Rice Hull Furnaces for Paddy Drying: the Philippine Rice Research Institute's Experience

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RICE hulls constitute 14–26% of the harvested weight of paddy. With the current annual Philippine paddy production of around 9 Mt, some 1.8 Mt of rice hulls are produced each year. Although some of the hulls produced by small rice mills are used as domestic fuel or as a livestock feed (when mixed with rice bran), vast quantities of husks are not utilised and are disposed of in vacant areas or along roadsides.

The energy content of rice hulls ranges from 14 to 16 MJ/kg (6000–6800 BTU/lb); a tonne of hulls is thus equivalent to about 84 gallons of heating oil having 140,000 BTU/gal (Beagle 1978). In the Philippines, the best potential use for rice hulls, aside from domestic fuel, is in paddy drying. Paddy drying is commonly accomplished by a combination of field and direct solar drying on a pavement or open road. Mechanical drying is employed when the harvesting occurs during the monsoon season. Most millers using batch dryers fire them with kerosene furnaces, but are beginning to shift to rice-hull-fired furnaces due to cost constraints. Other sophisticated dryers of several private traders/millers in the country are equipped with rice-hull-fired boilers which generate steam for drying.

This paper discusses the rice-hull furnaces adopted by the Philippine Rice Research Institute (PhilRice) in its dryer studies, their performance when fitted to dryers, and the dissemination work conducted to popularise and commercialise the dryers and furnaces.

Furnace Designs and Drying Performance

There is already available in the country a wide range of furnace systems designed for the direct combustion of rice hulls. PhilRice adopted three furnace designs in its paddy-drying studies and is in the process of refining one design for dissemination of dryers in the country.

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1. Grate-type furnaces

The first design utilised in flat-bed dryers is the IRRI BD-2 flat-grate furnace (Fig. 1) which is an up-draft type, flat-grate, rice-husk furnace. It consists of a hull feeding component, a combustion chamber, and an ash precipitation chamber. It is simple in construction and operation. The air for combustion is supplied by the suction of the dryer fan, while the fuel supply is facilitated by the vibration of a feeder connected by a wire to the fan shaft. At a feed rate of 10 kg/hour, furnace efficiency is 68–70% (IRRI 1979). However, it has incomplete combustion and inefficient ash separation so that ash and sparks are partially sucked by the fan into the dryer plenum (Phan Hieu Hien 1993).

Similar to the flat-grate furnace is the inclined grate furnace design (Fig. 2) from the University of Agriculture and Forestry (UAF), Vietnam and was based on the IRRI design. It has similar performance to that of the IRRI furnace but has more durable steel parts than the former, particularly the grate, which is made of mild steel. At 34 kg/hour rice hull feed rate, the drying air temperature at the plenum could ranged from 40 to 54.3°C, with a 484 to 509°C exhaust temperature; with a higher feed rate, drying air temperature can be pushed up at 80°C. Efficiency ranged from 48.4 to 86.1%. Combustion takes 10–20 minutes and is characterised by the production of much smoke. The hopper needs to be loaded with husks every 10–15 minutes. Once ignited, combustion is maintained while there are rice hulls. The ash has to be manually raked from the furnace.

Technical evaluation of the performance of the Vietnam-adapted 6 t/batch Maligaya flat-bed dryer (with concrete bin) using the inclined-grate furnace was conducted in Nueva Ecija and Davao del Norte, in order to establish parameters for its optimum operation. Parameters such as grain depth, fan speed, and drying air temperature were examined to determine their effects on drying rate, uniformity of moisture content, milling and head rice recoveries, and germination rates. Results (Table 1) indicate that the improved dryer performed best at 26 to 34 cm grain depth, and maximum air temperatures of 43 and 47°C for seed and milling purposes, respectively. Fan speed had no significant effect on headrice yield and germination.

Other problems formerly associated with earlier flat-bed dryer designs—such as the need to mix the grain during drying and the excessive moisture gradient between top and bottom grain layers—could be avoided because of the UAF dryer's efficient fan and if the recommended grain depth was adhered to. With systematic management of operations, even unloading problems could be minimised. However, the operator could be exposed to heat from the furnace, especially as rice hulls have to be loaded and ash removed every 10 to 15 minutes.

At present, PhilRice is refining or testing other designs to go with future installations of flat-bed dryers. The modifications are focusing on better ash separation (which causes the dryer's perforated screen to be plugged with continuous use), lighter weight (for mobility), better durability, and lower cost. The UAF, Vietnam has recently developed an improved furnace using an inclined grate with a more efficient cyclonic ash separation (Fig. 3). This was to be tested during the 1995 wet season.

2. Combustor furnace

Another design tested for batch drying and later commercialised for flash drying is the gasifier combustor designed by the Industrial Technology Development Institute (ITDI) for brick kilns. Its components include an air delivery and metering system utilising a separate blower, fuel inlet and hopper, which is actually the topmost section of the reactor, the reactor, and the grate-ash removal system at the lowest section (Fig. 4). It operates on the principle of an open-core, batch-type gasifier. Air from a separate blower flows downward through the fuel bed. The gasified products are burned to produce a bluish-to-light orange flame at the lower exhaust port.

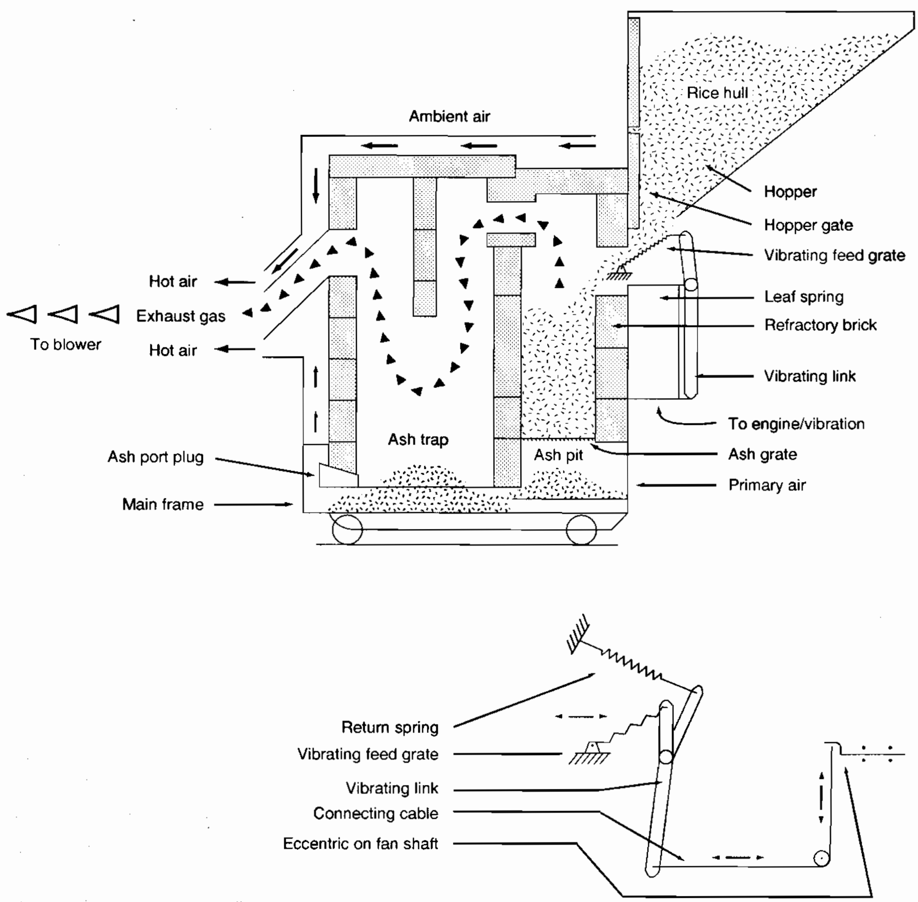

Figure 1. Schematic diagram of the IRRI BD-2 flat grate furnace (IRRI 1979).

Table 1. Results of drying tests at different grain depth, fan speed and drying air temperature for the Maligaya 6-ton flat-bed dryer-cum-inclined grate furnace. Philippine Rice Research Institute, 1994 wet season.

Test no.	FBD1	FBD2	FBD3	FBD4	FBD5	FBD6	FBD7	FBD8	FBD9	FBD10
Date	26 Aug.	7 Oct.	10 Oct.	11 Oct.	25 Oct.	4 Nov.	10 Nov.	23 Nov.	24 Nov.	26 Nov.
Crop conditions										
Variety	IR64	Rc14	BPIRi10	BPIRi10	IR72	Mix	Mix	Burdagol	Burdagol	Burdagol
Initial moisture content, %	23.2	22.5	22.5	22.9	22.7	17.5	17.5	22.3	18.6	25.1
Final m.c., %	15.3	14	14.1	13.4	13.8	12.3	14.2	13.8	12.7	13.8
Initial weight, t	4.75	3.50	2.92	4.79	4.80	4.22	4.41	5.09	3.30	3.61
Final weight, t	4.31	3.15	2.63	4.26	4.30	3.97	4.24	4.59	3.08	3.13
Grain depth, cm	27.0	24.3	19.9	29.8	29.6	26.1	27.9	31.3	20.5	22.6
Ambient conditions										
Temperature, °C	31	33.5	32	31	33	31	30	30	30	31
Relative humidity, %	75	64	67	75	60	60	56	80	75	72
Drying results										
Drying air temp., °C	43	43	41	43	51	49	43	49	49	49
Drying time, hours	3h45	3h00	5h30	5h00	4h00	2h30	2h30	4h00	2h45	3h30
Drying capacity, kg/hour	1149	1053	479	853	1076	1590	1695	1148	1119	895
Top & bot tom m.c. diff, %	2.1	1.8	0.5	2.0	1.8	1.7	0.8	1.4	0.5	0.9
Moisture removed, kg	443	346.4	285.5	525.5	495.6	250.5	169.5	502.5	223	472.8
Drying rate, % m.c./hour	2.1	2.8	1.5	1.9	2.2	2.1	1.3	2.1	2.1	3.2
% m.c. reduction	7.9	8.5	8.4	9.5	8.9	5.2	3.3	8.5	5.9	11.3
Ricehull consumption, kg	145	105	137	160	130	65	55	150	100	115
Feeding rate, kg/h	44.5	35.0	27.4	35.6	37.1	32.5	27.5	42.9	40	35.4
Fan operation										
Speed, rpm	1750	1500	1450	1630	1620	1770	1770	1740	1610	1630
Static pressure, mm H_2O	19	16	15	17	17	20	20	22	15	15
Airflow rate, $m^3/s\text{-}m^2$	0.22	0.19	0.195	0.19	0.19	0.22	0.22	0.21	0.22	0.22
Airflow, m^3/s	6.19	5.35	5.49	5.49	5.49	6.19	6.19	5.91	6.19	6.19

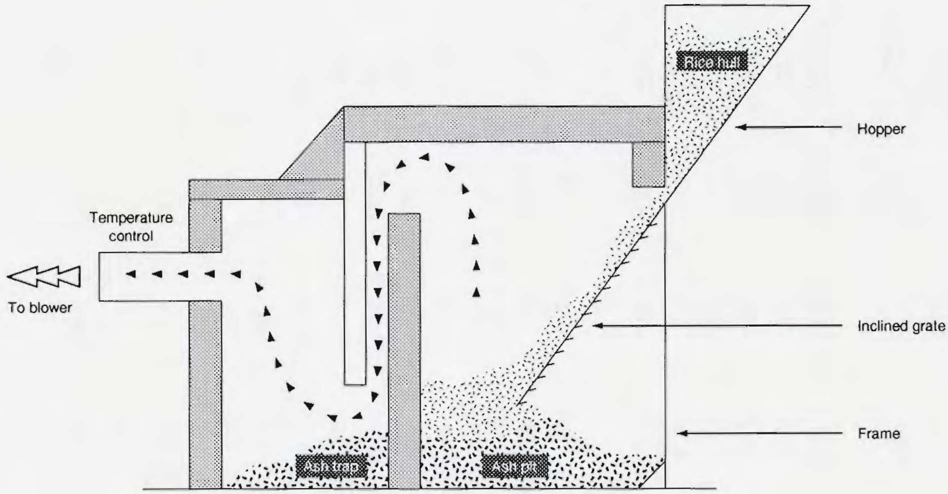

Figure 2. The UAF-designed inclined grate furnace (Tam et al. 1995).

Figure 3. Inclined grate furnace with cyclonic ash separator.

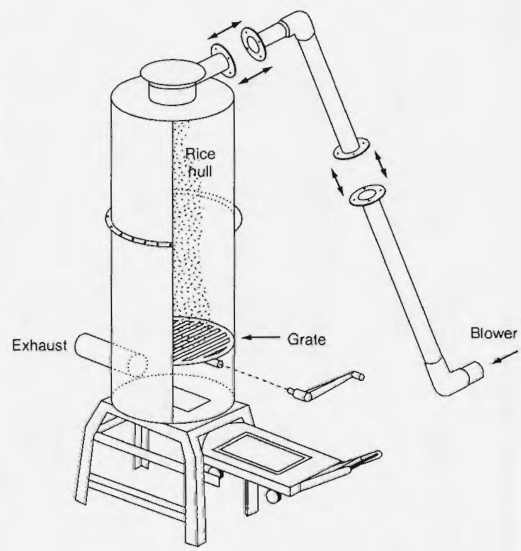

Figure 4. The ITDI rice-hull gasifier–combustor (Gagelonia 1993).

The gas generated in the reactor has a heating value of 3000–4000 kJ/m^3 with a conversion efficiency of 70 to 80%. Ash is removed after every batch by tilting the grate and manually scraping the ash out of the ash port. Phan Hieu Hien (1993) noted several features of this furnace as follows: simple construction, easy control of the heating rate, and the production of a clean-burning flame which is essential in direct-heat drying.

