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HEAT STERILIZATION AND ACCELERATED DRYING OF HIGH MOISTURE RICE FOR SAFE STORAGE

First progress report for the
period ending December 31, 1984

Submitted by
Dr. V.K. Jindal, Principal Investigator
Mr. L.G. Obaldo, Research Associate

Division of Agricultural & Food Engineering
Asian Institute of Technology
P.O. Box 2754
Bangkok, Thailand

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HEAT STERILIZATION AND ACCELERATED DRYING OF HIGH MOISTURE RICE FOR SAFE STORAGE

Summary

Preliminary tests on high-temperature short-time heating of freshly harvested rice having a moisture content of 20% w.b. were carried out in a laboratory oven at 80, 100, 120 and 140 °C. The results of heat treatment experiment have indicated that (i) fungal activity could be suppressed by appropriate heat treatment; (ii) hot air oven is not suitable for heat treatments due to time-lag in raising the grain temperature; (iii) cooling of grain samples following the heat treatment may play an important role in affecting the physical quality of grains and (iv) heat treatment may drastically reduce the germination percentage of the grain. Detailed experiments need to be carried out in a specially designed rotary heating unit to establish the guidelines for arresting the fungal invasion in high moisture rice in terms of grain moisture content, temperature and the exposure time. Consequently, several designs of rotary conduction heating units were considered. The design details of a rice-husk-fired conduction heating and cooling unit have been finalized.

I. GENERAL

The three experiments proposed in the project have been scheduled as follows:

Experiment 1 - Quality effects of HTST exposure of high moisture rice, August 1984 to July 1985

Experiment 2 - Heat sterilization and accelerated drying of high moisture rice in rotary conduction dryers, August 1985 to July 1986

Experiment 3 - Conduction versus fluidized-bed heating and economic feasibility, August 1985 to February 1987

For the period from June to December 1984 in Experiment 1, preliminary tests on the quality effects of HTST heating of wet rice were carried out using a standard laboratory oven. In addition, several designs of a rotary conduction heating unit were considered until a relatively acceptable design was finalized and completed. The proposed design is shown in Figure 1 and is now ready for fabrication.

II. APPOINTMENT OF PERSONNEL

Mr. L.G. Obaldo, who obtained his M.Eng. in 1983 from the Asian Institute of Technology, Bangkok, was appointed as a Research Associate effective August 1, 1984 to work full-time on the project. A technician will shortly be joining to assist in fabrication work. In addition, a laboratory helper has been working on temporary basis.

III. EQUIPMENT PROCUREMENT

There are obvious equipment needs but their availability and costs in Bangkok have been somewhat prohibitive. More information is being secured in order to enable direct ordering from abroad.

IV. DESIGN OF ROTARY CONDUCTION HEATING AND COOLING UNITS

The result of preliminary heating experiments based on a laboratory oven necessitated the incorporation of a suitably designed cooling units. As a matter of fact, cooling considerations were overlooked while proposing original designs. The design details have been completed and the fabrication work would commence soon.

V. PRELIMINARY HEAT TREATMENT EXPERIMENT AND DATA COLLECTION

A standard laboratory oven was used and tested for HTST heating of wet paddy. Prior to the actual heating experiment, the time required by the grain samples to reach the desired sterilization temperature was determined and established at any given oven air temperature. One variety (RD-23) of rice was used at 20% moisture content, wet basis. This was the highest moisture content of available fresh paddy during the period of study. Four heat treatments studied were based on 4 fixed combinations of exposure temperature (80, 100, 120 and 140 ^{o}C) and corresponding time (15, 25, 40 and 65 min) in succession to match the limited capacity of the oven. However, two modes of cooling were established, namely: rapid and slow cooling. Rapid cooling was done immediately after heat treatment by spreading the paddy samples on the floor using a nylon mat until grain temperature has cooled down to room condition. Slow cooling on the other hand, was done by holding the samples for some time to sustain heat for further sterilization and then cooled as in the former. The temperature and time combinations representing heating and modes of cooling are shown in Figure 2.

The treated samples including control were stored for 1, 3, 5, 7, 14 and 21 days in plastic buckets covered with perforated aluminum foil prior to quality assessment. Five quality indices were used to evaluate the combined effects of heating and cooling treatments upon the storage of wet paddy. A brief description of each quality measure is presented in the following sections.

Fungi Enumeration by Direct Plating Method

Direct plating was preselected over the dilution method because of its simplicity. In this method potato dextrose agar and malt salt agar were used as media for enumerating field and storage fungi that are either hydrophilic, mesophilic or xerophilic. Agar, petri dish and other materials were prepared and conditioned following standard laboratory procedure. Eight kernels of conditioned paddy samples were plated equidistantly into each petri dish containing sterilized malt salt and potato dextrose agar. Plated samples were incubated immediately at 25 and 37 ^{o}C for four and seven days, respectively. Fungal growth was examined and evaluated by identifying the color of colony and counting the number of infected kernels in each petri dish.

Color of Substrate

Color of samples as a measure of fungal invasion in wet paddy was evaluated using a superscan UV-visible spectrophotometer in terms of % transmittance or absorbance level. Solutions were prepared by extracting surface molds from a 20 g paddy sample using 30 ml normal saline solution with the aid of a shaker operated for 10 minutes at 100 cycles per minute. Resulting solution was filtered and stored in test tubes and further transferred into the cuvettes for scanning at 350 nm wavelength setting. UV spectrophotometer was operated after calibrating the solution and proper wavelength setting had been attained. Resulting percent transmittance and absorbance readings were recorded and evaluated.

Germination Test

Treated samples and control stored for six different time intervals were spread on the floor and allowed to dry under room condition to a uniform moisture content of 14%, wet basis before testing. Germination tests were replicated twice by growing 100 paddy kernels at room temperature in each petri dish containing frequently moistened filter paper. Samples were examined after one week and paddy kernels having both roots and shoots were considered germinated. The results were expressed in percentage germination.

Milling Test

Milling tests were run using standard laboratory equipment. Prior to milling, paddy samples were conditioned into 14% w.b. in a similar manner. A 125 g paddy sample was passed once through a rubber roll testing husker. The resulting brown rice was whitened for one minute using a laboratory testing mill. After weighing the milled rice, a laboratory grader was used to separate head rice from brokens. Both percent milled and head rice yields were calculated on the basis of 125 g paddy sample.

Temperature Rise

Temperature rise as a measure of quality depends upon the presence of fungi and their activity that builds up heat during storage. Samples were prepared and stored in plastic buckets immediately after heating and cooling treatment. Two sets of samples were prepared and covered with aluminum foil. One set was provided with plastic tube and perforated plate bed for grain aeration. Alcohol-glass-in thermometers were used to monitor daily temperature of the grain for 21 days at a fixed time.

VI. RESULTS AND DISCUSSION

The results of HTST heating upon the quality of wet rice are presented in Tables 1 to 5. These are briefly described in the following sections.

Fungi Enumeration by Direct Plating

Growth of field and storage fungi on grains sterilized at 120 and 140 ^{o}C for both cooling treatments was significantly suppressed for a period of 5 and 7 storage days, respectively. This was indicated in both media but malt salt agar appeared to be more effective.

Slow cooling indicated slight advantage over rapid cooling in arresting fungal growth at grain temperature levels of 120 and 140 °C. This may be attributed to the extended holding time during slow cooling.

The number of infected kernels at higher grain temperature levels showed inconsistent trends with increasing storage time. This observation could be attributed to the localized heating of some paddy grains in the standard laboratory oven. Hence, HTST heater should be provided with a stirring mechanism to apply heat uniformly during the sterilization process.

The color of fungi growing in both media is shown in Table 1. Identification of fungi by color of colony was not possible and thus proved to be of no practical significance.

Color Analysis

Color assessment of the substrate in terms of percent transmittance or absorbance level obtained through the use of UV spectrophotometer did not show any trend with regard to heating, cooling and storage treatments on wet paddy samples (Table 2).

Fungi infected grains are expected to show lower percent transmittance or higher absorbance level than their non-infected counterpart such as grains sterilized at 140 °C. However, insignificant fungal growth did not result in marked differences in transmittance or absorbance values. Therefore, the results from color assessment of the substrate may prove to be of limited use at low levels of fungal invasion.

Germination Percentage

Percentage germination of conditioned paddy samples was significantly reduced by heating treatments. This was absolutely clear for samples heated to 120 and 140° showing no germination at all (Table 3).

Samples subjected to slow cooling showed higher germination percentage than grains subjected to rapid cooling during subsequent storage.

No distinct reduction in percentage germination was observed for heat treated paddy samples with increasing storage time. However, a slight reduction in germination rate of the control was noticed with an increase in storage period. This was perhaps caused by increased fungal activity during the storage.

Milling Yield

Percent milling recovery and head rice yield of conditioned paddy samples are presented in Table 4. It may be noticed that heating treatment significantly reduced the head rice yield. This reduction was more pronounced for grain samples heated to 100, 120 and 140 °C at all levels of storage time. However, significant differences in percent milling recovery were observed only for grain samples heated to 120 and 140 °C.

Heated paddy samples subjected to slow cooling comparatively yielded higher percent head rice at almost all levels of storage time than samples subjected to rapid cooling.

Level of storage time did not appear to influence distinctly milling recovery and head rice yield of heat teated paddy samples. This suggested that at all levels of storage time fungal suppression was not complete. From milling point of view, lower heating temperatures should prove to be preferable.

Temperature Rise

No specific trends in temperature rise were observed in heat treated samples and control. This may be attributed to the frequent heat removal from the samples during storage and the low levels of fungal activity.

Perhaps the storage of samples in insulated containers and more accurate measurement of temperature could reflect on the generation of respiration heat due to the grain and fungi.

