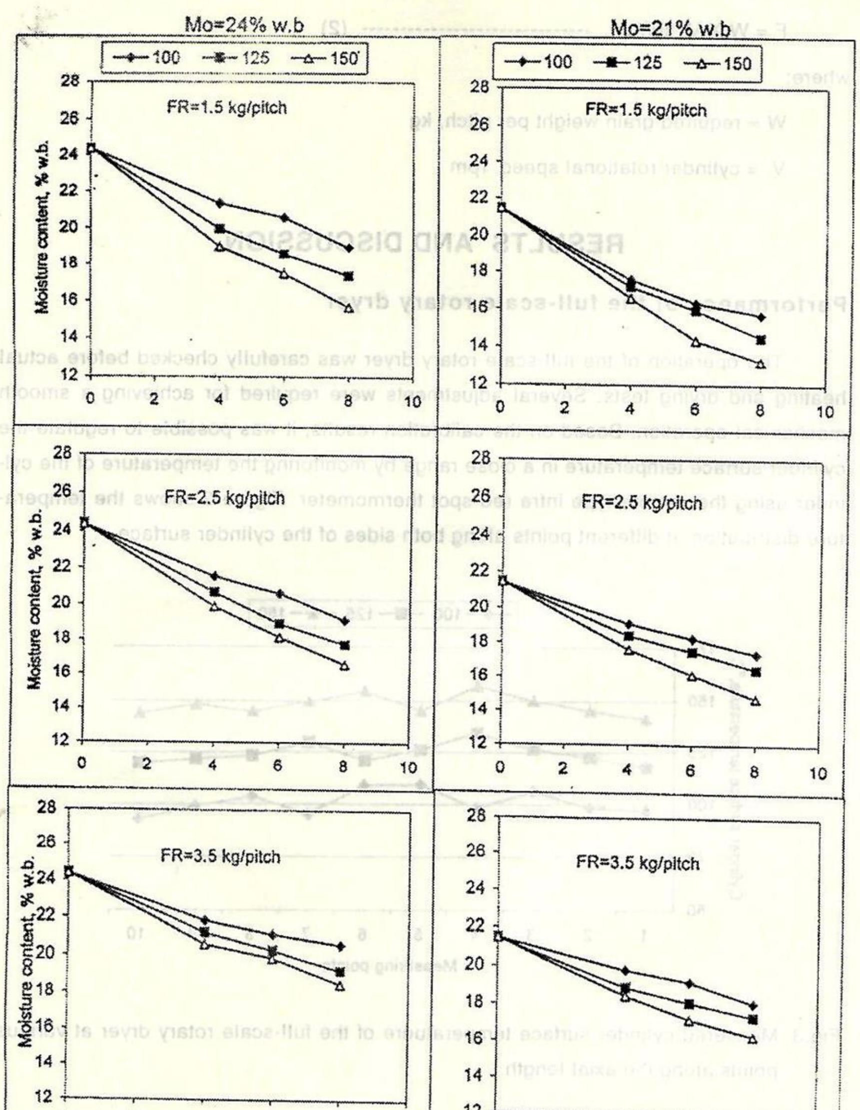


Fig.4. A typical plot of grain moisture content vs. exposure time using the full-scale conduction heating dryer.

2. Fungal mortality level during conduction heating

Figure 5 shows the change in fungal mortality level with exposure time for different grain initial moisture contents and feed rates. As illustrated in this figure, fungal mortality level has increased with increase of the cylinder surface temperature and exposure time for both levels of grain initial moisture content. A fungal mortality level of about 75-80% could be obtained using a heating surface temperature of 125-150 ^{O}C for exposure time of 6-8 min. This fungal mortality level accompanied with grain moisture reduction of 5-6% during conduction heating process are expected to keep the grain without deterioration during short and long-term storage.

3. Interrelationship between rice moisture content, fungal mortality level and milling quality

Table 1 summarizes the experimentally determined time-temperature combinations for obtaining a minimum broken ratio of milled rice samples using the full-scale rotary dryer and the corresponding grain moisture content, fungal mortality level, and whiteness degree of milled rice. It was obviously shown that, under specific time-temperature combinations, high temperature-short time conduction heating of high moisture rough rice resulted in a lower broken percentage in comparison with the naturally dried grain. The reduction in broken percentage of the heat-treated samples may be due to the parboiling effect, which partially gelatinized the starch granules, cementing the cracked grain and increasing the grain hardness. One potential application of conduction heating is thus using the process as a first- stage for partial drying and sterilization of high moisture rough rice. This approach will not only reduce grain moisture content by 5-6% but also minimizes the broken percentage of milled rice. The whiteness degree of milled rice may also be maintained over 0.75 under the above mentioned time-temperature combinations. In general, selecting the proper time-temperature combination for accelerating drying and sterilization of high moisture rough rice will produce milled rice whiteness comparable to the dried control sample.