The ITDI combustor could be coupled with a 2 t batch dryer for paddy seed drying. Because of the high heat generated at the exhaust (360–500°C), however, it is necessary to use an expansion duct between the fan and the plenum and to install and regulate a baffle plate at the exhaust to reduce the drying air temperature to 40 to 50°C. With such an arrangement, the drying system efficiency ranges from 20 to 31.4%, depending on the grain depth at the bin, at an airflow rate of 0.8 m^3/sec and static pressure of 20 to 26 mm water. An average moisture reduction of 1.3 to 1.5%/hour, equivalent to 20–31 kg water removed per hour, was obtained during tests.

Because of its capacity to generate high-temperature drying air, the ITDI combustor was also recommended to a manufacturer to be coupled to the NAPHIRE flash dryer design. Tests indicated a drying air temperature within the plenum chamber from 80 to 90°C; this temperature could be attained within 15 minutes after combustion. Drying rate (from 27.9 to 19.0% m.c. grain) was 9%/hour at a plenum air velocity of 0.6 m/second.

The main problems with this system are its slow ignition (which can take from 30–60 minutes with some units) and the excessive smoke produced, which is directed at the drying bin during ignition. Also, being a batch-type furnace, it could pose a problem for unskilled operators in a continuous drying system.

3. Zeta furnace

The latest design developed in collaboration with IRRI and GTZ is the Zeta furnace which is designed for low-temperature drying systems. Low-temperature drying is a process which utilises either natural air or air heated by only a few degrees (6 to 9 K above the ambient temperature) for drying, depending upon the ambient relative humidity. Unlike the other drying methods which use drying air temperature of around 43°C or higher, low temperature drying is a slow process which takes 7–15 days or more depending on the weather. It is also referred to as in-storage drying since the same bin can be used for both drying and storing. Its advantages over high temperature drying include modest investment, minimum energy consumption and labour requirement, and uniform drying (Muhlbaüer et al. 1992).

The furnace designed for such a system (Fig. 5) is a box-type, with an air-sweep floor inclined at 30°, similar to the inclined-grate system. The air-sweep floor was a sheet of metal with rectangular shaped slits where air passes to convey the rice hulls. On the lower side of the floor is a rectangular opening which leads to a cyclonic compartment where the ash falls to the bottom and is separated from the heated air which is sucked into the dryer by the dryer fan. During operation, the hot air, together with the ash, are conveyed to the second compartment through the combined action of air-sweep floor, gravity, and suction from the blower. It uses a feeding system which is adapted from the Colombian furnace.

Tests of the furnace with a 5 t/batch in-store drying bin indicated that, at a feeding rate of 4 to 10 kg/hour, the furnace had burning efficiency of 90–95% and drying air efficiency of 40–80%. Drying tests resulted in the desired moisture reduction and better milling recovery and germination capacity compared with shade-dried samples (Table 2). The dried grain was observed to be clean, which indicated that the furnace had been effective in burning the rice hull and in separating the ash from the heated air. The furnace was also capable of maintaining a nearly uniform fuel bed. No accumulation of a thick layer of rice hull was observed. Thus, there was uniform distribution of air throughout the rice husk fuel mass which led to better performance compared with other existing designs.

Aldas et al. (1995) noted several advantages of the Zeta furnace, including its compactness, lightweight design, and continuous automatic feeding of rice hull with its piston mechanism. However, the furnace is still in prototype stage and will have to be adapted together with the in-bin drying storage system in the country.

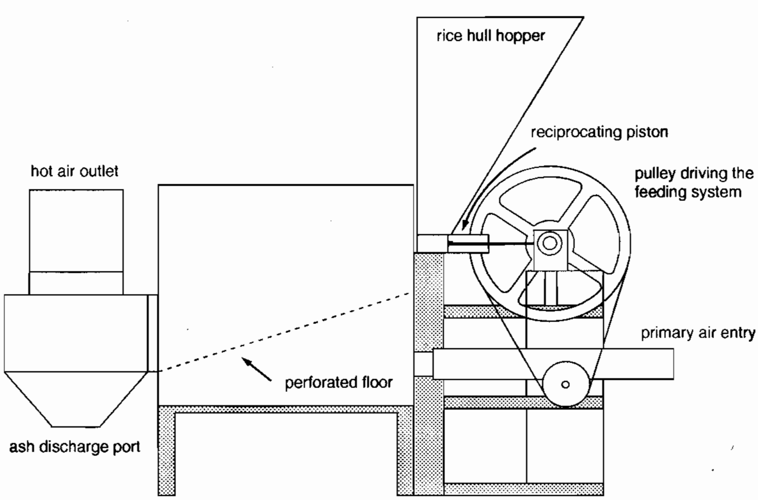

Figure 5. Schematic diagram of the Zeta furnace for low-temperature drying (Aldas et al. 1995).

Table 2. Summary of drying data for 5-ton in-bin dryer and storage system using Zeta furnace.

Test no.	1	2	3
Date and time begun	16 Mar., 1135	20 Apr., 1545	28 Apr., 1545
Date and time ended	28 Mar., 1100	26 Apr., 1100	4 May., 1520
Duration, h	287.4	142.3	143.6
Bulk depth, m	2.2	2.0	1.7
Crop data			
Variety	841	Sinandomeng	PSBRC 10
Initial weight, kg	6135.6	5923.0	5615.0
Initial moisture content, %	28.8	19	22
Operation			
Motor power, hp	3	3	3
Blower operating time, h	136.2	88.6	84.2
Air velocity, m/s	0.09	0.11	0.13
Static pressure, Pa	600-700	450-550	400-500
Airflow power, W	327.6	308.0	327.6
Energy delivered, kWh	44.6	27.3	27.6
Energy used, kWh	410.9	209.0	255.1
Furnace operating time, h	40.97	17.25	17.88
Increase in temperature, K	10	13	11
Fuel consumed, kg	127.9	61.5	59.0
Fuel consumption rate, kg/h	3.12	3.57	3.30
Heat available, MJ/h	44.038	50.305	46.560
During furnace operation			
Average relative humidity, %	80	75	80
Drying air temperature, °C	35	40	38
Air density, kg/m^3	1.119	1.101	1.107
Heat supplied, MJ/h	20.466	31.994	32.169
Results			
Final weight, kg	5034.4	5297.2	4787
Final moisture content, %	13.1	11.8	12
Water removed, kg	1101.2	625.8	828
Drying rate, kgH_2O/h	3.83	4.40	5.77
Motor and blower efficiency, %	10.86	13.06	10.82
Drying air efficiency, %	46.47	63.60	69.09
Spec. energy requirement, kWh/kgH_2O	0.828	0.719	0.587

Source: Aldas et al. (1995).

Furnace and Dryer Dissemination at PhilRice

PhilRice, in its dryer research and dissemination activities, focused only on tapping dryer designs and models which could be fitted with rice-hull furnaces rather than kerosene burners for economy purposes and which local adopters seem to prefer.

Since total investment cost is also one of the constraints in the wide adoption of dryers in the country, another strategy PhilRice has adopted is to encourage farmers and traders adopters to construct some of the parts of the dryers to further reduce the cost (following PhilRice specifications). This is one major reason for the adoption in the design of a concrete bin (utilising hollow blocks and cement) which ordinary farmers can construct or which others may already have (i.e. pig pens that could be converted during periods when drying is needed). The use of existing prime movers, normally diesel engines from hand tractors, is also being encouraged to further reduce farmer investment. Thus, only parts such as fan assembly, furnace, and the perforated screen are purchased at the recommended PhilRice cooperators.

In the dissemination of the Maligaya flat-bed dryer design, the following are important aspects being considered:

1. *Training operators* is an important component of dissemination that must always accompany installation of new dryer set-ups. At PhilRice, this training includes familiarisation with drying procedures and furnace operation, adjustment procedure for drying temperature, briefing on critical factors such as effect of temperature, and moisture content determination.
2. *Technical assistance* in the construction and manufacture of dryer components and in the initial operation. With the 6 t flat-bed dryer, assistance is needed in the construction of the furnace and in provision of jigs for the construction of the fan assembly. Testing of every set-up is also part of the dissemination strategy in order to monitor the performance of newly-installed set-ups in the sites, as well as assuring adopters of the presence of technical assistance.
3. *Monitoring of the performance of the dryer* is an important component of dissemination in order to determine if adjustments are needed, to meet problems, and to assure users of its good performance.

Factors to be considered in the introduction of furnaces include:

1. *Time taken for ignition/combustion.* Normally, operators and dryer users are particularly interested in the time for ignition for such rice-hull furnaces, especially if this time is characterised by exposure of the operator to heat and excessive smoke. To shorten ignition time, training for operators should be included in the dissemination of the system.
2. *Smoke generation.* Smoke during ignition cannot be avoided, but it is important that it be minimised and not directed to the grain in the bin to prevent any undesired odour in the product which may, in turn, reflect poorly on the whole system.
3. *Continuity of feeding.* Farmers normally prefer rice-hull furnaces (and dryers) which can be operated continuously for maximum efficiency and to minimise ignition. This is one constraint of the gasifier–combustor which has to be fed and cleared of ash in batches (although ignition is a lot faster with succeeding batches).
4. *Temperature control.* Because of varying paddy condition and desired operating requirements for the paddy output, e.g. seed drying, it is essential that furnaces should have some degree of control of temperature output. It is important that every dryer installed be fitted with a temperature gauge.

Strategy of promotion

With the flat-bed dryer cum inclined grate furnace. During the initial promotion activities, the target group was the seed growers and cooperatives who could afford the dryer and who have an incentive for drying. Initial information dissemination activities included the following:

- print material development and dissemination (bulletin, leaflet);
- video development (with an NGO and Philippine Channel 5) and a feature shown on TV;
- promotional briefings and actual demonstration (whenever practical) during seed grower trainings and farmer visits which are regularly done at PhilRice; and
- custom drying at PhilRice to make seed growers in the adjacent community aware of its advantages.

The focus of PhilRice at present is to set up demonstration units for each of the 14 regions of the country. It is expected that with actual units operating in the sites, farmers will become more aware of the improved flat-bed dryer.

In addition, PhilRice has chosen the Maligaya flat-bed dryer design for equipment loan (without interest, 5 years to amortise on seasonal payments) to farmer cooperatives and paddy seed growers. The loan program has already started with the promotion of the technology to regional and local extension engineers in the country.

With the combustor coupled with the flash dryer. Another agency, NAPHIRE, does the dissemination of the flash dryer-cum-combustor (in addition with other commercial furnaces) which was linked by PhilRice to one cooperating manufacturer who has mass produced the system. NAPHIRE has included the flash dryer with combustor in the Department of Agriculture's Grain Production Enhancement Program which selects farmer cooperatives for grants or loans in the form of postharvest equipment such as the dryer.

In commercialising the dryer-cum-gasifier, one concern being attended to by the manufacturer is the need to closely monitor the quality of mass-produced combustors (and dryers), which is perceived to be a constraint to wide acceptance, and the follow up training of cooperative operators. Another concern is the reduction of its ignition time, which with earlier prototypes took at most 15 minutes only but now takes up to 1 hour.

Local adoption

The dryer is being promoted to adopters who finance the whole dryer but with technical assistance from PhilRice.

The adoption of the dryer has peaked this season, with new installations in Northern and Central Luzon, Southern Tagalog, and Mindanao. There are several units that were installed last year by two seed growers, one local government unit (for demonstration), and one university (for commercial seed production). The university unit is also being used for seed maize drying while another local government unit, located in the middle of large banana plantations, was used on one occasion for drying banana chips (one farmer entrepreneur is planning to set up the same dryer solely for such purpose).

New installations are being made this season for private paddy traders (three units with one for both paddy and maize), two farmer cooperatives (one plans to explore its use for copra drying also), three progressive farmers, and two other seed growers. Inquiries are still pouring in this season. Because it is still the cheapest available dryer (in terms of investment cost/unit of paddy) and the simplest to operate and maintain, it is expected that the design will continue to become popular in the coming years with careful introduction from PhilRice.

Summary and Conclusions

Rice hulls offer the best fuel potential for paddy drying during the wet season harvesting in the Philippines. Several rice-hull furnaces were adapted and modified at PhilRice for this purpose. The inclined grate furnace, a modification of the IRRI BD-2 furnace, coupled to a 6 t capacity flat-bed dryer, has a feeding capacity of about 35 kg/hour and furnace efficiency of 50 to 80%.

The ITDI gasifier combustor, adapted for flat-bed drying and flash drying, operates on the principle of downdraft gasifier and, with a feed rate of 40 kg of rice hulls per batch, can generate heat output of 200,000 kJ/hour. Coupling with a 2 t flat-bed dryer resulted in a drying air temperature of 40 –45°C and drying air efficiency of 20–31%.

The Zeta furnace jointly developed with IRRI for low-temperature drying operates on the principle of thin layer of combustion. Its feed rate of 3–10 kg/hour resulted in a burning efficiency of 90–95% and drying air efficiency of 40 –80% when coupled with a 5 t in-bin drying and storage system.

Adaptation and commercialisation of the first two furnaces for paddy drying have already been implemented and their increasing acceptance is encouraging. Numerous units have already been installed in various localities. Promotion of these technologies included information, demonstration in pilot areas, and training and technical assistance to prospective farmer owners.

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Drying Maize and Maize Seed in Vietnam

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In recent years, maize production in Vietnam has expanded, especially hybrid maize. Drying maize and maize seed are urgent problems in Vietnam because the crop is harvested in the rainy season, and dryers have not yet been accepted by farmers.

Our research has sought to determine the most suitable practical designs of facilities for farmers drying maize and maize seed. In this paper, we present some designs of flat-bed dryers for maize and maize seed. These dryers are locally manufactured and were installed at 15 locations in the north of Vietnam in 1995.

The capacity of flat-bed dryers for maize on the cob is 45 t per batch and for grain is 25 t per batch. The drying bin is made of brick, timber, and bamboo. The perforated floor is made from timber and bamboo. Coal was used as fuel for the burner.

The airflow rate was 660 m^3/t.hour with a drying air temperature of 38–42°C. The fan was driven by a 20 kW electric motor. It took 62–70 hours to dry cobs from 32–35% moisture content (wet basis) to 18%, and 50 hours to dry grain from 18 to 10.5% m.c. The drying cost was about US$3.30/t of seed. Total investment for this dryer was about US$1700.