1	Rice husk hopper	6	Rotary dryer
2	Furnace	7	Perforated rotary cooler
2a	Adj. inclined grate	8	Electric motor
2b	Adj. ash trap	9	Chain drive
2c	Ash collector	10	Ball bearing
2d	Brick wall	11	Paddy outlet guide
2e	Husk flow equalizer	12	Angle bar frame
3	Paddy inlet hopper	13	Helical baffles
4	Electro-magnet vibrator	14	Chimney
5	Dryer brick housing	15	Flange joint

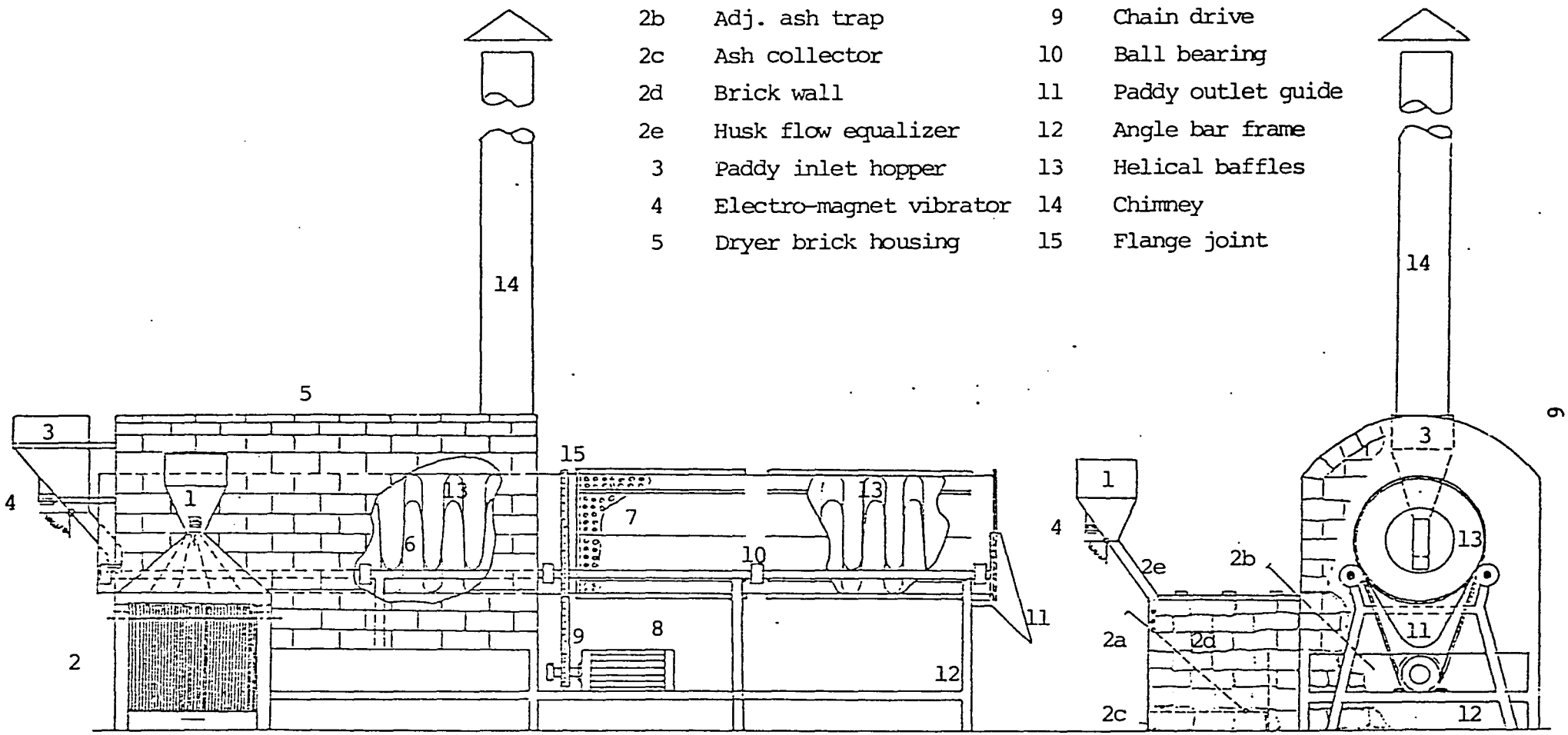

Figure 1 Schematic diagram of rotary dryer and cooler

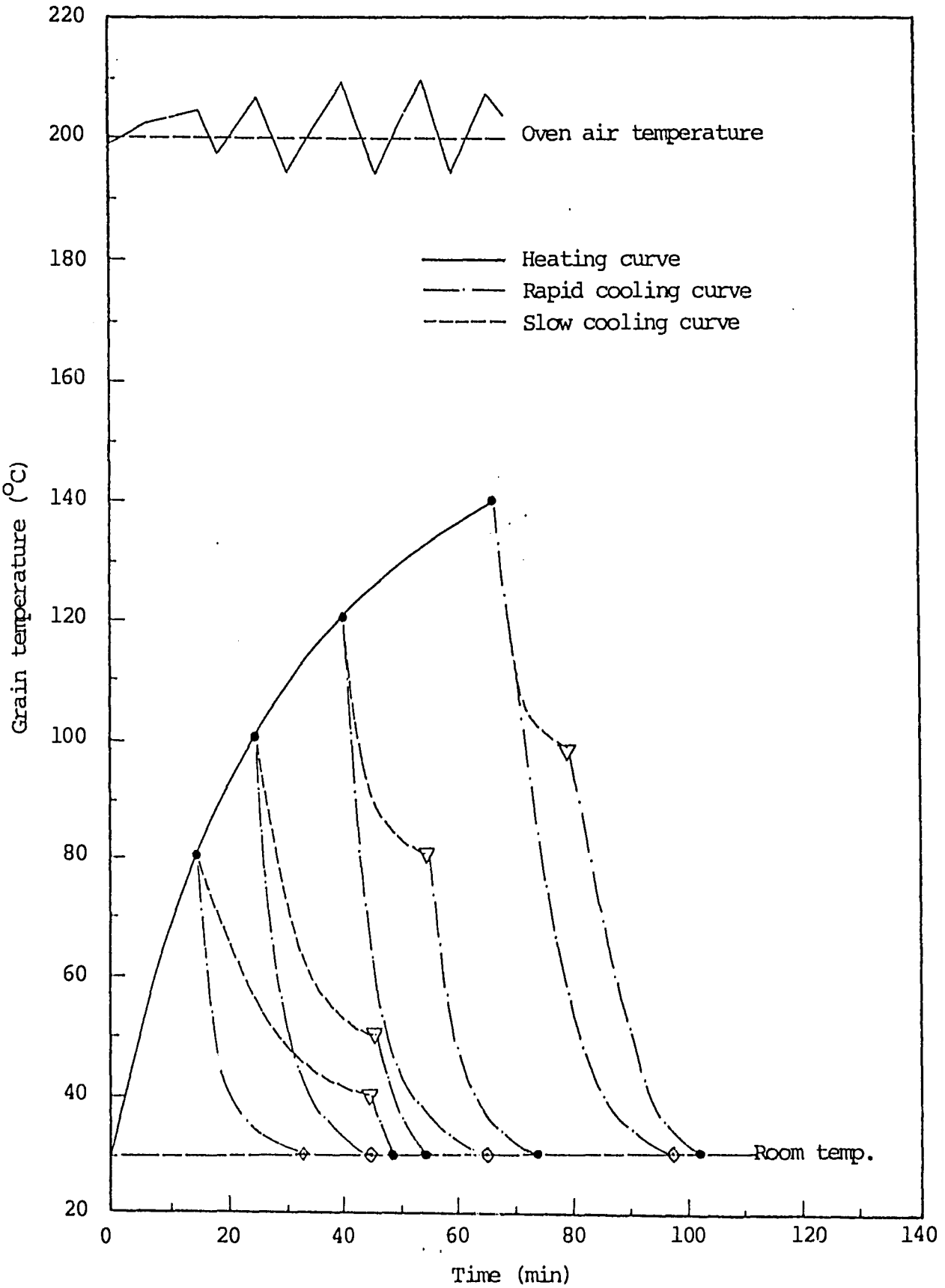

Figure 2 Heating and cooling treatments of wet paddy

Table 1 Fungi enumeration by direct plating method using malt salt and potato dextrose agar

Medium/storage period/color	Control	Grain temperature, °C							
		80		100		120		140	
		R	S	R	S	R	S	R	S
I. Malt Salt Agar									
Ia. No. of grains infected after storage time of									
1 day	8	8	8	4	5	2	0	0	0
3 days	8	8	8	4	8	1	1	1	0
5 days	8	8	8	8	8	6	3	2	1
7 days	8	8	8	8	8	7	1	1	0
14 days	8	8	8	8	8	8	5	1	1
21 days	8	8	8	8	8	8	2	1	0
Ib. Color of fungi growing	Black Brown Yellow White Green Silver	Black Brown Yellow White Green Silver		Black Brown Yellow White Green Silver		Black Brown Yellow White Green Silver		Green White Blue Brown	
II. Potato Dextrose Agar									
IIa. No. of grains infected after storage time of									
1 day	8	8	8	7	8	3	1	0	2
3 days	8	8	8	7	8	6	3	2	3
5 days	8	8	8	8	8	7	8	6	6
7 days	8	8	8	8	8	8	6	8	4
14 days	8	8	8	8	8	8	8	8	8
21 days	8	8	8	8	8	8	8	8	1
IIb. Color of fungi growing	Black Brown Yellow White Green Pink	Black Brown Yellow White Green Pink		Black Brown Yellow White Green Pink		Black Brown Yellow White Green Pink		Black Brown Yellow White Green Pink	

R Rapid cooling
S Slow cooling

Table 2 Color of paddy samples based on percent transmittance and absorbance level indicated on UV spectrophotometer