4. Thermal efficiency of the full-scale rotary dryer

The experimental data used in the calculation of thermal efficiency of the full-scale rotary dryer operated at a temperature range of 100-150 ^{O}C and exposure time range of 4-8 minutes are summarized in Table 2 and 3. For the grain having 24% initial moisture content, the average thermal efficiency was 69.70% and the corresponding specific energy for drying to remove 1 kg of water from rice grain was 3485.37 kJ. The corresponding average thermal efficiency for rough rice having initial moisture content of 21% was 65.09% and the specifi energy needed to remove 1 kg of water from rice grain was 3734.02 kJ.

CONCLUSION

The experimental procedure using the full-scale conduction heating rotary dryer, proved the applicability of the proposed dryer for accelerated drying and sterilization of high moisture rough rice. The developed rotary dryer showed good mechanical and thermal performance. Milled rice obtained form the heat-treated rough rice showed a definite improvement in its physical quality and milling potential in comparison with the naturally dried rice.

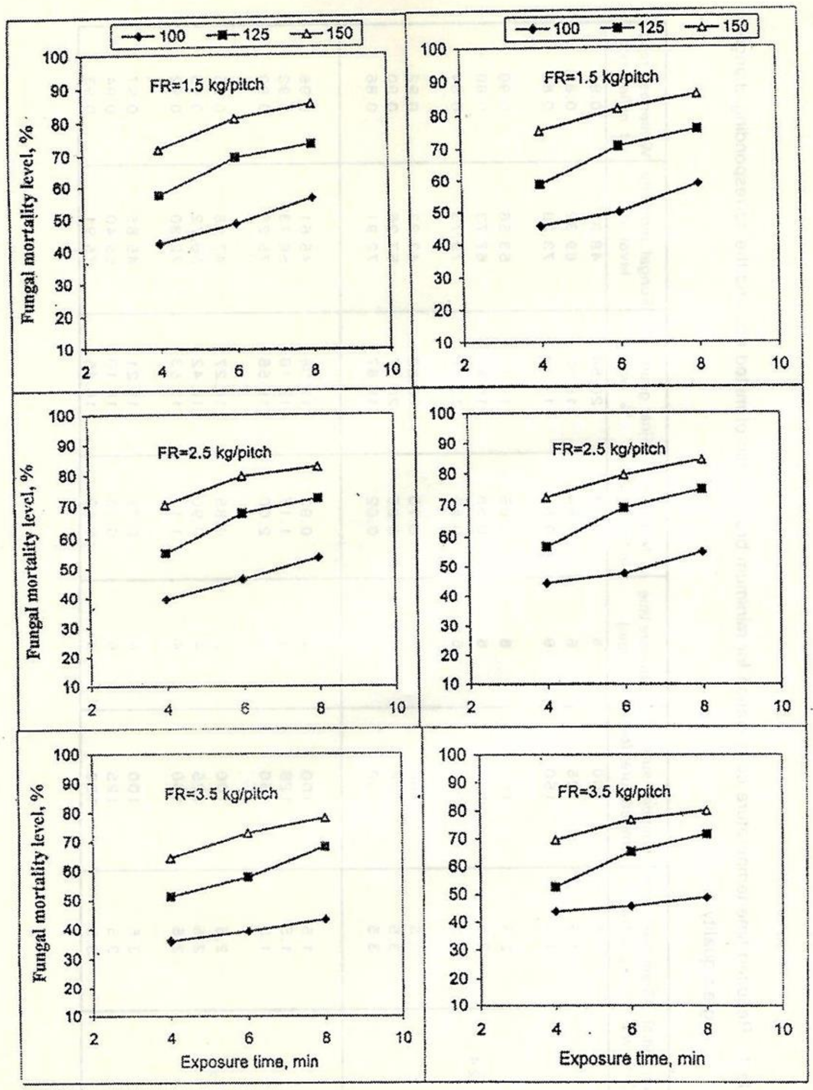


Fig.5. Change in fungal mortality level as related to exposure time using the full-scale conduction heating unit.

Table 1. Required time-temperature combination for minimum broken ratio of milled rice and the corresponding changes in grain quality.

Grain initial M.C. % w.b.	Grain feed rate kg/pitch	Cylinder surface temperature (oC)	Exposure time (min)	Minimum broken ratio	Final grain M.C. % (w.b.)	Fungal mortality level (%)	Whiteness ratio of milled rice
24	1.5	100	6	0.67	20.58	48.32	0.91
	1.5	125	6	0.64	18.59	69.32	0.86
	1.5	150	6	0.63	17.39	73.23	0.82
	2.5	100	8	0.65	19.15	53.56	0.90
	2.5	125	6	0.58	18.93	67.73	0.80
	2.5	150	6	0.54	18.16	79.73	0.84
	3.5	100	8	0.70	20.58	43.23	0.92
	3.5	125	6	0.65	20.37	57.26	0.90
	3.5	150	6	0.62	19.87	72.91	0.86
21	1.5	100	4	0.93	17.58	45.61	0.96
	1.5	125	4	1.17	17.18	58.73	0.92
	1.5	150	4	2.00	16.56	75.28	0.90
	2.5	100	6	0.85	18.27	47.58	0.95
	2.5	125	4	0.90	18.42	56.72	0.93
	2.5	150	4	1.17	17.63	72.30	0.92
	3.5	100	6	0.78	19.21	45.85	0.97
	3.5	125	6	0.73	18.10	65.40	0.94
	3.5	150	4	0.69	18.45	76.91	0.93