A flat-bed dryer for maize grain with an airflow rate of 1250 m3/t.hour took 4 hours to dry maize from 19 to 14% m.c. at a drying air temperature of 75–80°C. Specific energy consumption was about 7.29 MJ/kg water evaporated. Drying cost was US$1.80/t. Total investment was about US$1100.

These dryers, with their low operating cost and low initial investment have been accepted by farmers for drying maize and maize seed, especially by the small-scale private sector and seed-processing plants in Vietnam.

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Commercialisation of a Mobile Flash Dryer for Farmer Cooperatives

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DRYING of wet grains has been a problem besetting the Philippines' postharvest industry. Farmers and other sectors in the industry often suffer because of failure to immediately dry wet season crops. This is because the peak of the harvest season coincides with the rainy months when sun drying cannot be depended on.

Mechanical drying offers an alternative for drying grains, especially during uncertain weather conditions. However, the practice did not gain ready acceptance, for reasons such as the high cost of fuel and other operating expenses, incompatibility of dryer operation to the volume of paddy to be dried, and the lack of knowledge on dryer operation and maintenance (Cardiño et al. 1989). To address this problem, the National Postharvest Institute for Research and Extension (NAPHIRE) and the Australian Centre for International Agricultural Research (ACIAR) collaborated to develop a drying technology—the mobile flash dryer (MFD)—that will be accessible and compatible with the level of operations on farms.

Technology Generation

A project funded by ACIAR and conducted by NAPHIRE resulted in the development of a two-stage drying strategy using the 'flash drying' technique in the first-stage, and in-store drying in the second-stage (Tumambing and Bulaong 1988). This technique dries the paddy to a more manageable moisture content (m.c.) of 18% using high drying air temperature, enabling fast drying rates and more efficient heat energy utilisation. At this moisture level, paddy can be stored for about three weeks, allowing enough time to wait for either the availability of sunlight for sun drying or for the second-stage of mechanical drying to completely dry the grains to 14% m.c.

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In 1990, a prototype batch-type model of a mobile flash dryer (MFD) was developed and, after preliminary field tests and using feedback from farmers, an improved model was built in 1991. The enhanced model is a continuous-flow type with cooling and heat recycling systems and an elevator to facilitate loading of grains. After a satisfactory result from the pilot testing, the technology was promoted and commercialised in 1992 (Bulaong et al. 1992).

Improvements were further identified in the continuous-flow type model at its early commercialisation stage. All possible design improvements were introduced to some of the cooperating manufacturers who have the capability to do machinery design and development. As a result, the continuous-flow flash dryer underwent further improvements from the cooperating manufacturers. Thus, a model with enhanced overall performance and versatility is now available.

The latest model can be used as a flash dryer or as a recirculating batch dryer heated by either a pot-type kerosene burner or a rice-hull furnace.

Technology Package

Features and components

The MFD allows on-farm and off-farm drying of paddy. Its main components are (see also Fig. 1):

- rice-hull furnace—used for stationary drying operations;
- kerosene burner—used as an auxiliary burner for mobile drying operations;
- centrifugal blower—powered by a 5 h.p. gasoline or diesel engine;
- drying section—composed of an upper and lower drying section with heat recycling mode;
- cooling system—cools the grain before discharge, and recycles heat into the drying section;
- loading system—composed of a loading hopper and a bucket-type elevator;
- unloading system—oscillating hopper;
- recirculating chute—recycles undried grain back to the drying section.

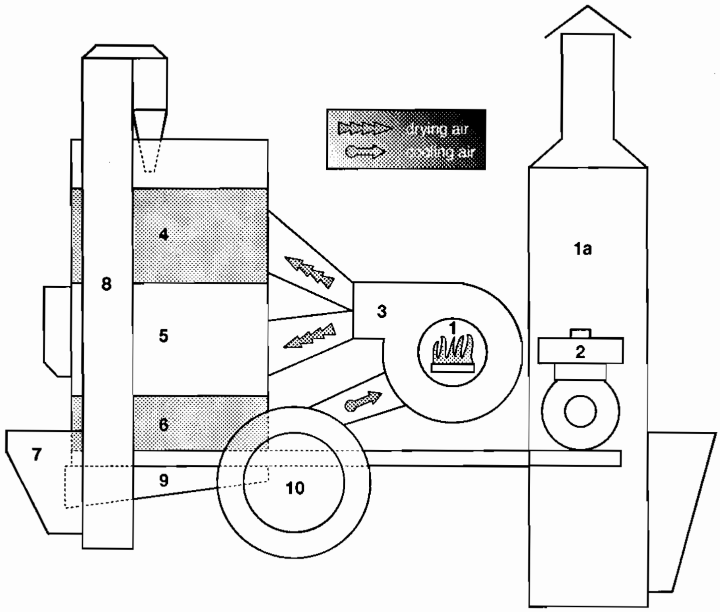

Figure 1. Schematic diagram of the Mobile Flash Dryer showing the principal components. (1) kerosene burner; (1a) rice-hull furnace; (2) engine; (3) centrifugal blower; (4) upper drying section; (5) lower drying section; (6) cooling section; (7) loading hopper; (8) elevator; (9) unloading hopper, and; (10) pneumatic tyre.

The dryer is simple in construction and uses locally available materials. This makes its cost relatively low and it can be fabricated by local manufacturers. Table 1 presents the design features and specifications of the dryer.

Principles of operation

Flash dryer. The wet paddy is continuously fed from the loading hopper and is subjected to temperatures of 80–90°C for 15–20 minutes. As the grain passes through the drying column, heated air crosses both sides of the grain column, outwards in the upper section, and inwards in the lower section (Fig. 2). This minimises the moisture content gradient common to high temperature drying. The grain is cooled in a cooling section before being discharged at the unloading hopper. Heat retrieved in the cooling section is recycled to the drying section, resulting in more efficient heat utilisation. Grain is fed into the dryer continuously, at the same time as semi-dried grain is being discharged.

Recirculating batch dryer. Wet grains are continuously recirculated into the drying bin until semi-dry or dry. Flash drying using drying temperatures of 80–90°C is applied to grains with an initial moisture content above 18%. When drying grains of 18–19% m.c., the drying temperature is reduced to 40–60°C. When drying from 18 to 14% m.c., exhaust air from the lower drying section can be optionally recycled to the system, resulting in greater heat efficiency in the drying operation.

Dryer operation

The dryer is powered by a 5 h.p. gasoline or diesel engine or a 2 kW electric motor which drives the blower, bucket elevator, and the unloading hopper. In operation, the grain is fed into the unloading hopper where it is picked up by the bucket elevator and poured into the drying column at a rate of at least 1 t/hour. Once the drying column is full, the engine is temporarily shut off to allow firing of the kerosene burner or rice-hull furnace for 5 or 15 minutes, respectively. With a steady flame from the burner or furnace, the engine is again started and the blower is engaged. The blower is set to operate at 2500 rpm.

The fuel feed rate is increased until the desired drying air temperature is reached, as indicated by a dial thermometer placed along the hot air duct. The required drying temperature depends on the initial moisture content of the paddy to be dried. When used as a 'flash dryer' (drying wet paddy to 18% m.c.) the air temperatures used for paddy with various ranges of moisture content are as follows: 80–90°C for 25–30% m.c. (very wet); and 70–80°C for 23–24% m.c. (wet). Drying 18–20% (skin dry) paddy to 14% m.c. will require 40–60°C. When drying paddy for seed, the temperature should not exceed 43°C for all moisture content levels.

Table 1. Design features and specifications of the mobile flash dryer.

Type	Continuous flow or recirculating batch
Height	2.5 m (without elevator)
	3.5 m (with elevator)
Width	1.0 m grain bin only
	1.5 m including wheels
Length	3.0 m overall length
	1.25 m bin only
Drying bin	Vertical, columnar mixing type with heat recycling system
Capacity	10–12 cavans (1 cav = 50 kg) of palay/hr at 70–80°C at 6% moisture extraction/hr
Power requirement	Minimum 5 h.p. engine
Heating system	Evaporating pot-type kerosene burner or rice-hull furnace
Blower	Centrifugal backward inclined, 3000 CFM at 1" stat. pressure
Temperature indicator	Dial thermometer
Elevator	1 t/hr, bucket-type
Engine (fuel) consumption	1.2 to 1.5 litres regular gasoline/hr
Burner (fuel) consumption	3–4 litres kerosene/hr at 70–80°C
	18–20 kg/hr rice hulls at 80–90°C
Labour requirement	At least 3 persons
Other features	a) Exhaust air recycling system
	b) Cooling section
	c) Grain recycling system

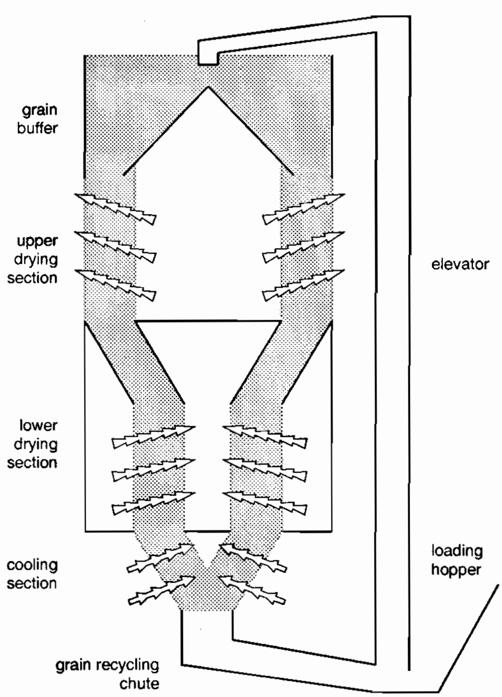

Figure 2. Schematic diagram of the Mobile Flash Dryer drying column.

The grain can be automatically recycled to the drying column if the required final moisture content has not been reached. This is done by closing the unloading hopper and diverting the grain back to the elevator by means of an oscillating sliding chute. For recirculating or multipass operation, the drying air temperature is correspondingly decreased as the grain moisture content decreases.

Once the desired moisture level is reached, the unloading hopper is opened slowly to start discharging the grain. The retention time of the grain inside the drying column can be controlled by the discharge rate. Discharge rate can be varied by means of a crank which adjusts the opening of the discharge hopper.

Viable drying scheme

The technology is cost-effective to operate as a two-stage drying scheme (MFD + sun drying, or MFD + in-store drying). Using MFD as the sole means of drying cuts its capacity by half and results in higher operating costs due to lower output.

Economic returns

The MFD with a convertible kerosene burner and rice-hull furnace (because of its bulk, use of the latter necessitates operation of the dryer as a stationary unit) costs approximately PHP110,000 (during October

1995, ca 25 Philippine pesos (PHP) = US$1), including a 5 h.p. gasoline engine. Table 2 gives a cost and return analysis for the MFD considering two utilisation rates and based on a custom-drying scheme at a drying fee of PHP12.00/cavan (1 cavan = 50 kg). The data indicate a reduced unit cost of drying and a correspondingly higher return on investment with an increase in annual utilisation rate. Using a rice-hull furnace, although it has a higher investment cost, results in the lowest drying cost of PHP5.51/cavan for 120 days use each year.

The data imply that the operation of the technology will be more profitable in areas with relatively long wet seasons which will require a longer dryer utilisation.

Table 3 illustrates the various options of a farmer in selling his paddy. He can either sell it wet, sell it dry using the MFD, or wait for the sunshine and risk deterioration. Using the MFD and sun drying combination gives the farmer greater profit than selling wet or selling dry but damaged grain.

Table 2. Cost–and–return analysis of the mobile flash dryer at varying utilisation rates in drying paddy grain from 23–24% initial moisture content to 18–20% m.c.

Heating unit	Rice hull furnace	Kerosene burner	Rice hull furnace	Kerosene burner
Annual utilisation rate, days[a]	60	60	120	120
Annual capacity, cavans[b]	10,560	10,560	21,120	21,120
Total investment cost, pesos	110,000	85,000	110,000	85,000
Dryer unit	65,000	65,000	65,000	65,000
Engine, 5 h.p. gasoline	10,000	10,000	10,000	10,000
Dryer shed	10,000	10,000	10,000	10,000
Rice hull furnace	25,000	–	25,000	–
Total fixed cost, pesos/year	27,280	21,080	27,280	21,080
Depreciation[c]	9,900	7,650	9,900	7,650
Interest on average capital invested[d]	9,680	7,480	9,680	7,480
Repair and maintenance[e]	5,500	4,250	5,500	4,250
Taxes and insurance[f]	2,200	1,700	2,200	1,700
Total variable cost, pesos/year	44,576	83,016	89,153	166,032
Labour[g]	26,400	26,400	52,800	52,800
Rice hull[h]	1,080	38,400	2,160	76,800
Gasoline[i]	14,400	14,400	28,800	28,800
Miscellaneous[j]	1,256	2,376	2,512	4,752
Oil and grease[k]	1,440	1,440	2,880	2,880
Total drying cost, pesos/year	71,856	104,096	116,433	187,112
Drying cost, pesos/cavan ($[l]/cavan)	6.80 (0.26)	9.86 (0.38)	5.51 (0.21)	8.86 (0.34)
Drying fee, pesos/cavan ($/cavan)	12.00 (0.46)	12.00 (0.46)	12.00 (0.46)	12.00 (0.46)
Total net income, pesos	54,863.60	22,598.40	137,007.20	66,316.80
Return on investment, %	49.88	26.59	124.55	78.02
Payback period, years	2.00	3.76	0.80	1.28

[a] Based on 16 hours/day operation
[b] 50 kg/cav at 11 cavan/hour capacity from 23–24% initial m.c. to 18–20% final m.c.
[c] Straightline method, 10% salvage value, 10 years life span
[d] 16% interest rate per year
[e] 5% of investment cost
[f] 2% of investment cost
[g] 3 persons at 2.50 pesos/cavan input
[h] 20 kg/hour at 0.025 pesos/kg
[i] 1.5 litres at 10 pesos/litre at 16 hours/day
[j] 3% of labour and fuel costs (for towing and other incidental expenses due to variation of days of utilisation
[k] 10% of gasoline cost
[l] The conversion rate used was 25 pesos to US$1.