Color criteria	Control	Grain temperature, °C							
		80		100		120		140	
		R	S	R	S	R	S	R	S
1. % Transmittance after storage period of									
1 day	38.8	48.3	48.6	46.6	50.9	34.8	45.5	44.1	45.8
3 days	46.3	43.7	47.8	49.9	48.0	46.5	48.1	49.0	47.1
5 days	43.3	50.0	48.8	51.2	53.4	50.8	45.1	43.4	46.1
7 days	41.2	35.8	35.2	44.0	43.5	43.6	41.2	33.1	37.4
14 days	53.2	47.0	50.3	49.3	52.8	54.6	56.8	48.1	51.7
21 days	51.7	51.3	53.4	54.3	59.5	56.2	56.5	50.9	51.7
2. Color absorbance after storage period of									
1 day	0.41	0.32	0.31	0.33	0.29	0.46	0.34	0.36	0.34
3 days	0.34	0.36	0.32	0.30	0.32	0.33	0.32	0.31	0.33
5 days	0.37	0.30	0.31	0.29	0.28	0.30	0.35	0.37	0.34
7 days	0.39	0.45	0.46	0.36	0.36	0.36	0.39	0.48	0.43
14 days	0.28	0.33	0.30	0.31	0.28	0.27	0.25	0.32	0.29
21 days	0.29	0.29	0.27	0.27	0.23	0.25	0.25	0.30	0.29

R Rapid cooling
S Slow cooling

Table 3 Percentage germination of heat-treated paddy samples during storage

Storage time	Control	Grain temperature, °C							
		80		100		120		140	
		R	S	R	S	R	S	R	S
a. 1 day									
r1	85	62	69	29	32	0	0	0	0
r2	85	58	58	25	32	0	0	0	0
average	85	60	63.5	27	32	0	0	0	0
b. 3 days									
r1	85	57	60	30	39	0	0	0	0
r2	83	50	55	28	31	0	0	0	0
average	84	53.5	62.5	29	35	0	0	0	0
c. 5 days									
r1	82	61	64	25	36	0	0	0	0
r2	76	58	59	23	35	0	0	0	0
average	79	59.5	61.5	24	35.5	0	0	0	0
d. 7 days									
r1	81	63	66	22	40	0	0	0	0
r2	75	59	75	24	35	0	0	0	0
average	78	61	70.5	23	37.5	0	0	0	0
e. 14 days									
r1	80	57	64	22	40	0	0	0	0
r2	73	64	63	17	29	0	0	0	0
average	76	60.5	63.5	19.5	34.5	0	0	0	0
f. 21 days									
r1	75	60	72	20	29	0	0	0	0
r2	73	58	69	31	43	0	0	0	0
average	74	59	70.5	25.5	36	0	0	0	0

R Rapid cooling
S Slow cooling

Table 4 Percent milling recovery and head rice yield of heat treated paddy samples during storage

Storage time	Control	Grain temperature, °C							
		80		100		120		140	
		R	S	R	S	R	S	R	S
a. 1 day									
Milling recovery, %	67.1	65.6	67.7	64.8	66.1	64.2	63.7	64.1	65.0
Head rice, %	48.3	48.6	50.8	46.4	47.8	44.1	45.8	42.0	43.8
b. 3 days									
Milling recovery, %	66.4	65.8	67.0	64.7	66.3	65.7	63.7	62.8	65.7
Head rice, %	49.3	48.0	52.6	45.6	48.4	45.1	46.1	42.9	44.7
c. 5 days									
Milling recovery, %	66.3	65.1	66.5	64.4	66.0	65.7	63.8	63.1	65.4
Head rice, %	48.6	47.9	49.7	46.4	46.6	45.5	47.2	42.7	44.7
d. 7 days									
Milling recovery, %	65.2	65.1	66.6	64.2	66.2	65.7	63.8	63.5	65.2
Head rice, %	49.2	47.4	50.9	46.0	47.2	45.8	45.2	43.2	45.0
e. 14 days									
Milling recovery, %	66.1	65.3	66.1	63.5	65.7	64.9	63.5	63.0	65.1
Head rice, %	48.8	49.2	49.3	47.5	46.7	46.5	45.4	42.4	45.8
f. 21 days									
Milling recovery, %	66.0	65.2	65.7	64.0	64.9	65.3	63.7	63.4	64.6
Head rice, %	48.3	47.7	49.5	46.1	46.0	45.8	47.4	43.7	45.2

R Rapid cooling
S Slow cooling

Table 5 Temperature history of heat-treated paddy samples during storage

Storage time (day)	Control	Grain temperature, °C								Room temp., °C
		80		100		120		140		
		a	b	a	b	a	b	a	b	
1	27.8	28	27.8	28	28	28	28	28	28.5	28
3	27.8	28	27.8	28	28	28	28	28	28.5	28
5	27.8	28	27.8	28	28	28	28	28	28.5	28.1
7	28.8	28.8	28.8	28.8	28	28.8	28	29.3	28.6	29.8
9	28.8	28.8	28.8	28.8	28	28.8	28	29.3	28.6	29.9
11	28.9	28.9	28.8	29	28	29	28	29.3	28.6	30
13	29	29	29	29	28	29.3	28.2	29.4	28.8	30
15	28.4	28.5	28.5	28.2	27.8	28.7	27.9	28.4	28	29
17	28	28	28	27.8	27.2	28	27.2	27.9	27.5	28.6
19	28.6	29	28.9	28.9	28	29.3	28.2	29.3	28.5	30.3
21	28.3	28.4	28.3	28.2	27.7	28.5	27.6	28.2	28.1	29

a Treated grains with aeration tube and plate
b Treated grains with no aeration mechanism

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HEAT STERILIZATION AND ACCELERATED DRYING OF HIGH MOISTURE RICE FOR SAFE STORAGE

Second progress report for the

period ending June 30, 1985

Submitted by

Dr. V. K. Jindal, Principal Investigator

Mr. L. G. Obaldo, Research Associate

Division of Agricultural and Food Engineering

Asian Institute of Technology

G.P.O. Box 2754

Bangkok, Thailand

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HEAT STERILIZATION AND ACCELERATED DRYING OF HIGH MOISTURE RICE FOR SAFE STORAGE

SUMMARY

Preliminary experiments on heat treatments and rapid drying of wet rice were carried out using the newly-fabricated rotary dryer prototype. System performance test of the prototype indicated that heating and drying employing conducted heat at very high temperatures (greater than 100°C) coupled with ambient air rotary cooling are practically feasible. Initial experiments on the rotary dryer have shown that (i) milling performance of high moisture rice could be improved by suitable heating, cooling and agitation treatments; (ii) high temperature heating and drying at short exposure time significantly induced loss of seed viability; (iii) rotary cooling with ambient air immediately after heating and drying treatments may play an important role in maintaining the physical quality of the grains; and, (iv) high temperature conduction heating and drying of high moisture rice may not only shortened the processing time but also improve the head rice yield due to induced parboiling effect. Detailed experiments need to be carried out to verify initial results and to establish guidelines for rapid drying and arresting fungal invasion in wet paddy in terms of grain moisture content, heating surface temperature, grain exposure time and grain agitation speed.

Research work on other heating and drying methods is also currently investigated and monitored to check and identify which technique may give a comparable and feasible alternative to rotary conduction heating, drying and cooling. Researches in progress include (i) heat treatment of wet paddy for temporary storage using a batch type rotary heater and microwave oven; (ii) characterization of fungal invasion in paddy; and, (iii) performance of a natural convection rotary dryer. Results of these researches are expected to be included in the 3rd progress report ending December 31, 1985.

I. GENERAL

For the period from January to June 1985, preparation and procurement of equipment, instruments and materials needed in the construction of project's working shed and fabrication of the rotary dryer prototype were successfully implemented. Immediately after completion of the prototype overall performance of the system was evaluated and preliminary test on the quality effects of high temperature short time (HTST) heating and drying of rewetted paddy followed by a rotary cooling with ambient air was carried out.

II. EQUIPMENT PROCUREMENT AND SITE PREPARATION

A one kilowatt electric motor with variable speed gear reduction ranging from 18 to 92 rpm was purchased to serve as prime mover of the rotary dryer. Recently, another electric motor (0.75 kw) with electrically controlled speed setting was obtained to serve as drive mechanism for a batch type rotary cooler. Requisition of basic instruments such as infrared thermometer, analog temperature controller, digital moisture meter, digital carbon dioxide analyzer, etc. intended for accurate data gathering and performance evaluation of the prototype is in progress and hope to be acquired very soon.

A working shed having a floor area of 96 sq m was constructed in front of the AIT Regional Experimental Center for housing the experimental prototype

and similar units including tools and equipment required in operating and maintaining the project (Fig. 1). Also, it provides a working space needed in conducting research studies and performing related works geared towards the attainment of the objectives of the project.

III. PERFORMANCE OF THE ROTARY DRYER

The rotary dryer was basically designed for sterilization and accelerated drying of high moisture rice for temporary and long term storage, respectively. The prototype is a continuous-indirect type rotary dryer employing conducted heat in effecting moisture removal from the grains. This type of dryer is suitable for heating, drying and cooling at wide ranges of temperature and at relatively low operating cost. It can provide heating and drying temperature up to 300°C and paddy capacities varying from several kilograms to hundreds per hour. The energy required to operate the dryer is supplied jointly by rice husk and electricity. The specific power required to propel the rotary heater and cooler could be determined from the following equation:

$$\text{Power (kw)} = 4.5 \times 10^{-4}\ Wv + 1.2 \times 10^{-4}\ BDfN$$

where: W = total weight of rotating parts of the prototype, kg
v = peripheral speed of carrying rollers, m/s
B = paddy hold-up in rotary heat exchanger, kg
D = diameter of rotary heat exchanger, m
f = average number of lifts, flight per rev.
N = speed of rotation of heat exchanger, rpm

The rotary heater and cooler is a continuous-mixing type heat exchanger in which the wet grains are frequently mixed by its rotation and helical baffles. The wet paddy either tumbles or rolls down through the heat exchanger surface and it gets heated and cooled while grains are conveyed to the other end until finally discharged into a grain container.