Table 2. Performance data for thermal efficiency calculation of the full scale rotary dryer for (Initial m.c. = 24.39% w.b., feed rate = 2.5 kg/pitch).

Cylinder surface temp. (°C)	Exposure time (min.)	Hold up (kg)	Final m.c. (%w.b.)	Loss in water (kg)	Energy used in water evaporation (kJ)	Input energy (kJ)	Thermal Eff. (%)	Specific energy kJ/kg
100	4	75	21.30	2.94	7220.64	11382.46	63.43	151.76
100	6	75	20.63	3.57	8767.92	13303.69	65.90	177.38
100	8	75	19.15	4.86	11936.16	16994.92	70.23	226.59
125	4	75	20.68	3.50	8596.00	12615.46	68.14	168.20
125	6	75	19.13	4.87	11936.16	17023.69	70.11	226.98
125	8	75	17.76	6.04	14834.24	20564.92	72.13	274.19
150	4	75	19.89	4.30	10560.80	14982.46	70.48	199.76
150	6	75	18.16	5.70	13999.20	19253.69	72.71	256.71
150	8	75	16.58	6.86	16840.16	22564.92	74.09	300.96

Table 3. Performance data for thermal efficiency calculation of the full scale rotary dryer (Initial m.c. =21.62% w.b., feed rate = 3.5 kg/pitch).

Cylinder surface temp. (°C)	Exposure time (min.)	Hold up (kg)	Final m.c. (%w.b.)	Loss in water (kg)	Energy used in water evaporation (kJ)	Input energy (kJ)	Thermal Eff. (%)	Specific energy kJ/kg
100	4	105	19.63	2.59	6361.04	11421.62	55.69	108.77
100	6	105	18.81	3.63	8915.28	14516.12	61.41	138.24
100	8	105	17.90	4.75	11666.00	17512.37	65.49	169.64
125	4	105	18.69	3.78	9283.68	14722.1	63.06	140.21
125	6	105	18.10	4.51	11076.56	17123.15	64.68	163.07
125	8	105	17.16	5.29	12992.92	19779.21	65.68	188.37
150	4	105	18.25	4.32	10609.92	15818.1	67.07	150.64
150	6	105	17.21	5.59	13729.04	19571.2	70.15	186.39
150	8	105	16.23	6.75	16578.00	22816.97	72.65	217.30

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تطوير نموذج كامل لمجفف دورانى يعمل بخاصية التوصيل الحرارى لغرض التجفيف السريع والتعقيم لمحصول الأرز ذو المحتوى الرطوبى المرتفع

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٣ باحث - بمعهد بحوث الهندسة الزراعية

أجريت هذه الدراسة لغرض تطوير وتصنيع نموذج كامل لمجفف دورانى يعمل بخاصية التوصيل الحرارى المباشر وتصل سعته الإنتاجية إلى حوالى ١ - ١,٥ طن / ساعة من الأرز ذو المحتوى الرطوبى المرتفع (٢١ - ٢٤ ٪ على الأساس الرطب). وتم إجراء مجموعة من التجارب المعملية والحقلية أظهرت إمكانية استخدام المجفف المقترح فى عملية التجفيف الجزئى السريع والتعقيم لمحصول الأرز ذو المحتوى الرطوبى المرتفع بالإضافة إلى إرتفاع الكفاءة الميكانية والحرارية للمجفف. أوضحت نتائج إختبارات الجودة للحبوب المجففة وصول نسبة قتل الفطريات الموجودة على سطح الحبة إلى حوالى ٧٥ - ٨٠ ٪ بالإضافة إلى انخفاض نسبة الحبوب المتشققة وزيادة درجة صلابة الحبوب مما أدى إلى انخفاض نسبة الكسر فى الحبوب إلى حوالى ٣٠ - ٣٥٪ بالمقاربة بالحبوب المجففة بالطريقة التقليدية .

كان متوسط الكفاءة الحرارية للمجفف حوالى ٦٨,٥٪ وكمية الطاقة اللازمة لإزالة ١ كجم من الماء من الأرز حوالى ٣٦٨١,٦٩ كليو جول وبصفة عامة أظهر المجفف خواص ميكانيكية وحرارية مقبولة من الناحية العملية .