Table 3. Comparison of costs of various drying options during wet season harvest.

Drying option	Final m.c.[a] %	Selling cost pesos/kg ($/kg)	Weight when sold[b] kg	Gross income pesos/cavan[c] ($/cavan)	Drying cost pesos/cavan ($/cavan)	Net income pesos/cavan ($/cavan)
1. Sell wet	24	4.0 (0.15)	50.0	200.0 (7.69)	0	200.0 (7.69)
2. Sell dry but damaged	14	5.0 (0.19)	44.2	221.0 (8.50)	10 (0.38)	211.0 (8.12)
3. Flash dry and sun dry	14	6.0 (0.23)	44.2	265.2 (10.20)	16 (0.62)	249.2 (9.58)
4. Flash dry to 18%	18	5.5 (0.21)	46.3	254.9 (9.80)	12 (0.46)	242.9 (9.34)
5. Flash dry to 14% m.c.	14	6.0 (0.23)	44.2	265.2 (10.20)	25 (0.96)	240.2 (9.24)

[a] From initial moisture content of 24%.
[b] From initial weight of 50 kg.
[c] One cavan = 50 kg.

Commercialisation

Credit assistance

The Land Bank of the Philippines (LBP) forged an agreement with NAPHIRE in 1991 for a credit assistance program to farmer cooperatives that wish to purchase NAPHIRE-designed improved postharvest technologies. LBP provides the financial resources while NAPHIRE gives the technical assistance to these cooperatives.

Accredited manufacturers

Recognising that cooperative development of machinery by both the research institution and the manufacturers is a highly effective method for successful technology development and transfer, NAPHIRE enlisted the participation of eligible machinery manufacturers in building the dryer. From among the 35 manufacturers who have signified their intention to build MFDs, NAPHIRE has selected and accredited 12 manufacturers (Table 4). Accreditation of manufacturers is a continuing activity of the Training and Extension Department of NAPHIRE.

Commercialized units

As of December 1994, 385 units of flash dryers have been sold. The units marketed have been adopted by cooperatives throughout the Philippines as beneficiaries of the Grains Production Enhancement Program (GPEP) of the government.

Aside from GPEP, the mobile flash dryer has been selected by cooperating government agencies of the GPEP Postharvest Component including local government units to be the type of dryer disseminated to eligible cooperatives.

Table 4. List of fully accredited manufacturers of flash dryers in the Philippines.

1.	**CMC Metal Craft**	Bayugan, Agusan del Sur, Philippines.
2.	**Emerald Machinery Sales, Inc.**	Diamond Motor Service Bldg., 41-B Serrano Ave. Quezon City.
3.	**Gregorio Danganan Welding & Repair Shop**	3438 Liboro St., Pag-asa, San Jose, Occidental Mindoro.
4.	**Josian International Machines**	Maahas, Los Banos, Laguna.
5.	**KATO Machineries**	Manila.
6.	**Los Banos Agricultural Machineries**	Maahas, Los Banos, Laguna.
7.	**Mateo Tayag Metal Craft**	Juan Luna St., San Jose, Occidental, Mindoro.
8.	**Morallo Iron Works**	661 Highway 1, San Miguel, Iriga City.
9.	**MTP Metal Craft**	Turayong, Cauayan, Isabela.
10.	**Prime Index Philippines**	1651 Oroquieta St., Sta. Cruz, Manila.
11.	**R & B Metal Craft c/- Equity Enterprises**	Cauayan, Isabela.
12.	**ROPALI Trading Corporation**	Cauayan, Isabela.
13.	**Tropics Agro-Industries, Inc.**	25 Panganiban St., Naga City, Camarines Sur.

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Grain Condition Monitoring and Aeration Control Systems

Cao Guanzhi*

THE Grain Condition Detection, Analysis, and Ventilation Control System (GCDAVCS) can monitor remotely the temperature and humidity of a grain mass. The computer controls detection of grain conditions and determines the requirements for aeration, temperature change, and moisture adjustment. Depending on the conditions provided by the host computer (control unit), the substations then provide dynamic real time and closed-loop control through the software of the aeration model.

Operational Procedure

The GCDAVCS transmits the field signals to the host computer, through the sensors, substations (data collectors), and double twist wires in a predetermined sequence. The host computer then computes the aeration necessary based on the information provided. To improve the calculation, the analysis of the grain mass is done by a mathematically-based model. Figure 1 shows the components and arrangement of the GCDAVCS.

Main Functions

Timing of the data collection

If the time for reading of the sensors in the detection circuit is set, the GCDAVCS units will operate automatically at that time every day. The host computer will store data for three days and it can be saved and printed.

Real time data recovery

Operators can read the sensors at any time when the detection circuit is not operating (including grain and air temperatures and humidities).

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Grain condition dynamic intelligent analysis

Compared with the use, collection and analysis of temperature information by hand, GCDAVCS has been an important breakthrough. With its analysis based on artificial intelligence and fuzzy logic, GCDAVCS can analyse the grain temperature range present and detect signs of heating using the special mathematical model for changing patterns of conditions in grain. The model induces automatically the local temperature change patterns and modifies the temperature curves to forecast the limit of the temperature trend and its pattern of change. Three dimensional pictures are used to provide easily seen illustrations of the temperature change.

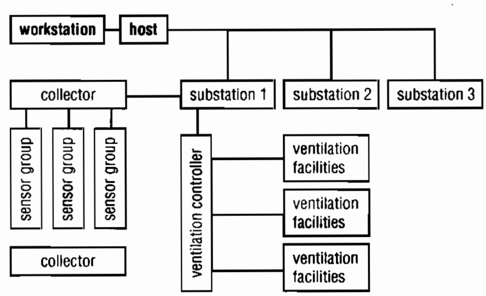


Figure 1. Diagram of the Grain Condition Detection, Analysis, and Ventilation Control System (GCDAVCS).

Intellgent automatic aeration control

Because of the equations and data provided by the 'Mechanical Ventilation of Provision Reserve Technical Rules,' the GCDAVCS does not require operators to calculate the equilibrium humidity and temperature difference for aeration air to establish the required temperature and humidity differences in the grain mass. Thus, mechanical ventilation (aeration) can be controlled automatically by the GCDAVCS if the storage identification number, grain present, its moisture content and the purpose of the aeration (lowering temperature, reducing moisture contact, or adjusting) are put into the computer. In this way, condensation is prevented during aeration.

Practical Application

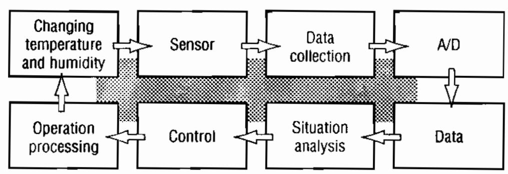
The field signals by the collector substations of temperature, humidity, A/D converter and data can be computed into the control substations independently. Each substation may cut short the reading of the circuit of sensors. They also send out on/off signals to the aeration controllers according to the aeration conditions required by the central host computer. Store keepers can thus program sensor monitoring and aeration control off line from the network. When grain temperature is being reduced and aeration is carried out according to the 'Mechanical Ventilation of Provision Reserve Technical Rules', the allowable temperature conditions are: at the beginning, $T_2 - T_1 \geq 8°C$ (subtropical zone $T_2 - T_1 \geq 6°C$); during the course $T_2 - T_1 \geq 4°C$ (subtropical zone $T_2 - T_1 \geq 3°C$); where T_2 is the average temperature in the grain mass (°C); and T_1 is the air temperature (°C) outside the granary.

The allowable humidity conditions for temperature reduction with aeration are: below the interstitial grain temperature, the equilibrium absolute grain humidity, PS_2, is higher than the interstitial absolute air humidity PS_1, that is, $PS_2 > PS_1$. To end the temperature reduction with aeration, the condition is $T_2 - T_1 \leq 4°C$ (subtropical zone, $T_2 - T_1 \leq 3°C$); the temperature gradient of the grain mass $\leq$ 1°C/m grain layer thickness: the grain mass moisture gradient $\leq$ 0.3%/m grain layer thickness. The conditions for moisture reduction and aeration vary among grains. During moisture reduction with aeration of wheat of moisture content below 16%, late rice below 18%, maize below 20%, beans below 18%, and rapeseed below 12%, the allowable humidity conditions for moisture reduction and aeration are: grain moisture reduces 1%; grain temperature = grain average temperature T_2 > air dew-point temperature T_{11}, that is, $T_2 > T_{11}$.

The allowable temperature conditions for moisture reduction with aeration are: grain moisture reduces 1% and grain temperature = air temperature T_1; equilibrium absolute grain humidity PS_{21} > interstitial absolute air humidity PS_1, that is $PS_{21} > PS_1$. When the aeration air is introduced to the bottom layer of the grain the drying front moves through to the top grain layers. When the aeration air is sucked from the bottom layer, the drying front moves to the bottom of the mass and when the grain temperature gradient ≤1°C/m grain layer thickness, the aeration should be stopped.

Temperature and moisture adjustment with aeration must be done before grain processing. The allowable conditions for adjusting temperature with aeration are: the average grain temperature T_2 > air dew-point temperature T_{11}, that is, $T_2 > T_{11}$. After aeration, the upper grain mass temperature should not exceed the safe storage temperature after the moisture content of the grain mass has increased. The allowable humidity conditions for adjusting moisture content with aeration are: the grain moisture increasing 2.5% and the grain temperature = air temperature T_1; the equilibrium absolute humidity PS_{22} < the interstitial absolute air humidity PS_1, that is, $PS_{22} < PS_1$. When the moisture content of the grain mass reaches the required level, it should be below the safe reserve moisture level, with the grain mass moisture gradient ≤ 0.5/m grain layer thickness; and the grain mass temperature gradient ≤ 1°C/m grain layer thickness. At this point the aeration should be stopped.

Using the above-mentioned principles, the intelligent automatic aeration control system can operate on many automatic aerated storages at the same time. When the storage identification number, grain present, its moisture content, and the purpose of the aeration are put into the computer, the GCDAVCS uses this information to provide dynamic real time control for monitoring of conditions and automatic operation of the aeration. The working diagram (see below) is a control circle.



Data collection is done once every two minutes monitoring the temperature changes. After the control information is programmed into the computer, the substations collect temperature and humidity of the ambient air and the temperature of the grain to enable calculation of the relative equilibrium humidity, the absolute humidity and the grain mass dew point. Aeration is then done according to the following:

Aeration Purpose	Allowable conditions for aeration	
Temperature reduction	The first temperature difference and the operating tempering difference $PS_1 < PS_2$	
Moisture reduction and adjustment	$PS_1 < PS_3$	$T_2 > T_4$
	$PS_1 > PS_5$	$T_2 > T_4$

T_1 Air temperature; T_2 Grain mass temperature; PS_1 Air absolute temperature; PS_2 Below the interstitial grain temperature, the equilibrium absolute grain humidity; PS_3 When the grain temperature is close to the air temperature, the grain moisture w%–1% to the equilibrium absolute humidity; T_4 Air dew-point; PS_5 When the grain temperature is close to the air temperature, the grain moisture w% + 2.5% to the equilibrium humidity.

Summary

Advanced mathematical models are used to manage grain conditions and provide dynamic real time control of aeration. This automatic control replaces the experienced technicians in analysis, collection of data, and decision making. Because of the large quantities of data involved, the mathematical model for grain monitoring and analysis of grain conditions is installed in the computer. The model for aeration control can be installed in the substations. Because of the differences in grains involved, their moisture and the purpose of the aeration, the substations work independently. If the central host computer is out of order, the substations can still operate. The system is now widely distributed, being installed in about 100 state grain reserve depots. The results have all been good.

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Use of Rice Husk Gasification in Grain Drying

Chen Zhishun*

JIANGSU is one of the important agricultural provinces of China producing on average 32 Mt of grain. Some 8 Mt of this is held in storage. Jiangsu is located on the east coast of Asia and is seasonally very hot and humid.

A recent estimate located nearly 750 grain dryers of diverse type in the province. This accounts for about 30% of the total number of dryers in China. Of these, there are 580 fluidised-bed dryers with the balance being rotary dryers, steel tower dryers, flat dryers, vibrating fluidised-bed dryers, and infrared dryers. These units handle on average, 1 Mt of wet grain annually. Performance data for the three main types of dryer are given in Table 1.

Jiangsu has a large amount of storage with varied facilities using appropriate methodology for handling the wet grain in an area which, as indicated above, is seasonally very hot and humid. It is typical of China.

Rice Husk Gasification for Grain Drying

The yearly average of 1 Mt of wet grain being dried by the 750 dryers consumes 24 000 t of fuel. It is thus very important and urgent to exploit renewable resources to replace the fuel oil and coal which are in short supply and expensive. Grain dryers are commonly located near rice mills which produce large quantities of husk residues. This rice husk may be regarded as an appropriate and cheap source of heat energy for drying grain.

Jiangsu province consumes approximately 18 500 t of rice husk each year for drying grain. This accounts for 77% of the total fuel consumption in the province for grain drying and 90% of national use of rice husk for this purpose.

Four types of rice husk furnace were designed to match the growth of the grain drying in the rice industry:

(i) Manually operated furnace constructed of brick
(ii) Manually operated furnace fabricated from metal
(iii) Down-draft rice husk gas producer
(iv) Up-draft rice husk gas producer.

The following is a brief introduction to the operation of these types of furnace.

Manually operated furnaces

This type is commonly installed in primary grain depots. The facilities have low construction costs, are convenient in operation, and have a higher calorific efficiency. They have a brick or metal casing with the furnace body comprising a burning chamber and a mixing chamber

Rice husk gasification units

A unit consists of a rice-husk gas producer, a conditioning drum, and a burning chamber. The unit supplies steady heat to the grain dryer and its main advantage is that it does not pollute the dried grain. In a random sampling test, the BaP content of the grain is nearly constant at 0.72 ppb before and after drying whereas with hard coal and rice husk tunnel gas the BaP content increases to 1.28 ppb and 2.05 ppb respectively.