The rotary dryer prototype is presented in Figure 2. It consists mainly of a paddy feeder, rotary heater, rotary cooler, furnace, flue gas chamber, rockbed heat storage and chimney. A detailed description and performance of each part is discussed in the following sections.

Paddy Feeder

The paddy feeder has a capacity of 20 kg per batch. The feeder assembly consists of an electromagnet serving as a vibrator to regulate and maintain a desired feed rate, a hopper for loading the wet paddy, and a spout for feeding the grain into the dryer (Fig. 3). Paddy feed rate could be regulated manually by simply adjusting the rotary feeding gate attached to the electromagnet. The feed rates that could be obtained vary from 1 to 45 kg/min.

Rotary Heater

The rotary heater is basically a cylinder serving as a heat exchanger for conduction heating and drying wet paddy (Fig. 4). It has an internal helical flights welded inside the wall of the cylinder, machined girth sprocket ring

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and chain drive assembly powered by an electric motor with variable speed, flat bar girth rings riding on heavy duty ball bearings, a discharge spout and chute from which heated or dried grains are unloaded.

The horizontal travel of the wet grains in the heat exchanger is effected by the helical flights. As the heat exchanger rotates, these flights push and convey the wet paddy causing them to slide, roll or tumble through the inner wall of the hot cylinder. The helical flights actually serve as an additional heating surface aside from providing grain agitation and transport. The rotation speed could be varied from 1 to 45 rpm by regulating the speed control of the one kilowatt electric motor.

Rotary Cooler

The rotary cooler is made of a similar cylinder with 1.5 mm perforations all throughout its periphery and length (Fig. 5). The perforations serve as inlet or outlet for ambient air desired for cooling the grains. The cooling section has internal helical flights exactly similar to the rotary heater where it is directly attached by a flange joint. This section provides cooling of hot grains immediately after heating or drying. However, if rotary cooling with ambient air is not desired, a discharge spout (10 x 20 cm) and chute assembly is provided beneath the lower end of the rotary heater section for unloading or discharging heated paddy for subsequent cooling treatment by other methods. The rotary cooler is actually a detachable unit and could be intentionally disconnected if continuous heating and drying experiments are desired. Cooling speed ranging from 1 to 45 rpm could be regulated by adjusting the speed control of the same electric motor used for the rotary heater.

Furnace

The furnace is the main heat source of the rotary heater (Fig. 6). It is fueled by a rice husk with a maximum furnace temperature of 800°C attainable at about 30 kg/hr feed rate. The furnace is made of hollow bricks and consists of a hopper, husk feeder, husk flow equalizer, inclined fire grate, ash dropper and ash collector. The husk feeder is of vibrating type which was designed and fabricated to facilitate uniform feed rate. The husk flow equalizer regulates even distribution of the husk as it drops down to the inclined grate. The inclined grate is built up to 110 rows of sloping and horizontal fire bars. This is the main part of the furnace that is used for firing rice husk. The husk feed rate ranging from 5 to 30 kg/hr could be regulated manually by adjusting the rotary feeding gate attached to the electromagnet or by on/off swicth mechanism directly attached to a temperature controller.

In operating the furnace, rice husk is loaded into the fuel hopper and fed into the furnace through a vibrating gate and husk flow equalizer directly connected above the fire grate. Priming the furnace is simply done by burning scratch papers or spraying small amounts of kerosene or gas just enough to establish initial burning of the rice husk. As the husk burns and ash is removed (from the lower horizontal row of the fire bars), new portions of rice husk drop from the fuel hopper and move along the inclined fire grate by gravity. Firing of the furnace can be done intermittently or continuously depending upon the duration of heat exchanger surface temperature desired for heating and drying. In this type of furnace, the three stages of combustion

are separated in space: thermal preparation of fuel occurs on the top section of the furnace; combustion of rice husk takes place in the middle section; and, aftercombustion products develop at the bottom section. This type of furnace is suitable for firing rice husk and involves less physical effort compared to a manually-operated horizontal fire grate.

Flue Gas Chamber

The flue gas chamber was designed for enclosing the rotary heater and hot gases coming from the rice husk furnace. It sustains a given volume of hot gases required for heating the rotary heat exchanger to a temperature level desired for heating and drying the grains. The walls are mainly made of 12 cm thick hollow bricks strong enough to enclose the protoype and thermally efficient to prevent heat losses due to convection, conduction and radiation. A frame support assembly for the hollow bricks was made of 5 x 5 cm mild steel angle bars and the sealing joints are enclosed with 3 mm mild steel sheet. The chamber bed was made of small rocks with a sloping configuration that induces complete combustion as well as draft of hot gases flowing from the furnace to the chimney.

Rockbed Heat Storage

The rockbed heat storage was purposedly incorporated in the prototype design primarily to help minimize temperature fluctuation of the heat exchanger heating surface. It consists of 8 to 10 cm diameter ordinary rocks with a total volume of 0.5 cu m located just beneath the rotary heater. It absorbs heat coming from the furnace and its sloping surface arrangement induces draft. The highest temperature stored (based on preliminary runs) at the rockbed was recorded at 110°C lasting for at least four hours before it drops gradually into the ambient temperature. The stored heat helps stabilize the desired heating or drying temperature and sustains that temperature at a relatively longer exposure time. In addition, it keeps the system efficient and operating cost reasonably economical.

Chimney

The chimney is the exhaust port of the unused heat by the rotary heater and products of combustion coming from the furnace. The main function of this unit is to establish the minimum draft desired for complete combustion and regulates the flow of hot gases (indirectly desired for heating and drying purposes) by manually adjusting (full open, half open or quarter open) a baffle located at its base. The chimney is made of a 1.5 mm thick mild steel sheet with a diameter and height of 20 and 365 cm, respectively.

IV. PRELIMINARY EXPERIMENT

Heating and Cooling Test

Paddy samples with initial moisture content of 23 percent, wet basis were heat treated at heat exchanger surface temperature of 100, 120, 140 and 160°C, grain agitation speed of 4 rpm and paddy feed rate of 10 kg/min. Heating test was started after setting the desired paddy feed rate, grain agitation speed and after attaining the required heating surface temperature. Cooling test immediately following heating was performed in two modes: rapid and slow cooling. Rapid cooling was conducted at an average cooling rate of 3 °C/min

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using the rotary cooler and a nylon mat for spreading grains until its temperature has cooled down to ambient condition. Slow cooling on the other hand, was done by simply holding the hot grains in plastic buckets to cool gradually at an average rate of 0.3°C/min until grain temperature has reached ambient. The bulk grain temperature and moisture content before and after heating and cooling treatments were measured using thermocouples and Kett moisture meter, respectively. Temperature readings were recorded only when grain temperature has already stabilized. Changes in moisture content were monitored and five moisture readings were taken for each treatment. The moisture content, wet basis was adjusted to standard oven values using a calibration chart established for the meter.

The samples were conditioned at room temperature immediately after completing the treatments to attain a uniform moisture of 14 percent, wet basis prior to milling and germination tests. Milling yields of treated samples including control were determined by following the standard laboratory milling procedure.

Accelerated Drying Test

Preliminary drying test was run at 120 °C heat exchanger surface temperature, 4 rpm grain agitation speed and 10 kg/min paddy feed rate. The technique employed in this study to accelerate drying was a combination of high temperature conduction heating and ambient air rotary cooling at very short exposure time. Initially, about 20 kg of rewetted paddy with moisture content of 25 percent, wet basis was dried using the rotary dryer prototype. Drying was started after setting the desired paddy feed rate, grain agitation speed and after attaining the required heating surface temperature. The same procedure carried out in heating and cooling test was followed in recording grain temperature, measuring grain moisture content, conditioning paddy samples, and conducting germination and milling tests. Paddy samples taken from the same sample lot used in conduction drying were also dried under shade to serve as control.

V. RESULTS AND DISCUSSION

Heat Sterilization

The method of heat sterilization initially tested for arresting fungal invasion in wet paddy consists of a combined conduction heating and cooling treatments at short exposure time in the rotary dryer. Initial findings indicated that heating at 100, 120, 140 and 160°C heat exchanger surface temperatures for an average exposure time of 165 seconds and grain agitation speed of 4 rpm produced a bulk grain temperature of 58, 65, 75 and 80 °C, respectively. Moisture loss due to heating was observed lowest (1 percentage point) at 100°C heating surface temperature and highest (3 percentage points) at 160°C. Cooling treatment immediately followed the heating process and was accomplished in tow modes: rapid and slow. Rapid cooling (3 °C/min) has significantly induced moisture removal in wet grains while slow cooling (0.3 °C/min) did not show any meaningful changes at all (Table 1).

The quality effects of heating and cooling treatments on high moisture rewetted paddy were evaluated in terms of milling quality and percentage germination. Other quality evaluation techniques such as dilution plating, carbon dioxide determination, etc. were not used due to inadequate

instrumentation, time and manpower constraints. However, these techniques will be tested and used for evaluating results of replicated tests and succeeding experiments.

The milling performance of treated paddy samples is presented in Table 2. Both percent milled and head rice yields of heat treated grains were significantly improved by heating and cooling treatments at any given heating surface temperature used in the study. A maximum increase of 5 and 12 percentage points over the control were observed for percent milled rice and percent head rice, respectively. In addition, both yields indicated an increasing trend with increasing heat exchanger surface temperature. Cooling treatment on the other hand, has shown that rapid cooling was favorable for temperatures up to 120 °C while slow cooling was suitable for higher temperatures up to 160°C. These observations reveal that conduction heating in the rotary dryer accompanied by suitable grain agitation speed and cooling treatment at short exposure time can yield a desirable milling quality of the grain. However, a detailed study need to be carried out to investigate and determine the optimum conditions necessary for obtaining the most feasible heating and cooling scheme without any substantial loss in grain qaulity.

The percentage germination of the sterilized wet grains was drastically reduced in all treatments. Only 9 and 6 percent germination were observed for paddy samples heat treated at 100 °C and exposed at rapid and slow cooling, respectively compared to 92 percent for the control. On the other hand, zero germination was observed for grains heat treated at 120, 140, and 160 °C heating surface temperature. This observation indicates that the high temperature heating of wet paddy even for short exposure time can markedly result to loss of grain viability by actually killing the germ. However, rapid cooling seems to be better than slow cooling in conditioning heat treated paddy samples despite the dramatic reduction in grain viability.

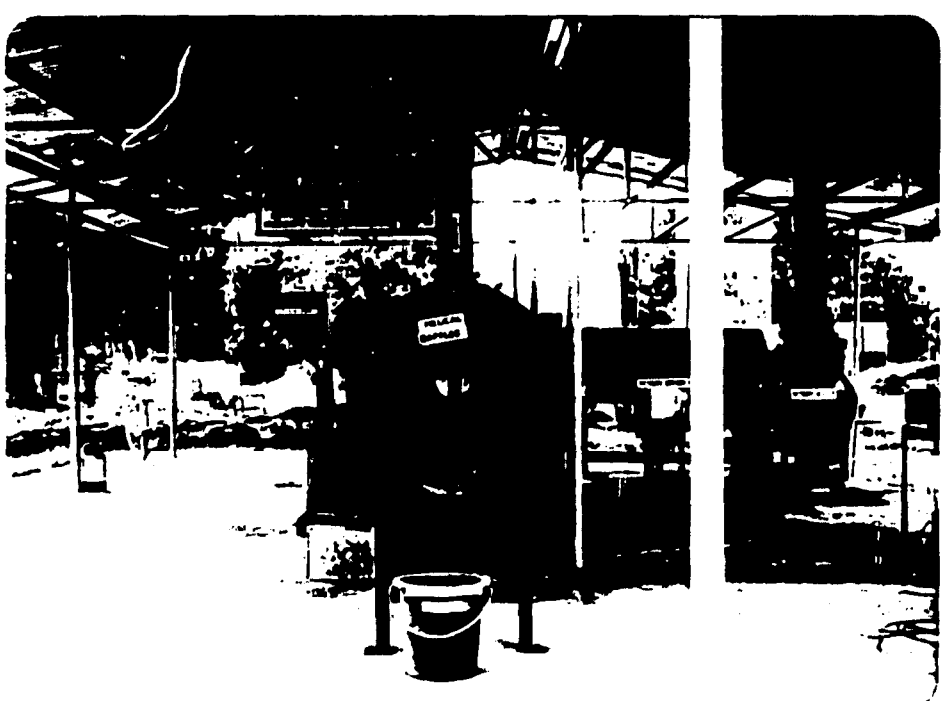
Accelerated Conduction Drying

The conduction drying process designed to accelerate moisture removal of high moisture paddy consisted of high temperature heating and ambient air cooling treatments at short exposure periods in the rotary dryer. Initial drying results revealed that about six continuous heating and cooling cycles at 420 seconds total exposure time per cycle were necessary to reduce the moisture of a 20 kg rewetted paddy sample from 25 to 15 percent, wet basis. Most of the moisture removed from the grains was observed during the cooling treatment and not during heating (Table 3). It could be deduced that during conduction heating while the grains develop a high vapor pressure and give off moisture, the natural convection flow of air may not be sufficient to establish rapid moisture transfer out of the heating cylinder. And hence, most of the moisture is liberated during the subsequent rotary cooling with ambient air. Moisture removal during cooling was observed to be induced by the uniform agitation of the grain. The maximum grain temperature attained at the end of the drying process was 75°C and the average heating and cooling rate of 11 and 12°C/min, respectively can be inferred as one of the suitable conditions for high temperature short time heating and ambient air rotary cooling of high moisture rewetted paddy. Further investigation of these results and detailed experiments need to be done to determine and establish optimum conditions for the most feasible accelerated conduction drying technique for conditioning high moisture grains intended for temporary or long term storage.

The quality effects of accelerated drying treatment on high moisture rewetted paddy were evaluated in terms of milling quality and percentage germination of dried product. Preliminary results indicated that both percent milling yield and percent head rice of dried paddy were significantly higher than the control by an average of 3 percentage points (Table 4). The significant increase in both yields can be attributed to an induced parboiling effect. This was observed to be favorable for high moisture rewetted grains exposed at high heating surface temperature and short exposure time.

The high temperature short time exposure of rewetted paddy for six continuous heating and cooling cycles has dramatically reduced the percentage germination of the grains. A zero germination was observed in all samples compared to 65 percent indicated by the control. This shows that the grain germ was completely destroyed by several exposure cycles and high temperature heating of the grains.

a. Perspective view



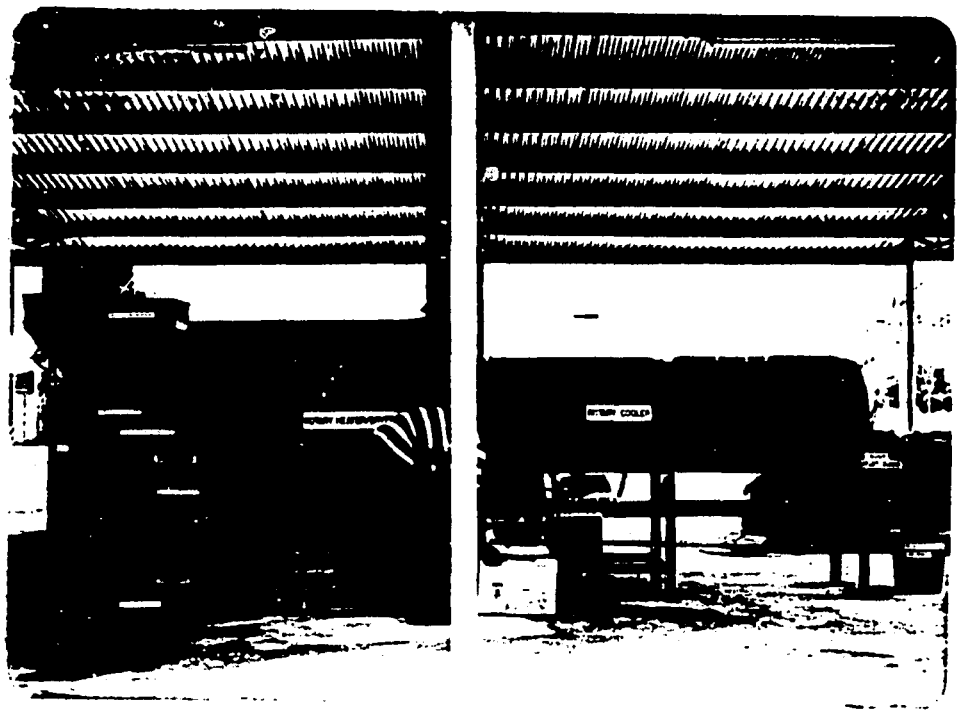
b. Close-up view

Fig. 1. The USAID Dryer Project Working Shed

a. Preparing paddy samples

b. Loading paddy samples at inlet hopper

Fig. 2. The Rotary Dryer



c. Preparing grain container for samples desired immediately after rotary heating