The gasification process

Rice husk is fed from the top of the furnace into the reaction chamber and the producer gas led to the conditioning drum for storage and thence to the burning chamber. The producer gas is mixed with air and burnt in the 'heat exchanger' to produce high temperature flue gas which is then mixed with twice the volume of air and then used as the heat source for drying the grain.

The reaction in the gas producing furnace is divided from top to bottom according to temperature into a drying layer, a distillation layer, and an active gasification layer. The reaction formulae are as follows:

$$C + O_2 = CO_2 + 97{,}650 \text{ kcal}$$
$$C + 1/2O_2 = CO + 29{,}430 \text{ kcal}$$
$$C + CO_2 = 2CO - 38{,}790 \text{ kcal}$$
$$C + H_2O = CO + H_2 - 28{,}800 \text{ kcal}$$
$$CO + H_2O = CO_2 + H_2 + 9{,}849 \text{ kcal}$$

* Jiangsu Grains, Oils and Foods International Corporation, 53 Shanxi Rd, Nanjing, China.

Table 1. Test data of the three main types of dryer

Types	HH32x320 Fluidised-bed dryer	HY125x10 Rotary dryer	HLZ-30 Netted Column dryer
Capacity (t/h)	7.80	15.08	11.64
Moisture removal (%)	2.07 (15.92–13.85)	3.33 (18.03–14.70)	2.20 (16.2–14.00)
Fuel	Rice husks	Coal	Coal
Fuel consumption (kg/h)	85.2	122	58.8
Energy consumption in water removal (kcal/kg water)	1321	1079	1023
Breakage rate (%)	+1	+2.5	+0.5

Table 2. Analysis of rice husk

Components	Content (%)
Water	11.66
Volatiles	55.62
Fixed carbon	16.33
Ash	18.32
Calorific value	2960 kcal/kg

There are two types of gas producer: the down-draft and the up-draft system.

The down-draft rice husk gas producer

The body of the producer is the gasification chamber. The top is open for feeding in the rice husk and air. There is a gas outlet in the jacket of the furnace to remove the producer gas and the bottom of the chamber is sealed with water to prevent explosions.

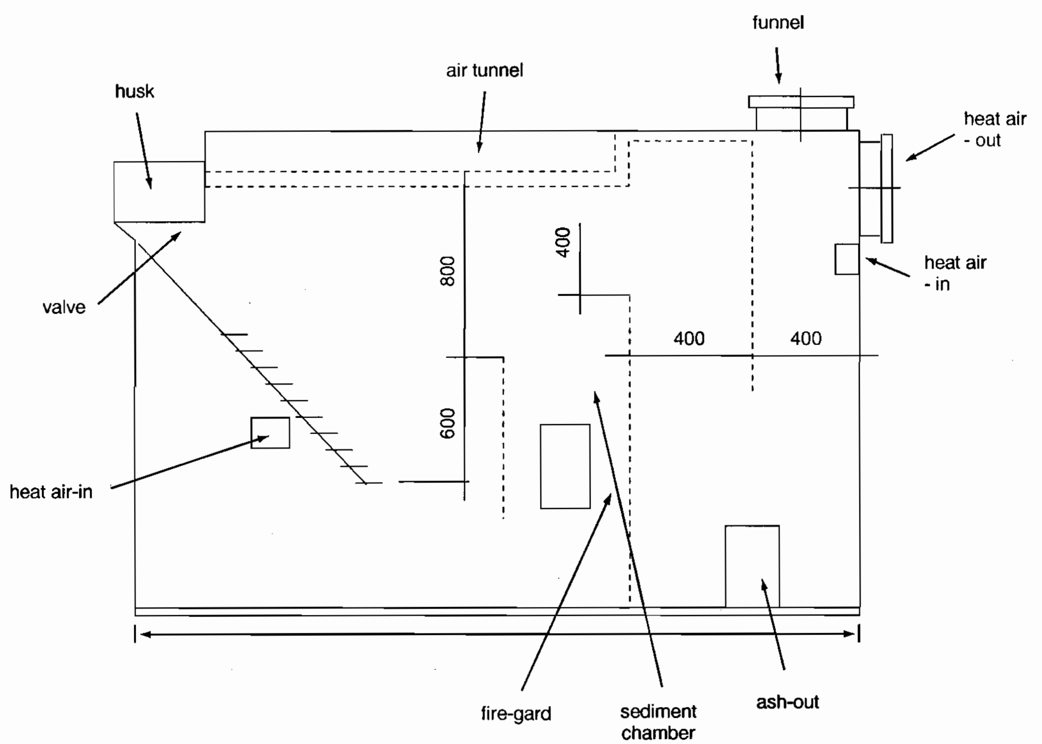

Figure 1. Manually operated furnaces for rice husk.

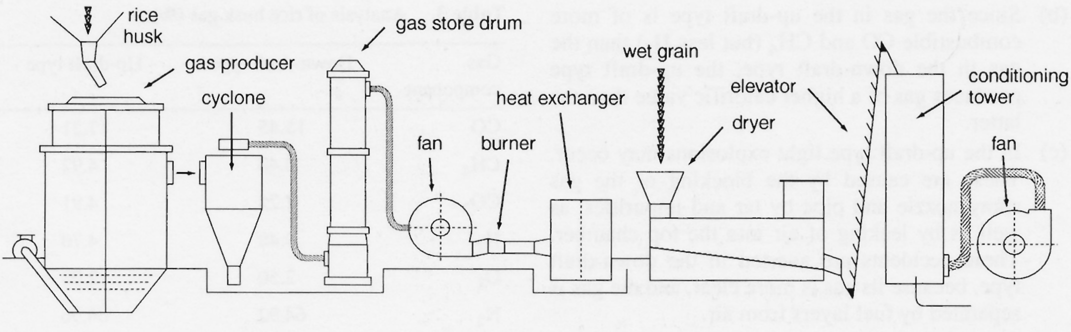

Figure 2. Integration of rice-husk gasification into grain drying

Ash falls into the water through the grate at the bottom of the chamber and is removed by a screen conveyor. The body of the furnace is filled with a water-jacket for heat insulation. A fan assists starting the combustion process and moving the gas when the unit is operating.

The up-draft rice husk gas producer

This is another application of the gasification system for indirectly drying grain. The air-flow is in the reverse direction to that of the previous gas producer and construction is different. The furnace cover is sealed and is blown by a fan from the bottom of the chamber. After the several reactions as in the down-draft process, the gas is drawn off from the empty space in the top of the reaction chamber and passed to the conditioning drum and then burnt to dry the grain.

A comparison between the down-draft and up-draft gas producers

(a) Gasification strengths are respectively 132 kg/m^2h for the down-draft type and 149 kg/m^2h for the up-draft type. This indicates that the dimensions of the second type may be reduced by 10% to reduce costs. In such modification of design, however, attention should be paid to the attenuation of calorific efficiency in that type of gas producer.

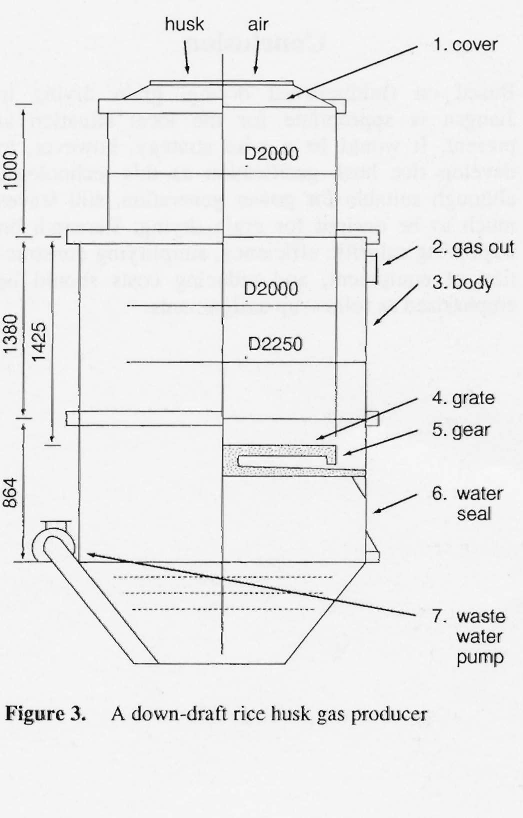

Figure 3. A down-draft rice husk gas producer

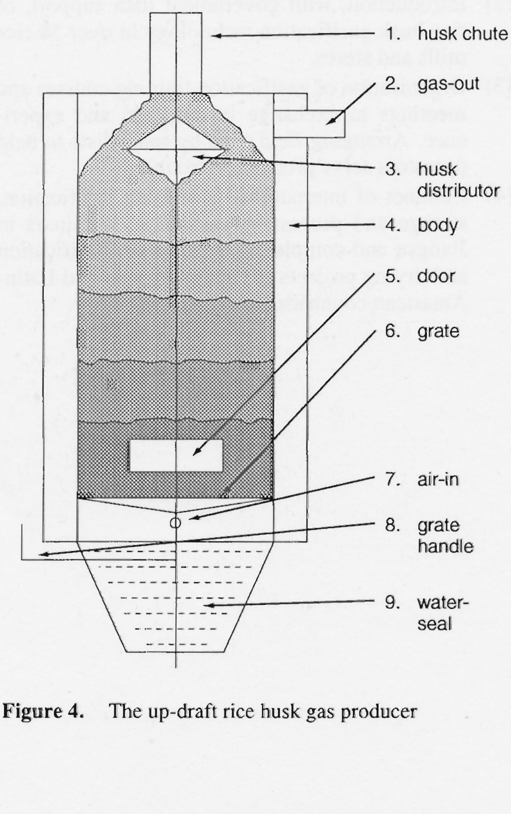

Figure 4. The up-draft rice husk gas producer

(b) Since the gas in the up-draft type is of more combustible CO and CH_4 (but less H_2) than the gas in the down-draft type, the up-draft type produces gas of a higher calorific value than the latter.
(c) In the up-draft type light explosions may occur. These are caused by the blocking of the gas spray nozzle and pipe by tar and impurities, as well as by leaking of air into the top chamber. These accidents are averted in the down-draft type, because its gas is more clear, and the gas is separated by fuel layers from air.
(d) The down-draft drying system may be operated in parallel with the gas generating system. Thus the combined system can supply a rice mill with heat for drying and electric power for mill operation.

Diffusion of Rice Husk Gasification Technology

On behalf of the Jiangsu Provincial Grain Bureau, the Jiangsu Grains Oils and Foods International Corporation has promoted rice husk gasification technology, and accomplished programs as follows.

(1) Research on rice husk gasification and successful design of Models 6250 and 6160 rice husk gasification units.
(2) Introduction, with government loan support, of rice husk gasification technology in over 50 rice mills and stores.
(3) Organisation of gasification training courses and meetings to exchange information and experience. Arranging field trips by specialists to help operators solve production troubles.
(4) Conduct of international rice husk gasification, storage and processing technology seminars in Jiangsu and completing 9 rice husk gasification and drying projects in Asian, African and Latin-American countries.

Table 3. Analysis of rice husk gas (%).

Gas component	Down-draft type	Up-draft type
CO	15.45	17.21
CH_4	0.40	4.92
CO_2	7.25	4.91
H_2	9.48	4.70
O_2	2.50	2.98
N_2	64.92	64.96
C_nH_m	–	0.32

Table 4. Technical data on gas producers.

Item	Down-draft type	Up-draft type
Diameter of container	2 m	1 m
Gasification strength	132 kg/m^2h	149 kg/m^2h
Gasification effect	4.5 m^3/kg	2.3 m^3/kg
Calorific efficiency	73%	63.7%
Calorific value	750 $kcal/m^3$	1 100 $kcal/m^3$
Husk consumption	400 kg/h	138 kg/h

Conclusion

Based on fluidised-bed drying, grain drying in Jiangsu is appropriate for the local situation at present. It would be a wise strategy, however, to develop rice husk gasification as this technology, although suitable for power generation, still leaves much to be desired for grain drying. Research on improving calorific efficiency, simplifying construction of equipment, and reducing costs should be emphasised as follow-up assignments.

The Effects of Drying and Shelling on *Fusarium* spp. Infection and *Fusarium* Toxins Production in Maize

O.S. Dharmaputra*, H.K. Purwadaria†, H. Susilo§, and S. Ambarwati§

TOXIGENIC *Fusarium* species can grow on some of the staple foods of both humans and animals, among them maize. According to Miller (1994) deoxynivalenol was produced by both *F. graminearum* and *F. culmorum*, while nivalenol was produced only by *F. graminearum*. Deoxynivalenol could cause some diseases, among others necrosis of the skin (Ueno 1977), while nivalenol caused vomiting in ducks and dermal toxicity in rabbits (Betina 1989).

According to Dharmaputra et al. (1994), a survey conducted by a BIOTROP team in 1992 revealed that:

- the highest percentage of maize kernels infected by *F. moniliforme* and *F. semitectum* was in freshly harvested maize cobs (77.4%), while the lowest was on dry shelled maize stored at trader level (30.8%);
- the highest nivalenol content was on shelled maize (12.5 ppm), while the lowest was on dry maize cobs (5.8 ppm);
- during the dry season the highest deoxynivalenol content was on dry maize cobs (2.8 ppm), while the lowest was on dry shelled maize (1.2 ppm);
- during the wet season the highest content was on freshly harvested maize cobs (3.8 ppm), while the lowest was on dry shelled maize stored at trader level (1.9 ppm).

Postharvest handling (including drying and shelling) can affect fungal infection. In general, the moisture content of freshly harvested maize is still high, and it is therefore a good substrate for fungal growth. Shelling can cause mechanical damage, and fungal spores can infect the kernel through the damage. Consequently, the kernels should be shelled using a proper tool and at an appropriate moisture content to reduce the damage.

The objective of this study was to obtain information on the effects of some methods of drying and shelling on *Fusarium* spp. infection and *Fusarium* toxins production in maize stored under laboratory conditions. Also sought was information on the effect of drying and shelling on the integrity of kernels, and the effect of storage duration on changes in moisture content.

Materials and Methods

Maize variety

Two maize varieties (Arjuna and CPI-2) were used in this study. They were grown at the experimental plot of the Research Institute for Food Crop Biotechnology, Bogor, harvested at 90 and 97 days after planting, respectively, and husked immediately after harvest.