d. Preparing grain container for heated and cooled samples

Fig. 2 The Rotary Dryer

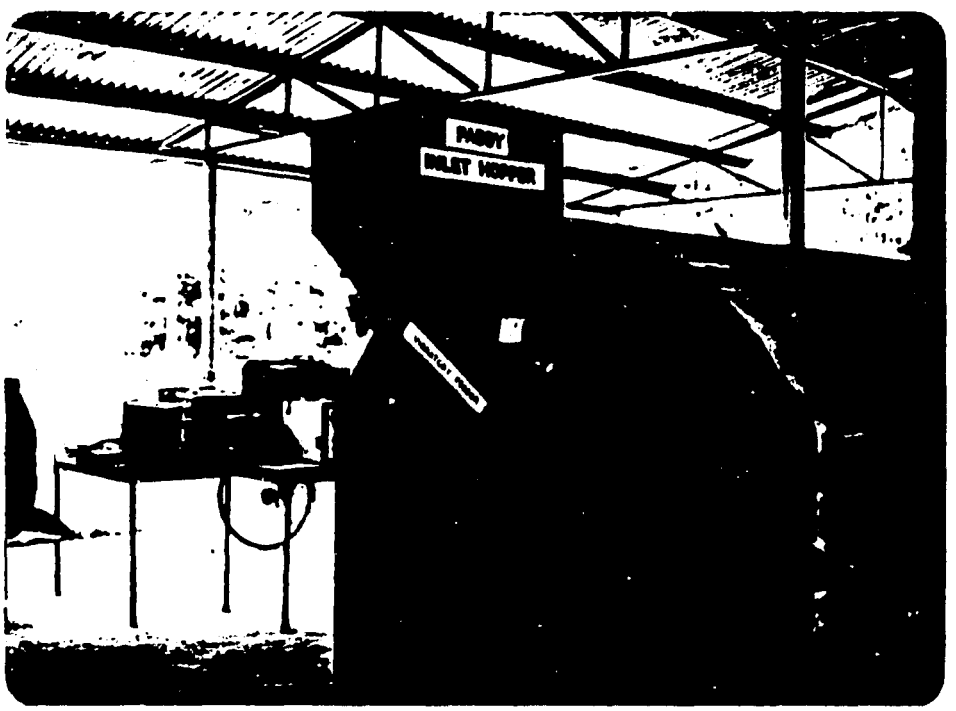


Fig. 3. The Paddy Feeder

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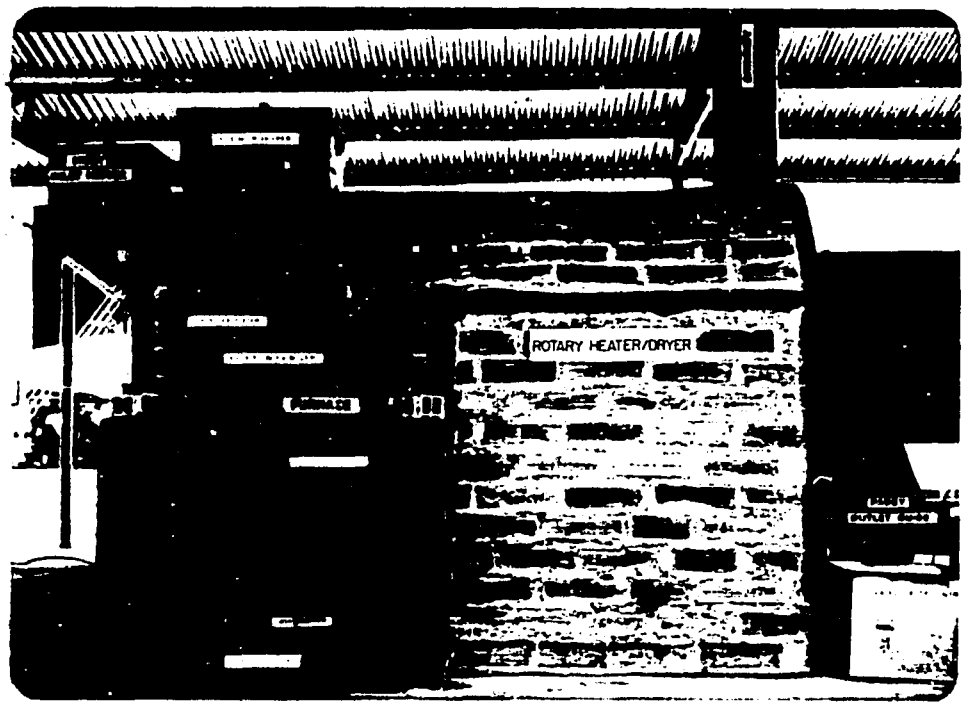
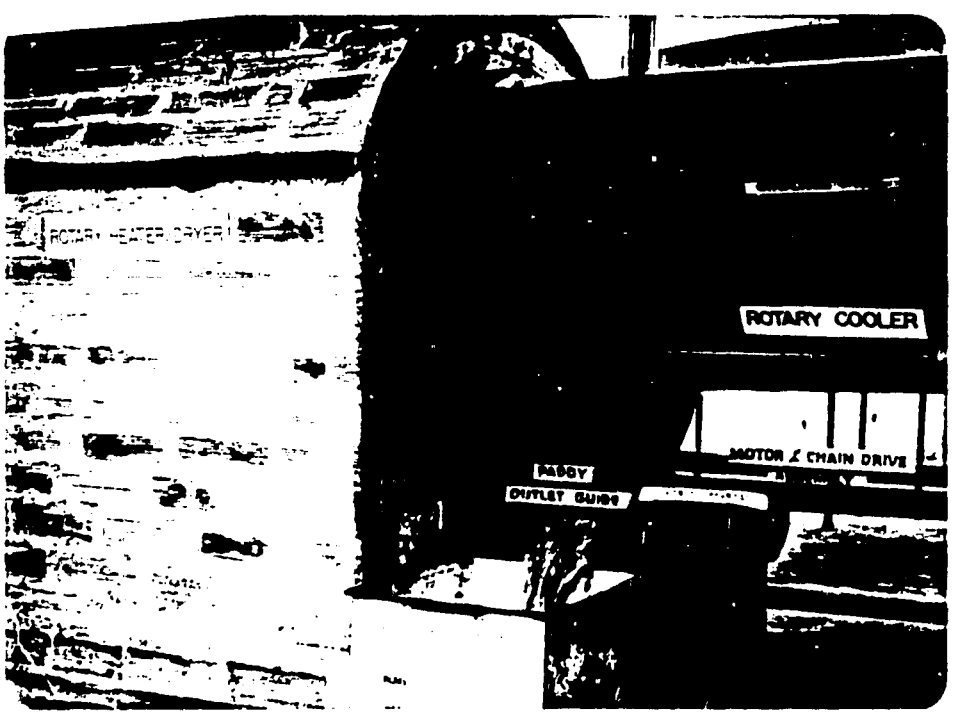
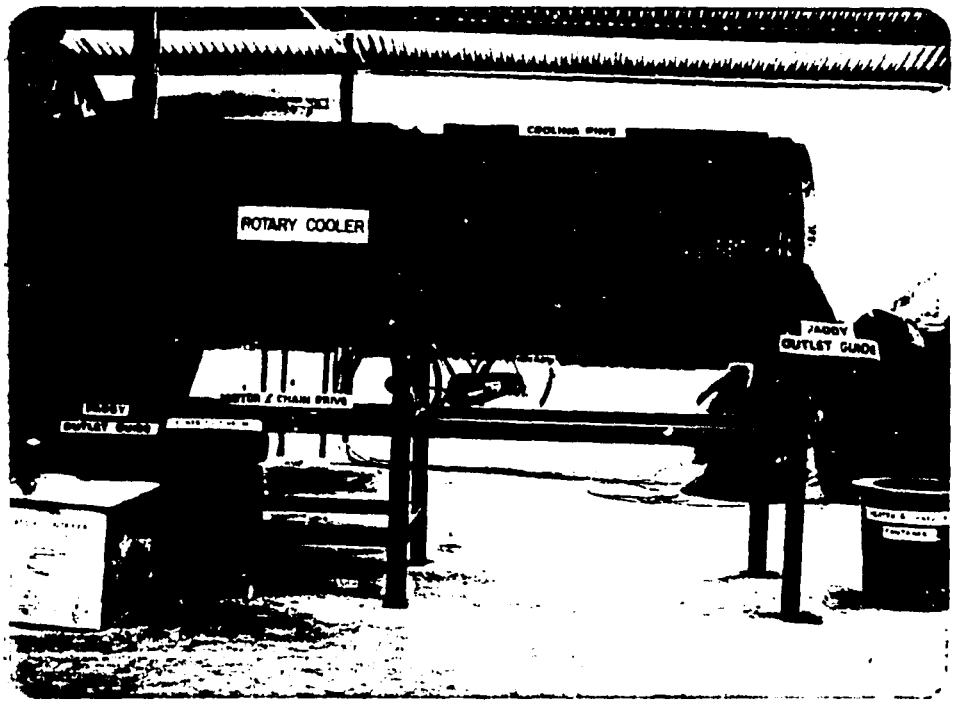


a. Perspective view
(main heater is enclosed by the brick housing)