Drying and shelling

Cobs of maize were divided into four lots. The 1st and the 2nd lots were sun dried to 20% moisture content (m.c.), then shelled and further dried after shelling to 17 and 14% m.c., respectively. The 3rd lot was sun dried to 17% m.c. then shelled but was not dried further. The 4th lot was sun dried to 17% m.c., then shelled and further dried after shelling to 14% m.c. All maize samples were sun dried by spreading the cobs or kernels on a paved floor.

Nail-down wood and a mechanical sheller type Yanmar TF 55-di with a cylinder rotation of 500-700 rpm were used for shelling the maize.

Storing of maize and method of sampling

After drying and shelling, 500 g of maize from each treatment was placed in a 3.3 L jar covered with muslin cloth, and stored for 1, 2, and 3 months under laboratory conditions. Two replicates were used for each treatment. The ambient temperature and relative humidity of the storage were recorded using a Wilh. Lambrecht thermohygrograph type 252.

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An initial sample was obtained from each replicate (jar) at the beginning of storage, and further samples at 1, 2, and 3 months of storage. Each sample was divided twice using a sample divider to obtain working samples for moisture content, damaged kernels, population of *Fusarium* spp., and *Fusarium* toxins content analyses.

Moisture content, damaged kernels, population of *Fusarium* spp., and *Fusarium* toxins content analyses

Moisture content (wet basis) was determined using the oven method at 130°C for 2 hours (BSI 1980). The damaged kernels analyses were carried out at the beginning of storage to obtain the percentage of damaged kernels caused by shelling.

Fusarium spp. was isolated using dilution method on Dichloran Chloramphenicol Peptone Agar (DCPA) (Pitt and Hocking 1985). *Fusarium* toxins content was determined using high performance liquid chromatography (HPLC) methods (Blaney et al. 1986).

Experimental design

The data were analysed using a completely randomised factorial design with 4 factors. The 1st, 2nd, 3rd, and 4th factors were maize variety, method of drying, method of shelling, and duration of storage, respectively.

Results and Discussion

The effect of maize variety, methods of drying and shelling, and storage duration on moisture content and incidence of damaged kernels

Based on statistical analysis, the effects of drying, duration of storage, and their interaction caused significant differences to moisture content, while variation in variety and method of shelling was not significant (Table 1).

At the beginning of storage, the moisture contents of the grain subjected to drying methods I, II, III, and IV were 16.84, 14.10, 17.11, and 14.35%, respectively. Following 1 month of storage moisture contents had fallen (13.98, 13.51, 14.05 and 13.75%, respectively), and then remained almost constant for 2 and 3 months of storage (Table 2). It was assumed that the moisture content of maize at 2 and 3 months of storage would approach an equilibrium with the relative humidity of the storage. According to Hall (1957) and Henderson and Perry (1976), this equilibrium moisture content is reached when the grains cease to either absorb or release vapour. Brooker et al. (1974) reported that the equilibrium moisture content is affected by temperature, humidity, variety, and maturity of grains. The ranges of temperature and relative humidity of the storage were 21.75–29.25°C and 47.88–88.25%, respectively (Table 3).

Maize variety, drying, and shelling each had a significant effect on occurrence of damaged kernels, but their interaction was not significant (Table 4).

The percentage of damaged kernels of maize var. CPI-2 (5.0%) was higher than that of var. Arjuna (3.6%) (Table 5). It was presumed that the kernels of var. CPI-2 were larger and less solid than var. Arjuna, and therefore could be more easily cracked or broken during shelling.

Table 1. Analysis of variance on the effects of variety, drying, shelling, duration of storage and their interaction on moisture content of maize.

Source of variance	df	SS	MS	F Value
A	1	0.0200000	0.0200000	0.22
B	3	22.2191000	7.4063667	81.58**
A×B	3	0.1580750	0.0526917	0.58
C	1	0.1682000	0.1682000	1.85
A×C	1	0.0288000	0.0288000	0.32
B×C	3	0.7585250	0.2528417	2.78*
A×B×C	3	0.2064250	0.0688083	0.76
D	3	137.6364812	45.8788271	505.32**
A×D	3	0.2039063	0.0679688	0.75
B×D	9	40.7079438	4.5231049	49.82**
A×B×D	9	0.6937437	0.0770826	0.85
C×D	3	0.2252688	0.0750896	0.83
A×C×D	3	0.1070437	0.0356812	0.39
B×C×D	9	1.3455312	0.1495035	1.65
A×B×C×D	9	0.4364063	0.0484896	0.53
Error	63	5.7198875	0.0907919	

A	Variety
B	Drying
A×B	Interaction between variety and drying
C	Shelling
A×C	Interaction between variety and shelling
B×C	Interaction between drying and shelling
A×B×C	Interaction among variety, drying and shelling
D	Duration of storage
A×D	Interaction between variety and duration of storage
B×D	Interaction between drying and duration of storage
A×B×D	Interaction among variety, drying and duration of storage
C×D	Interaction between shelling and duration of storage
A×C×D	Interaction among variety, shelling and duration of storage
B×C×D	Interaction among drying, shelling and duration of storage
A×B×C×D	Interaction among variety, drying, shelling and duration of storage
*	Significantly different at 95% confidence level
**	Significantly different at 99% confidence level

Table 2. Moisture content of maize treated with different methods of drying during storage.

Drying method[a]	Moisture content (%) Duration of storage (months)			
	0	1	2	3
I	16.84 a	13.98 cd	13.18 g	13.08 g
II	14.10 bc	13.51 ef	13.04 g	13.02 g
III	17.11 a	14.05 bcd	12.95 g	13.21 g
IV	14.35 b	13.75 de	12.99 g	13.01 g

Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

[a] I Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 17% moisture content.
II Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 14% moisture content.
III Cobs of maize were sun dried to 17% moisture content, then shelled and were not re-dried.
IV Cobs of maize were sun dried to 17% moisture content, then shelled and re-dried after shelling to 14% moisture content.

Table 3. Range of temperature and relative humidity in the storage room.

Duration of storage (month)	Temperature (°C)	Relative humidity (%)
1	21.8–28.4	61.0–88.3
2	21.8–28.4	61.0–88.3
3	21.8–29.3	47.9–88.3

Table 4. Analysis of variance on the effects of variety, drying, shelling and their interaction on damaged kernels of maize at the beginning of storage.

Source of variance	df	SS	MS	F Value
A	1	15.52637813	15.52637813	16.33**
B	3	22.82528438	7.60842813	8.00**
AxB	3	3.33008437	1.11002812	1.17
C	1	63.59100313	63.59100313	66.89**
AxC	1	0.05695312	0.05695312	0.06
BxC	3	1.97750938	0.65916979	0.69
AxBxC	3	2.94960937	0.98320312	1.03
Error	15	14.2605719	0.9507048	

A Variety
B Drying
AxB Interaction between variety and drying
C Shelling
AxC Interaction between variety and shelling
BxC Interaction between drying and shelling
AxBxC Interaction among variety, drying and shelling
** Significantly different at 99% confidence level

The percentage of damaged kernels of maize shelled at 20% m.c. (drying methods I and II) (4.7 and 5.4%, respectively) was higher than for maize shelled at 17% m.c. (drying methods III and IV) (3.7 and 3.2%, respectively). According to SFCDP (1990), low quality maize generally contains more than 3% damaged kernels, and the percentage increases if the grain is shelled at greater than 18% m.c..

The percentage of damaged kernels (5.7%) in maize shelled by mechanical sheller was higher for maize shelled by nail-down wood (2.9%). It was assumed that shelling of each cob of maize using a nail-down wood did not result in friction between cobs, in contrast to shelling using a mechanical sheller. Moreover, manual shelling using a nail-down wood can be controlled to reduce friction between the sheller and the maize. According to Suprayitno (1980) the percentage of damaged kernels of maize shelled using a mechanical sheller is higher because of friction between intact kernels and between intact kernels and the cylinder of the mechanical sheller.

Table 5. The effect of maize variety, methods of drying and shelling on damaged kernels at the beginning of storage.[a]

Effect	Damaged kernels (%)
Maize variety	
Arjuna	3.6 a
CPI-2	5.0 b
Method of drying[b]	
I	4.7 cd
II	5.4 c
III	3.7 de
IV	3.2 e
Method of shelling	
Nail-down wood	2.9 f
Mechanical sheller	5.7 g

Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

[a] Damaged kernels analysis was carried out only at the beginning of storage

[b] I Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 17% moisture content.
II Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 14% moisture content.
III Cobs of maize were sun dried to 17% moisture content, then shelled and were not re-dried.
IV Cobs of maize were sun dried to 17% moisture content, then shelled and re-dried after shelling to 14% moisture content.

The effect of maize variety, methods of drying and shelling, and storage duration on population of *Fusarium* spp.

Two species of *Fusarium* were isolated: *F. moniliforme* and *F. nygamai*. *F. moniliforme* can produce moniliformin (Martin 1976) and fumonisin (Gelderblom et al. 1988). According to Dharmaputra et al. (1993), *F. moniliforme* and *F. nygamai* can produce deoxynivalenol.

Based on statistical analysis, maize variety had a very significant effect on the population of *Fusarium* spp. duration of storage gave significant differences, while drying, shelling, and interaction among maize varieties, and drying, shelling and duration of storage did not give significant differences (Table 6).

The population of *Fusarium* spp. on maize var. Arjuna (8892 colonies/g) was higher than that on var. CPI-2 (3282 colonies/g) (Table 7). It was assumed that maize var. Arjuna was more susceptible to *Fusarium* spp. than var. CPI-2.

Fusarium spp. population on maize shelled at 20% m.c. (drying methods I and II) (9715 and 8846 colonies/g) was higher than that on maize shelled at 17% m.c. (drying methods III and IV) (2283 and 2953 colonies/g), but the difference was not significant (Table 7). It was assumed that *Fusarium* grew well on substrate with a high moisture. According to Christensen and Kaufmann (1974), *Fusarium* needs substrate with high moisture content (22–23%) for its growth.

The population of *Fusarium* spp. on maize shelled by mechanical sheller (7129 colonies/g) was higher than on that shelled by nail-down wood (5044 colonies/g), but the difference was not significant (Table 7). It was assumed that the proportion of damaged kernels in maize shelled by mechanical sheller was higher than in maize shelled by nail-down wood, and consequently that maize shelled by mechanical sheller could be more easily infected by *Fusarium*.

Fusarium spp. population increased at 1 and 3 months of storage, from 2537 colonies/g to 9385 and 9096 colonies/g, respectively, but it decreased at 2 months of storage. It was assumed that there were fungi antagonistic to *Fusarium* spp., because one kernel could be infected by more than one fungal species.

The effect of maize variety, methods of drying and shelling, and storage duration on *Fusarium* toxin content

Two *Fusarium* toxins were obtained: nivalenol (NIV) and deoxynivalenol (DON). Tamm and Tori (1984) and Dharmaputra et al. (1993) reported that *F. moniliforme* and *F. nygamai* produced DON.

The effects of maize variety, shelling, duration of storage, and interaction among varieties, drying, shelling, and duration of storage gave very significant differences to NIV content, while drying did not give significant differences (Table 8).

The effects of maize variety, drying, and duration of storage resulted in very significant differences to DON content, shelling gave significant differences, while interaction among maize varieties, drying, shelling, and duration of storage did not give significant differences (Table 8).

Table 6. Analysis of variance on the effects of variety, drying, shelling, duration of storage and their interaction on population of *Fusarium* spp. (transformed into log. population of *Fusarium* spp. + 1) of maize.

Source of variance	df	SS	MS	F Value
A	1	34.48470925	34.48470925	7.32**
B	3	1.76225659	0.58741886	0.12
A×B	3	9.53619213	3.1783071	0.67
C	1	5.05448890	5.05448890	1.07
A×C	1	8.04765365	8.04765365	1.71
B×C	3	15.37478516	5.12492839	1.09
A×B×C	3	10.55589127	3.51863042	0.75
D	3	40.04969385	13.34989795	2.83*
A×D	3	2.86088526	0.95362842	0.20
B×D	9	54.59030187	6.06558910	1.29
A×B×D	9	60.03023921	6.67002658	1.49
C×D	3	5.31038397	1.77012799	0.38
A×C×D	3	10.02239775	3.34079925	0.71
B×C×D	9	32.61029761	3.62336640	0.77
A×B×C×D	9	29.27228927	3.25247659	0.69
Error	63	296.6930382	4.7094133	

A Variety
B Drying
A×B Interaction between variety and drying
C Shelling
A×C Interaction between variety and shelling
B×C Interaction between drying and shelling
A×B×C Interaction among variety, drying and shelling
D Duration of storage
A×D Interaction between variety and duration of storage
B×D Interaction between drying and duration of storage
A×B×D Interaction among variety, drying and duration of storage
C×D Interaction between shelling and duration of storage
A×C×D Interaction among variety, shelling and duration of storage
B×C×D Interaction among drying, shelling and duration of storage
A×B×C×D Interaction among variety, drying, shelling and duration of storage
* Significantly different at 95% confidence level
** Significantly different at 99% confidence level

NIV and DON contents of maize var. CPI-2 (1.86 and 0.28 ppm) were higher than those of var. Arjuna (1.80 and 0.25 ppm) (Table 9).

NIV contents of maize dried using the four methods were not significantly different from each other (1.81–1.85 ppm). The DON content of maize dried using the 1st and 3rd methods (0.24 ppm) was lower than in the 2nd and 4th methods (0.31 and 0.26 ppm, respectively) (Table 9).

Table 7. The effect of maize variety, methods of drying and shelling, and duration of storage on population of *Fusarium* spp.