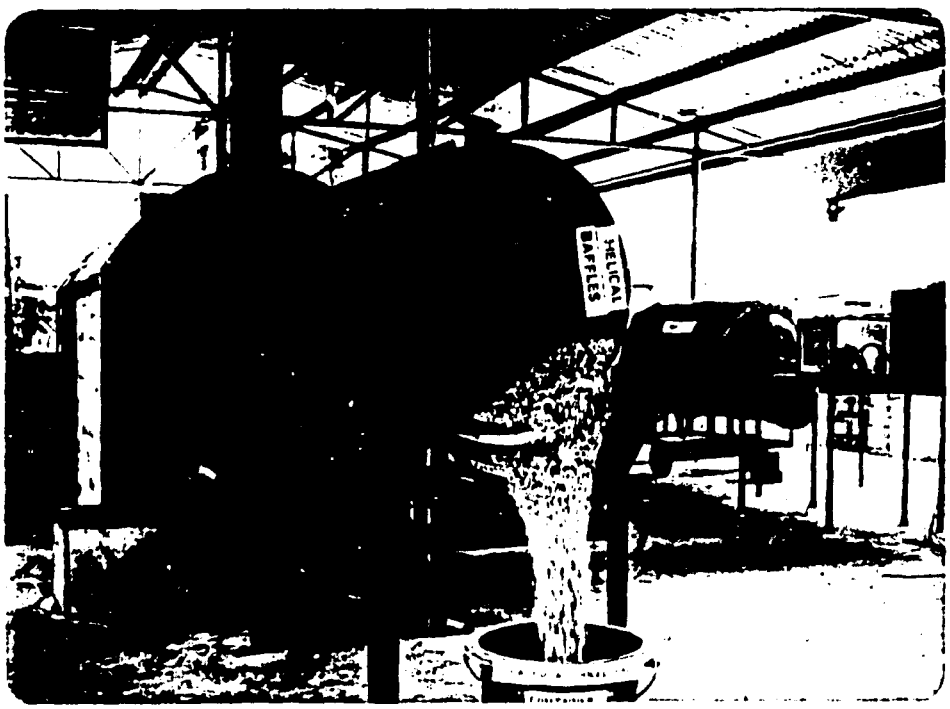


b. Paddy samples discharged immediately after rotary heating

Fig. 4. The Rotary Heater



a. Perspective view



b. Discharging heated and cooled paddy samples

Fig. 5. The Rotary Cooler

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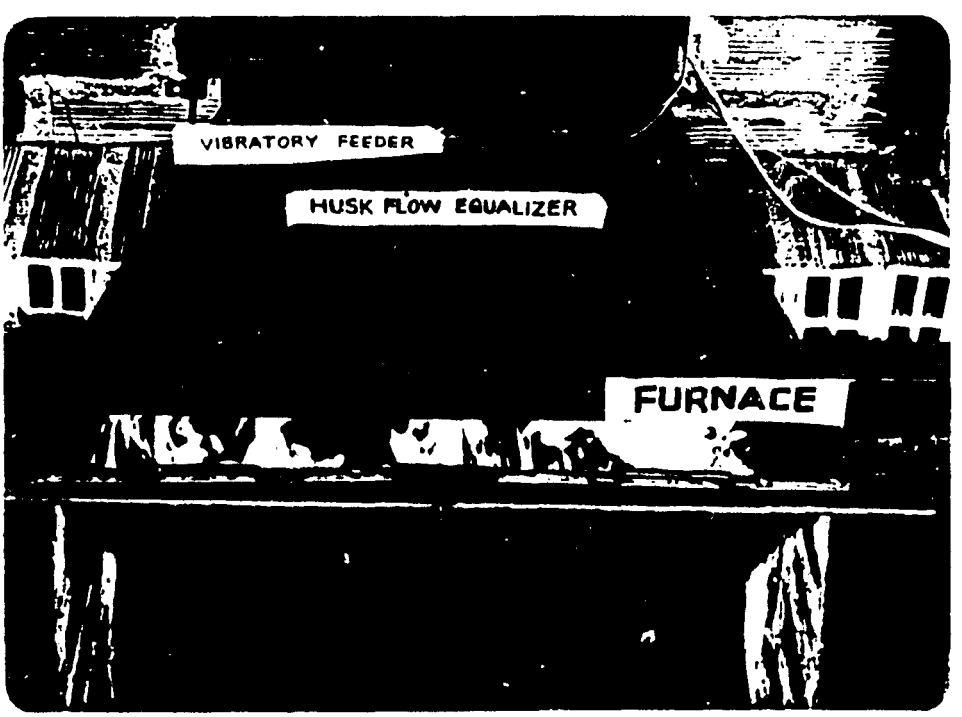
a. Perspective view



b. Close-up view

Fig. 6. The Rice Husk Furnace

Table 1. Heating and cooling treatments on rewetted paddy at grain agitation speed of 4 rpm and paddy feed rate of 10 kg/min

Sample	Heating						Cooling										
							Rapid						Slow				
Size	HST	GET	GT1	GT2	MC1	MC2	CR	GT1	GT12	GT2	MC1	MC2	CR	GT1	GT2	MC1	MC2
kg	°C	sec	°C	°C	%	%	°C/min	°C	°C	°C	%	%	°C/min	°C	°C	%	%
5	100	165	29	58	23	22	3	58	46	32	22	20.6	0.29	58	32	22	21.8
5	120	165	29	65	23	21.8	3	65	54	32	21.8	20	0.30	65	32	21.8	21.6
5	140	165	29	75	23	21	3.1	75	56	32	21	19.4	0.32	75	32	21	20.7
5	160	165	29	80	23	20	3.3	80	58	32	20	18.8	0.33	80	32	20	19.8

HST Heating surface temperature
GET Grain exposure time
GT1 Grain initial temperature
GT12 Grain temperature after rotary cooling
GT2 Grain final temperature
MC1 Grain initial moisture content, wet basis
MC2 Grain final moisture content, wet basis
CR Cooling rate

Table 2. Milling and germination performance of heated and cooled paddy samples at grain agitation speed of 4 rpm and paddy feed rate of 10 kg/min

Quality Index	Control[a]	Heating Temperature, °C							
		100		120		140		160	
		R	S	R	S	R	S	R	S
a. Percent Milled Rice	67.4	69.5	68.7	71.4	69.8	72.8	72.3	73.0	73.9
	68.6	69.1	68.5	71.3	70.5	72.4	72.8	72.3	73.7
Average	68.0	69.3	68.6	71.4	70.2	72.6	72.5	72.6	73.8
b. Percent Head Rice[b]	48.4	50.8	48.9	55.2	51.1	57.2	58.2	59.5	61.2
	50.1	50.0	48.8	53.9	52.7	56.5	58.0	58.2	61.0
Average	49.3	50.4	48.9	54.5	51.9	56.9	58.1	58.9	61.1
c. Percent Germination	88	10	7	0	0	0	0	0	0
	96	8	5	0	0	0	0	0	0
Average	92	9	6	0	0	0	0	0	0

[a] Air-dried under shade

[b] Based on 125 g paddy sample

R Rapid cooling (~ 3 °C/min)
S Slow cooling (~ 0.3 °C/min)

Table 3. Accelerated drying test on rewetted paddy (25% w.b.) at heating surface temperature of 120°C, grain agitation speed of 4 rpm and paddy feed rate of 10 kg/min

Pass	Heating						Cooling						Drying Time
No.	GET sec	HR °C/min	GT1 °C	GT2 °C	MC1 %	MC2 %	GET sec	CR °C/min	GT1 °C	GT2 °C	MC1 %	MC2 %	sec
1	165	13.8	30	68	25	23.5	135	12	68	41	23.5	22	420
2	165	10.5	41	70	22	21.8	135	12.4	70	42	21.8	20	420
3	165	10.9	42	72	20	19.5	135	12.9	72	43	19.5	19.3	420
4	165	10.9	43	73	19.3	19	135	12.9	73	44	19	18.5	420
5	165	10.9	44	74	18.5	18	135	12.4	74	46	18	17.6	420
6	165	10.5	46	75	17.6	16	135	12.4	75	47	16	15	420
									47[a]	30	15	14	

[a] Ambient cooling by spreading thin layer of grains on a nylon mat

GET Grain exposure time
HR Heating rate
GT1 Grain initial temperature
GT2 Grain final temperature
MC1 Grain initial moisture content, wet basis
MC2 Grain final moisture content, wet basis
CR Cooling rate

Table 4. Milling and germination performance of conduction-dried paddy (14%, w.b.) at heating surafce temperature of 1[illegible]0 °C, grain agitation speed of 4 rpm and paddy feed rate of 10 kg/min

Quality Index		Control[a]	Treated Paddy
a. Percent Milling Recovery		68.4	70.3
		68.7	70.9
		68.6	73.9
		----	----
	Average	68.6	71.3
b. Percent Head Rice[b]		46.5	48.8
		47.5	48.0
		46.8	52.8
		----	----
	Average	46.9	49.9
c. Percent Germination		64	0
		56	0
		76	0
		--	-
	Average	65	0

[a] Air-dried under shade

[b] Based on 125 g paddy sample

PRESENT ACCOMPLISHMENT AND MAIN ACTIVITY

I. PRESENT ACCOMPLISHMENT

As of December 20, 1985 about 200 drying treatments and 2 heating trials were already carried out on the rotary dryer employing selected combinations of the following drying and heating parameters:

1. Heating Surface Temperature	:	100 - 180	C
2. Grain Agitation Speed	:	2 - 45	rpm
3. Grain Exposure Time	:	1 - 30	min
4. Grain Feed Rate	:	10 - 40	kg/min
5. Grain Moisture Content	:	22 - 28	% w.b. (Initial)
	:	14 - 18	% w.b. (Final)

A detailed description of methods and results will be covered in the 3rd progress report ending 31 December 1985 scheduled to be submitted in early February 1986.

Photographs of the rice husk fired rotary dryer are presented in the 2nd progress report. Photographs of other related accomplishments directly in line with the objectives of the project are shown in Figs. 1-5.

II. MAIN ACTIVITY

The main activity undertaken at present is rapid drying and heat treatment studies on wet paddy using the rice husk fired rotary dryer and electric powered rotary heater, respectively.

On-going Research:

Heat treatment of high moisture rice for temporary storage

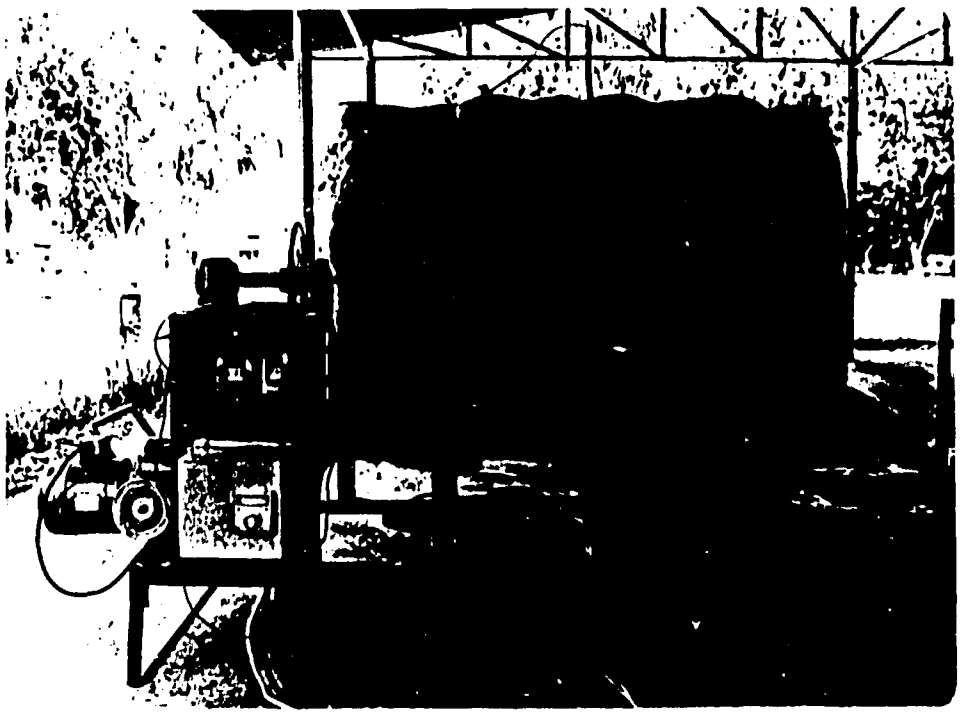


Fig. 1 The Batch-Type Rotary Heater

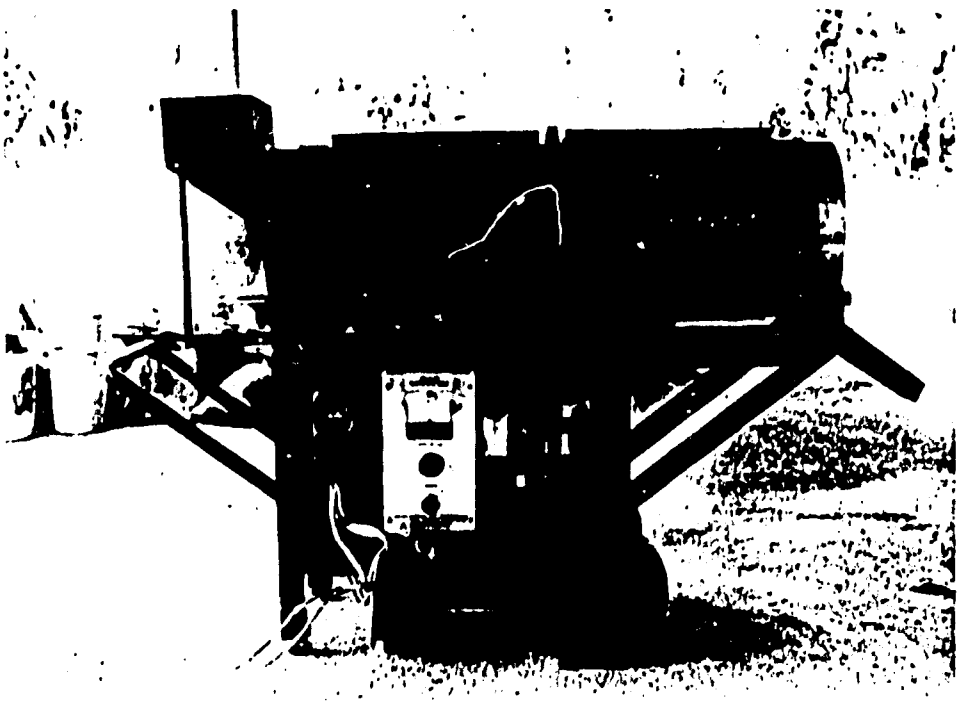


Fig. 2 The Batch-Type Rotary Cooler

Completed Research:

Microwave heating of high moisture paddy for safe storage

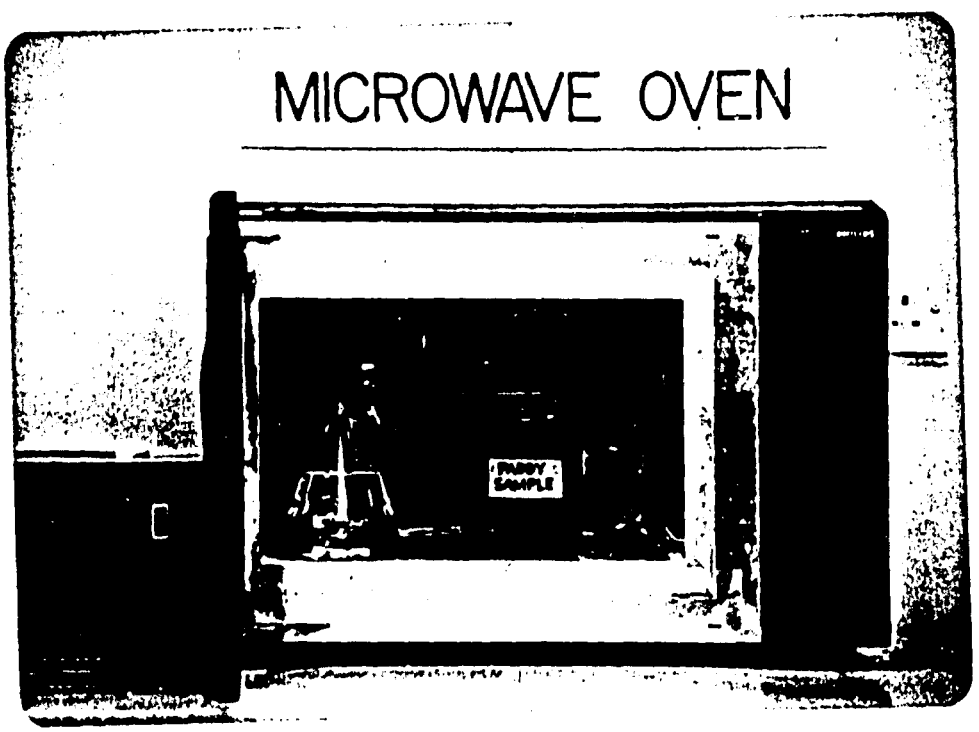


Fig. 3 The Microwave Oven

Completed Research:

Characterization of fungal invasion in paddy

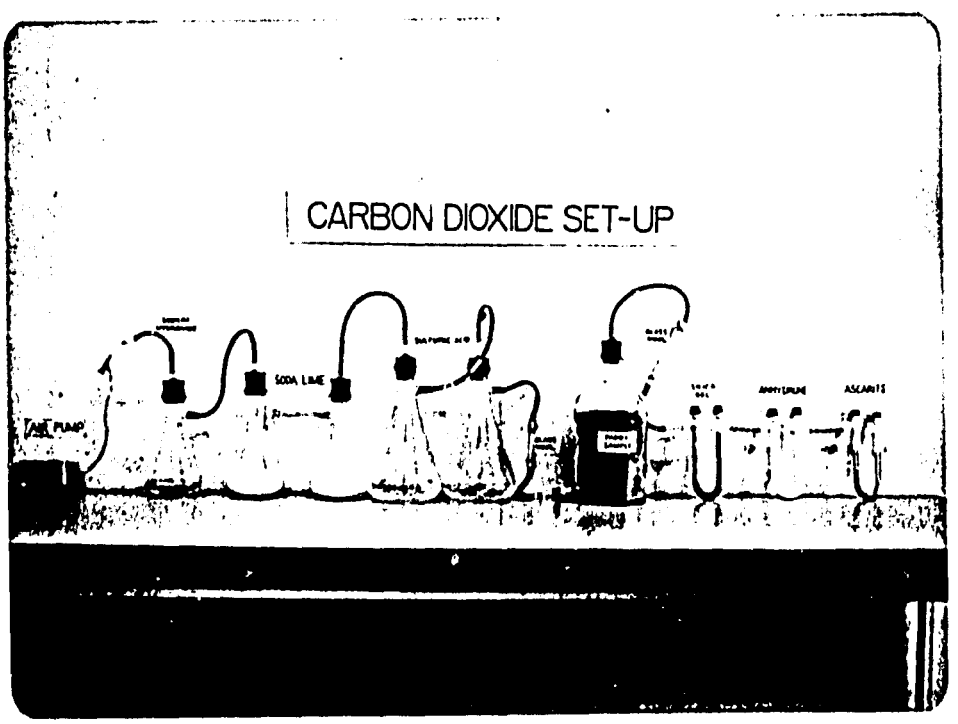


Fig. 4 The Absorption-Type Carbon Dioxide Analyzer

Completed Research:

Performance of a natural convection rotary dryer

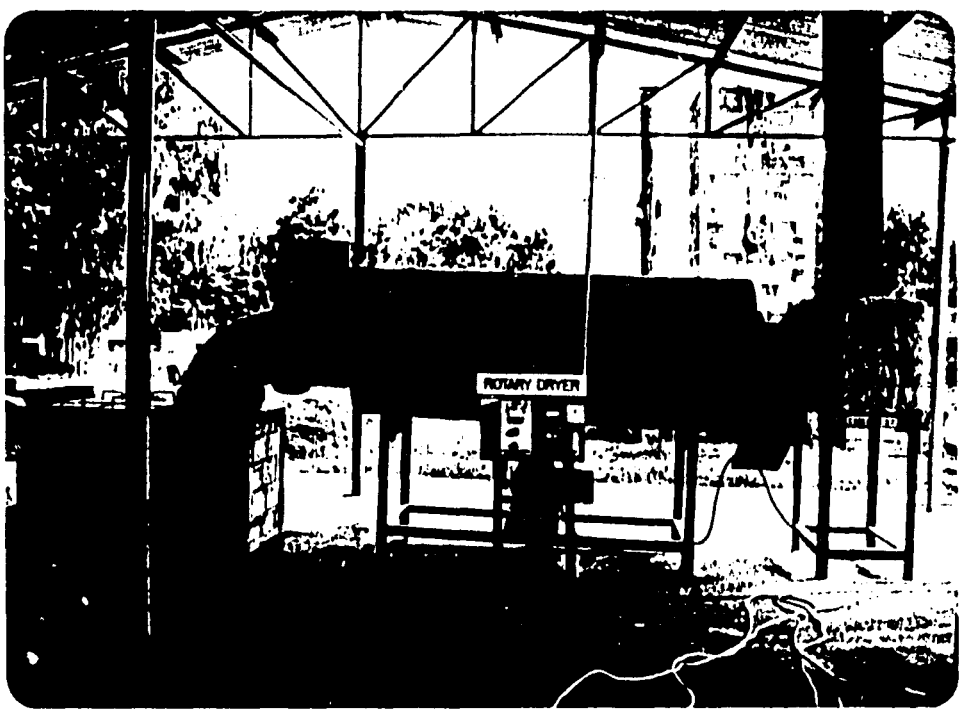


Fig. 5 The Convection-Type Rotary Dryer