Effect	Population of *Fusarium* spp. (colonies/g)	
	Not transformed	Transformed into log *Fusarium* spp.+ 1
Maize variety		
Arjuna	8892	6.739 a
CPI-2	3282	5.701 b
Method of drying[a]		
I	9715	6.351 c
II	8846	6.321 c
III	2833	6.132 c
IV	2953	6.078 c
Method of shelling		
Nail-down wood	5044	6.022 d
Mechanical sheller	7129	6.419 d
Duration of storage (months)		
0	2537	5.522 e
1	9385	6.784 f
2	3329	5.820 ef
3	9096	6.755 f

Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

[a] I Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 17% moisture content.
II Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 14% moisture content.
III Cobs of maize were sun dried to 17% moisture content, then shelled and were not re-dried.
IV Cobs of maize were sun dried to 17% moisture content, then shelled and re-dried after shelling to 14% moisture content.

NIV content of maize shelled by mechanical sheller (1.87 ppm) was higher than that shelled by nail-down wood (1.78 ppm), while for DON content it was the opposite (0.25 and 0.27 ppm, respectively).

NIV and DON contents increased with increasing storage duration, but they were still lower than the lethal doses for mice. Their contents at the beginning of storage, and at 1, 2, and 3 months of storage, were 1.22 and 0.08 ppm, 1.99 and 0.30 ppm, 2.02 and 0.32 ppm, and 2.08 and 0.34 ppm, respectively (Table 9). According to Betina (1989) the lethal dose of NIV for mice is 4.1 ppm, while Miller (1994) reported that animal feed should contain not more than 1 ppm of DON in the diet. According to Betina (1989), the LD_{50} of DON for male and female mice are 70.0 and 76.7 ppm, respectively.

Conclusions

1. Moisture contents of maize decreased at 1 month of storage, and remained almost constant at 2 and 3 months of storage.
2. Maize var. CPI-2 was more resistant than var. Arjuna to *F. moniliforme* and *F. nygamai* infections, although the percentage of damaged kernels of maize var. CPI-2 was higher than in var. Arjuna.

Table 8. Analysis of variance on the effects of variety, drying, shelling, duration of storage and their interaction on *Fusarium* toxins contents of maize.

a. Nivalenol

Source of variance	df	SS	MS	F Value
A	1	0.10927812	0.10927812	24.12**
B	3	0.03221094	0.01073698	2.37
A×B	3	0.03534581	0.01178194	2.60
C	1	0.22411513	0.22411513	49.47**
A×C	1	0.02880000	0.02880000	6.36**
B×C	3	0.01106856	0.00368952	0.81
A×B×C	3	0.20265469	0.06755156	14.91**
D	3	15.74015056	5.24671685	1158.17**
A×D	3	0.01365519	0.00455173	1.00
B×D	9	0.05657450	0.00628606	1.39
A×B×D	9	0.09951387	0.01105710	2.44*
C×D	3	0.03161769	0.01053923	2.33
A×C×D	3	0.08266656	0.02755552	6.08**
B×C×D	9	0.11851963	0.01316885	2.91**
A×B×C×D	9	0.11831575	0.01314619	2.90**
Error	63	0.28540047	0.00453017	

Table 8. Cont'd.

b. Deoxynivalenol

Source of variance	df	SS	MS	F Value
A	1	0.03455163	0.03455163	16.74**
B	3	0.10848777	0.03616259	17.53**
A×B	3	0.03191734	0.01063911	5.16**
C	1	0.01254132	0.01254132	6.08*
A×C	1	0.04832163	0.04832163	23.42**
B×C	3	0.03306677	0.01102226	5.34**
A×B×C	3	0.00005109	0.00001703	0.01
D	3	1.38876634	0.46292211	224.34**
A×D	3	0.01499727	0.00499909	2.42
B×D	9	0.03933220	0.00437024	2.12*
A×B×D	9	0.01657438	0.00184160	0.89
C×D	3	0.01547184	0.00515728	2.50
A×C×D	3	0.02377527	0.00792509	3.84*
B×C×D	9	0.02272820	0.00252536	1.22
A×B×C×D	9	0.00119113	0.00013235	0.06
Error	63	0.12999862	0.00206347	

A	Variety
B	Drying
A×B	Interaction between variety and drying
C	Shelling
A×C	Interaction between variety and shelling
B×C	Interaction between drying and shelling
A×B×C	Interaction among variety, drying and shelling
D	Duration of storage
A×D	Interaction between variety and duration of storage
B×D	Interaction between drying and duration of storage
A×B×D	Interaction among variety, drying and duration of storage
C×D	Interaction between shelling and duration of storage
A×C×D	Interaction among variety, shelling and duration of storage
B×C×D	Interaction among drying, shelling and duration of storage
A×B×C×D	Interaction among variety, drying, shelling and duration of storage
*	Significantly different at 95% confidence level
**	Significantly different at 99% confidence level

3. In general, the best drying method was to sun dry maize cobs to 17% m.c., then shell them and further dry to 14% m.c.
4. *Fusarium* spp. population of maize shelled by mechanical sheller was not significantly different from that in maize shelled by nail-down wood, though the percentage of damaged kernels in maize shelled by mechanical sheller was higher.
5. Populations of *Fusarium* spp. increased at 1 and 3 months of storage, but decreased at 2 months of storage.
6. Nivalenol and deoxynivalenol contents increased with increasing length of storage.

Table 9. The effect of maize variety, methods of drying and shelling, and duration of storage on *Fusarium* toxins contents.

Effect	*Fusarium* toxins contents (ppm)	
	NIV	DON
Maize variety		
Arjuna	1.80 a	0.25 j
CPI-2	1.86 b	0.28 k
Method of drying		
I	1.84 c	0.24 l
II	1.85 c	0.31 m
III	1.81 c	0.24 l
IV	1.81 c	0.26 l
Method of shelling		
Nail-down wood	1.78 d	0.27 n
Mechanical sheller	1.87 e	0.25 o
Duration of storage (months)		
0	1.22 f	0.08 p
1	1.99 g	0.30 q
2	2.02 h	0.32 r
3	2.08 i	0.34 r

Numbers followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at 95% confidence level

I	Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 17% moisture content.
II	Cobs of maize were sun dried to 20% moisture content, then shelled and re-dried after shelling to 14% moisture content.
III	Cobs of maize were sun dried to 17% moisture content, then shelled and were not re-dried.
IV	Cobs of maize were sun dried to 17% moisture content, then shelled and re-dried after shelling to 14% moisture content.

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Drying Simulation: a PC–based, User-orientated Decision Support System for In-store Drying and Aeration of Grains

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SIMULATION of grain drying in deep beds, also known as in-store drying, has been extensively used in agricultural engineering research to acquire a better understanding of the drying processes and related systems. The old mainframe versions of the simulation models developed for predicting the changes in the air and grain conditions are not easily accessible or user-interactive for direct applications. Also, many users are discouraged from utilising the computer simulation techniques because of their complexity.

Drying Simulation is an easy-to-use, PC–based decision support system which offers a user-interactive environment for computer simulation of in-store drying of paddy, maize, and soybeans. The software package developed can be used for designing and performance evaluation of in-store drying and aeration of selected grains. It has a menu-driven user-interface and can display results graphically for quick interpretation and analysis. *Drying Simulation* should prove to be a practical and useful means to find out what would happen under different available options for in-store drying and aeration of grains, and for subsequent decision making.

Drying Simulation Features

The program relies on the modified Thompson et al. (1968) and the Thompson (1972) near-equilibrium models to simulate grain drying and rewetting in deep beds. *Drying Simulation*, developed and compiled in Microsoft BASIC 7.0 (also known as BASIC PDS), provides a user-interactive environment which allows users to easily perform drying simulations based on these models and their combined form.

Drying Simulation offers the following features:

- *Drying Simulation* is a stand-alone software package with menu-driven user-interface and graphics capability. There is on-line HELP available for the explanation of various items in each menu. In addition, general information on important aspects of in-store grain drying/aeration simulation and the software package itself is included in a README file.
- Built-in choices for different grain selection include paddy, maize, and soybeans. The program supports the Plot, View, Print, and Save options for both simulation and plot data when pausing intermittently during a simulation run and at the end.
- Selection of three different simulation approaches along with related model equations can be made for general comparison.
- An easy-to-use interface facilitates input of the simulation conditions. A data window showing the input data and selected models can be displayed and closed instantly before and after a particular simulation run.
- Uniform and non-uniform initial grain and inlet air conditions can be handled. Users can select a stopping criterion (e.g. average final moisture content, drying duration, etc.) to end a simulation run. Several fan and heater control strategies can be examined.
- In simulation runs with non-uniform input air conditions and/or initial grain bed conditions, the corresponding air and grain data files can be created and/or edited directly in the program.
- When the simulation program is running, the changes in condition of the grain bed as drying progresses are continuously displayed and updated on screen. Current drying time, and fan and heater operating times, are also displayed. The heater and fan energy requirements, moisture removal, and dry matter loss are computed and displayed continuously on the screen during a simulation run based on 1 m^2 cross-sectional area of the grain bed.
- Simulation results can be plotted on screen. Users can plot various simulation profiles of the moisture content, temperature, relative humidity, and dry matter loss against drying time or depth of grain bed.

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- Simulation results can be saved on a file and imported into other software packages for further analysis. *Drying Simulation* does not offer direct support for printing of the simulation plots. However, the simulation data and other graphics information can be saved on a file and imported into a spreadsheet package (e.g. Lotus 1-2-3) for plotting and printing.

System Requirements

Drying Simulation will run on an IBM® PC or compatible machine with at least 640 kb of available memory. The software requires a CGA, EGA, or VGA display for the graphics routines. When using a monochrome monitor with Hercules driver, the file MSHERC.COM available from MS DOS 5.0 must be loaded to support the plotting of graphs by *Drying Simulation.*

The software can be run from a floppy disk system with a minimum of 720 kb disk drive capacity (e.g. two 360 kb drives, or one 1.2 Mb or higher capacity drive). A hard disk is recommended for best performance.

Drying Simulation would run under DOS 3.3 or higher. A spreadsheet package like LOTUS 1-2-3 is required for printing the simulation plots. Alternatively, the graphics screen capture utilities, such as GRAB available from WordPerfect Corporation, may be used. Further details on the printing of simulation plots are provided in a README file.

Availability

Copies of *Drying Simulation* are available for US$50 from Dr V.K. Jindal, AIT, GPO Box 2754, Bangkok, Thailand; fax: 66 2 524 6200 or 66 2 516 2126; email: < jindal@ait.ac.th >.

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The Current Situation and Prospects for Grain Drying in Northeastern China

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THE Songliao Plain of northeastern China is a major grain-producing region. In the provinces of Heilongjiang, Jilin, and Liaoning, the total output of grains is 60 Mt. In the north of Heilongjiang, wheat and soybean are the principal crops, in Jilin, Liaoning and the south of Heilongjiang maize predominates, whilst in the east of the three provinces close to the mountains, rice is produced. All the area is influenced by the climate of Siberia, that is cold in winter and warm in summer. In spring and early summer, from March to June and in autumn from September to October, the climate is dry with little rain. The frost-free period is about 140–160 days each year, and the grain moistures are high. The meteorological conditions and moisture contents of grains are shown in Tables 1 and 2.

An average of 50% of grain produced in the three provinces passes through commercial channels. Local government agencies in three provinces purchase a total of 26–28 Mt of which 21.25 Mt need drying. This is equal to 70% of grain dried throughout the whole country. The amount of high moisture grain that needs drying is shown in Table 3 for the three provinces.

Current Grain-drying Technology in Northeastern China

Grain drying is a key measure for long-term safe storage of grain. Because of different grain varieties, grain moisture contents, and meteorological conditions, drying methods and equipment are different. The major methods are high temperature drying, sun drying, and aeration (Table 4).

The technique of grain drying

In north-east China, grain drying machines appeared first in the 1940s. From the 1950s, the Kuaibas grain drying unit was introduced from the former USSR and a steam drying unit, the Berico crossflow grain drying unit, was obtained from the Behlein Co., USA (Fig. 1). Further developments were the concurrent drying unit from the Weslaken company, Canada and the crossflow drying technique (Figs 2–3). Large amounts of capital and manpower were thrown into the development of grain dryers and the series connection mixed flow grain drying unit was developed in Canada (Fig. 4). Various mixed flow units were developed in China including one based on cyclic high temperature water and other equipment generally suited to drying high moisture grain (Fig. 5).

Table 2. Moisture content of grain in three provinces of North East China (%).

Province	Maize	Rice	Soybean	Wheat	Other Grains
Liaoning	22–30	15–17	13–15	–	16–19
Jilin	24–30	15–17	14–15	–	15–17
Heilongjiang	25–33	15–17	14–17	14.5–15.5	15–17

Table 3. Amount of high moisture grain that needs drying in three provinces of North East China ('000t).

Province	Total grains	Maize	Rice	Soybean	Wheat	Other grains
Liaoning	6050	4000	1250	50	–	750
Jilin	9350	7500	500	–	–	550
Heilongjiang	4850	3000	750	500	500	100
Total	20250	14500	2500	550	500	1400

To meet the needs for drying paddy and rapeseed on a small scale in central and southern China, the vibration dryers, fluidised-bed dryers, and rotating dryers were developed rapidly.

After 50 years of development of techniques for grain drying, there are now about 1200 drying units of various types in use in northeastern China. Most of the large units which can process 150 t of wet grain per

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day are kept by state granaries, grain processing factories, state farms, and feed-processing plants, totalling about 858 units. Most small, tower type drying units are kept by rural stores or collectives. Units developed after the introduction in 1992 of the policy of reducing state purchases are, in major part, concurrent drying units. Such units make up about 15% of the total drying capacity.

The grain drying equipment which is now in use and has been so for the past 6 years, consists of series connected mixed flow tower type drying units and steam drying units. The number, processing capacity, regional distribution, and main technical functions are given in Table 5.

The mixed-flow, multiple series drying units of brick construction (Fig. 6) have advantages such as even drying, use of local materials, ease of construction, and long service life. The disadvantages are the high capital cost, lengthy construction times, and high breakage rate of grain during drying. The strong points of the steam drying units are the high quality of dried grain and the low consumption of energy. Most are series connected and a high breakage rate of grain is very common. Their cost of manufacture is 25% higher than that of the mixed-flow brick drying units.

The emergence and development of drying units constructed of steel

Since the early 1980s, and because of the disadvantages listed above, steel grain drying units have been introduced and manufactured. A sample unit of the Bekley type of dryer was introduced by Hongqi State Farm in 1981. A multiple-ring mixed flow drying unit manufactured in 1987 in China was put into use in the Mudanjiang granary (Fig. 5).

Work in this period proved that steel construction for drying units had the advantages of low cost, suitability for large-scale production, and ease of introduction of advanced technology and process control.

Currently, there are three types of steel tower drying units in China—mixed flow, crossflow, and concurrent. In winter and spring, the target for energy use (kcal/kg H_2O) differs between northern and southern areas. Mixed flow direct grain drying units target 2000–2300, indirect units 2200–2500, crossflow units 2000–2300, and concurrent units 1900–2200 kcal/kg H_20.

Equipment for supplying heat for grain drying

Grain dryers consist of the drying unit and the heat supply equipment. The heat supply technique is vital to the function of drying machines. It affects the investment costs, the choice of fuel, the quality of the dried grain, pollution, and the service life of the equipment.

Table 1. Meteorological data for three provinces of North East China.

Province	Average annual temperature (°C)	Average annual relative humidity (%)	Average temperature from March to June (°C)	Average relative humidity from March to June (%)	Average annual moisture evaporation (mm)	Average moisture evaporation from March to June (mm)	Average annual wind velocity (m/sec)	Average wind velocity from March to June (m/sec)	Average annual precipitation (mm)	Average precipitation from March to June (mm)
Liaoning (ShenYang)	8.1	63	12.4	57	1445	731	3.0	3.6	680	200
Jilin (ChangChun)	4.9	65	9.6	56	1719	929	4.3	5.1	594	164
Heilongjiang (Harbin)	3.7	68	8.4	59	1099	584	3.8	4.4	582	146

Table 4. Amount of grain dried by different methods in three provinces of North East China (x1000t).

Province	Total grain				Maize				Rice				Soybean				Wheat		Others
	Sun drying	Heat drying	Aeration	Wind drying	Sun drying	Heat drying	Aeration drying	Wind drying	Sun drying	Heat drying	Aeration drying	Wind drying	Sun drying	Heat drying	Aeration drying	Wind drying	Sun drying	Aeration drying	Sun drying
Jilin	2450	5000	–	30	2000	5000	–	–	450	–	–	30	–	–	–	–	–	–	–
Liaoning	1615	2300	80	–	600	2300	–	–	600	–	80	–	270	–	–	–	–	–	145
Heilongjiang	1500	2250	400	350	650	2000	–	50	150	250	300	50	150	–	100	250	500	–	100
Total	5565	9550	480	380	3250	9300	–	50	1200	250	380	80	420	–	100	250	500	–	245

Table 5. Types of drying equipment in North East China.

Province	Technology						Type of machine									
	Mixed flow		Cross–flow		Concurrent		Anthracite direct		Soft coal indirect		Steam & high temperature water		Mechanical		Manual	
	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)	No of units	Capacity (×1000t)
Liaoning	82	4000	20	400	150	2000	–	–	170	2400	82	4000	102	4400	150	2000
Jilin	348	5400	40	600	–	–	–	–	260	3000	128	4000	180	4920	208	2080
Heilongjiang	205	2610	10	300	3	90	135	1650	78	1200	5	150	38	1000	180	200
Total	635	12010	70	1300	153	2090	135	1650	508	6600	215	8150	320	10320	538	6080

Because gas, oil, and electricity are prohibited for heat generation in China, the heat supply for most early stage grain drying is from anthracite and steam stoves. During the last 20 years, because of the high costs and pollution, studies on new equipment and technology for soft coal, indirect heating, and hot-air drying which began in 1978 were examined and approved in 1982, thus making such technical equipment available in the 1980s.

Research work in the past 10 years has led to a new stage in the development of grain-drying technology. The features of the main unit and the indirect heating supply are low costs, suitability for use with a range of fuels, high quality, large-scale production, and short construction period. These are the solid foundations for the rapid development of steel dryers using soft coal in heated air stoves in China in the 1990s. It is also a basis for the formulation of policy and development plans for grain drying technology throughout China.

Sun drying

Sun drying involves spreading the grain on a flat surface to a depth of 6–9 cm when there is abundant sunshine and little rain. The grain is turned with a wooden spade until the moisture content has fallen to the level for safe storage—windy conditions assist drying. In the three provinces a total 5–6 Mt is sun dried, approximately 35% of the total quantity involved (Tables 3 and 4). To prevent cracking and heating of high moisture grain, soybean is normally dried in the sun first and then the wheat and other grains. In the province of Heilongjiang, soybean is sun dried as it cannot be stored at high moisture content after 10 April when ambient temperatures are rising. The advantages of sun drying are the larger quantities that can be done compared with high-temperature drying, and the drying cost is one third to one half that of heated drying. The disadvantages are that it is dependent on weather conditions, only small drying pavements are often available, more labourers are used and the work is heavier, and minerals may contaminate the grain requiring that the site be prepared by consolidation and sweeping as well as spreading mats and using cover.

Use of natural air and heated air for drying

Grain may be dried by ventilation with natural air when conditions are warm and dry, or by air which has been heated using medium- or low-pressure blowers. The storehouse must be appropriately constructed for such aeration. Various materials may be used, e.g. iron sheet-storehouses, bamboo grain barns, and so on. Such storehouses can reduce grain moisture to safe levels and so enable grain to be stored for years without mould growth. The three provinces of northeastern China have a continental climate as can be seen from Table 1. From March to June the temperature is high during the day, with little rain, a low relative humidity and thus high evaporation and so is suitable for drying. The larger grains give grain masses that are more porous and so easier to ventilate. As long as the most suitable aeration method is chosen, the shape of the grain mass is adequate, the correct times for ventilation are chosen, and management is good, the desired results will be achieved. This method is suitable for drying soybean, rice, and wheat where the moisture is a little high, or maize when sun dried or dried by heated air and the moisture again is a little high.

An advantage of the method is that it uses the latent heat of evaporation using little or no fuel and so saving energy. The amount of grain that can be dried is large and the grain is not subject to cracking or pollution from decomposition products of the fuel. Aeration is simple and convenient in operation with low costs that can be spread across normal operational costs. The cost of drying is one third of the cost of drying with heat and 30% of the cost of sun drying. As a result the method is accepted in the rice-producing areas such as Wa Chang, Yan Shou, and Tailai county of Heilongjiang. In this area aeration drying has almost replaced drying with heat and sun drying. Wuchang county dries 50000 t of rice each year and the technology has been in use since 1990. Currently 500000 t are dried by aeration of which 400000 t are in Heilongjiang.

The major types of aeration are as follows:

Radial flow ventilation

Studies on this type of aeration drying began in 1980 and were finalised in 1983. Originally bamboo-clappers were used but were replaced by perforated steel. A unit had four or more grain houses with a central bucket elevator and the complex later was enclosed in a weatherproof shed. This type of equipment found application in Heilongjiang in the middle of the 1980s and following preparation of model specification, there are now 30 such units in this province and in Jilin (Fig. 9).

The radial-flow dryer is a low-temperature aeration type dryer which strips moisture from the grain by using the dynamic equilibrium between grain moisture and ambient air when dry air is forced through the grain by a fan. The dryer has a central porous air cell from which the air passes radially through the grain and out through porous walls. The air passing through the grain may be heated to assist drying. The heated air has two functions: to provide the energy for drying and to remove the evaporated water from the grain mass. Thus safe moisture levels which prevent mould growth can be achieved gradually.

The specifications for drying units are given in Table 6. The temperatures of different grains during the drying process are given in Table 7 and the least input air ratios of various wet grains in Table 8. According to the data for the J30/60 Model drying barn, a 4-72-116A pneumatic conveyer was used.

The dryer was operated at temperatures of 15–30°C and relative humidities of 30–50%. Table 9 gives the drying time per barn, and Table 10 throughput rates. The energy dissipation index data are as follows.

Host machine power wasting:
maize 0.06 kg water
rice, soybean 0.09 kg water

Unit heat consumption (heating with bituminous coal hot-blast stove, temperature rises 15°C:
maize 200–700 kcal/kg H_2O
rice, soybean 1000 kcal/kg H_2O.

At 15°C and a suitable relative humidity, it is possible to use ambient air and not need supplementary heating, so there is no heat waste.

Aeration and drying with ducting for air distribution

Currently, there are 276 silos which use below-floor ventilation, and 514 silos which use above-ground ducting. With horizontal storages, 78 stores use below-floor ventilation and 252 use above-ground ducting. The design of all these storages conforms to the regulations issued by the Ministry of Agriculture. In the arrangement, consideration is given to lower temperatures, rain and ventilation, and the processing quantity is less than 1.4.

According to Ministry of Agriculture regulations, unit ventilation quantities are as follows:

- the moisture content of grain 14, 16, 18, 20%
- the lowest unit ventilation quantity is 25, 30, 60, 80 m^3/h.t.

The height of the grain in silos in Heilongjiang province is 12 m, and in horizontal storages and squat round storages is 3–7 m. The unit ventilation quantity is usually lower than 5–16 m^3/h.t. Above 15°C and under 60% r.h., 40–200 hours of ventilation are required to reduce the moisture content of rice from below 18% and maize from below 20% to maximum safe moisture contents.

Radial ventilation drying in a bamboo screen grain bin

In the bamboo screen grain bin, the bamboo screen forms a circle of 6 m diameter. There is a central air cell duct of 500–700 mm diameter and the unit may load 60–70 t of rice. The air blower is 4-72-11 6 A type, made in China. The unit ventilation quantity is 70–80 m^3/h.t. Above 15°C and under 60% r.h. between 20–120 hours of mechanical ventilation will reduce the moisture content of paddy and soybean to a safe level of 15–17%.

The merits of this method are the fixed investment costs and the ease with which it can be popularised. This method has been generally adopted for grain drying in part of the counties of Heilongjiang province, replacing sun-drying and stoving.

Natural air-drying in stacks

The warm, dry, and windy weather of early summer (February–June) may be used to dry soybean, rice, and maize in open stacks if the moisture content is less than 18%. The bags are stacked in single or double layers in a copper coin hole form. The moisture content will reach safe levels in 15-40 days. This method may be used where there is insufficient power and will lower the drying expenses as there is no need for further investment and equipment. In Xhaozhou county of Heilongjiang province, there are 30000–40000 t of maize and soybean dried with this method. The method may be used when the moisture content is below 18%. Attention must be paid to the orientation of the stack, to guarding against moisture and rain, and to generally maintaining the site.

Table 6. The specification and capacity of the drying granary.

Specification	Diameter of granary (m)	Height of granary (m)	Area (m^2)	Diameter of air cell (m)	Capacity (m^3)	Weight of grain per batch (t)
J25/60	2.5	6.0	4.9	1.0	25.0	maize 20.0
						rice 13.6
J30/60	3.0	6.0	7.1	1.0	37.9	maize 31.3
						rice 20.0

Table 7. The temperature of various grains in the aeration–drying process.

Grain	Lowest temperature (°C)		Wind temperature (°C)	Relative humidity	
	Grain in air	Heating air		Air	Heating air
Maize	15	–5	15–40	<60	Not considered
Rice	15	0	15–30	<60	Not considered
Soybean	10	–5	10–30	<60	Not considered
Wheat	15	0	15–40	<60	Not considered

Table 8. The least input air ratio of various wet grains in aeration drying.

Moisture content of wet grain (%)	Least input air ratio (m^3 air/ m^3 grain.h)
Below 16	80
16–20	140
20–24	200
Above 24	260

Prospects for Grain Drying in the Northeastern Provinces

Importance of grain drying technology

Grain drying is one of the most important measures in storage of grain. The variety, moisture content, and temperature features of grain must be taken into account in grain drying to preserve the quality and conserve energy, lowering the costs of drying and preventing pollution. Rice, soybean, and wheat at low moisture contents should be dried with ambient or heated air. With maize, with its high moisture content, larger quantities to be handled, and limited drying period, it is necessary to adopt high-temperature drying (stoving) or combine the stoving, aeration, and natural air drying methods. We may divide the drying process into steps by first making most use of drying pavements for sun drying and, in the western plains area, making most use of the natural conditions which are dry and windy and suitable for aeration and natural air-drying in stacks.

Low-temperature drying

The various methods of low-temperature drying should be studied to develop the equipment, facilities, and ventilation systems necessary to raise the efficiency of the drying and lower the moisture contents achievable.

High-temperature drying equipment

This method involves advanced technology, relatively simple structures, and ease of operation. The cost also is low. With this method, we may lower the moisture content to a safe level for long term storage. Grain quality is good, energy is conserved, and costs are low. It is thus appropriate to develop the mixed flow, cross flow, and concurrent drying machines. The silo type cross flow dryers will be used and developed in the south part of Harbin and Mudanjiang—the 45° latitude area.

Table 10. The processing quantity (t) per storage in radial aeration drying.

Type of store	Maize	Rice, wheat	Soybean
J 25/60	0.6	0.7–1.4	–
J30/60	0.8	1.0–2.0	1.0–2.0

Large-scale dryers

The development of dryers designed in series and produced on a large scale mostly from steel.

Computer control

The inclusion of computer-based monitoring and controlling systems including for measurement of moisture content.

Alternative energy sources

Soft coal and rice husks should be used as the sources of heat energy, combined with indirect drying methods using heated air from heat exchangers. These should replace all anthracite direct drying machines lowering energy consumption to 20–30% of the original level.

Technical improvements

Improvement of the furnace and drying machine, to extend their service life to more than 5 years and 15 years, respectively.

Matching dryer capacities to drying needs

The state granaries should adopt mainly the large and medium type drying machine, supplementing them with the small types. In smaller enterprises, lower capacity units would be appropriate.

Improving grain quality

Improve the grain handling to reduce breakage of grain.

Table 9. Drying time per barn.

Grain	Moisture content (%)	Ventilation quantity (m^3/h)	Ventilation quantity ratio (m^3/m^3 grain.h)	Time to safe moisture level in drying
Maize	26	10500	277	35–60
Rice	16.5	9876	261	15–30
Wheat	15.5	7740	204	20–20
Soybean	16.0	11000	280	10–20

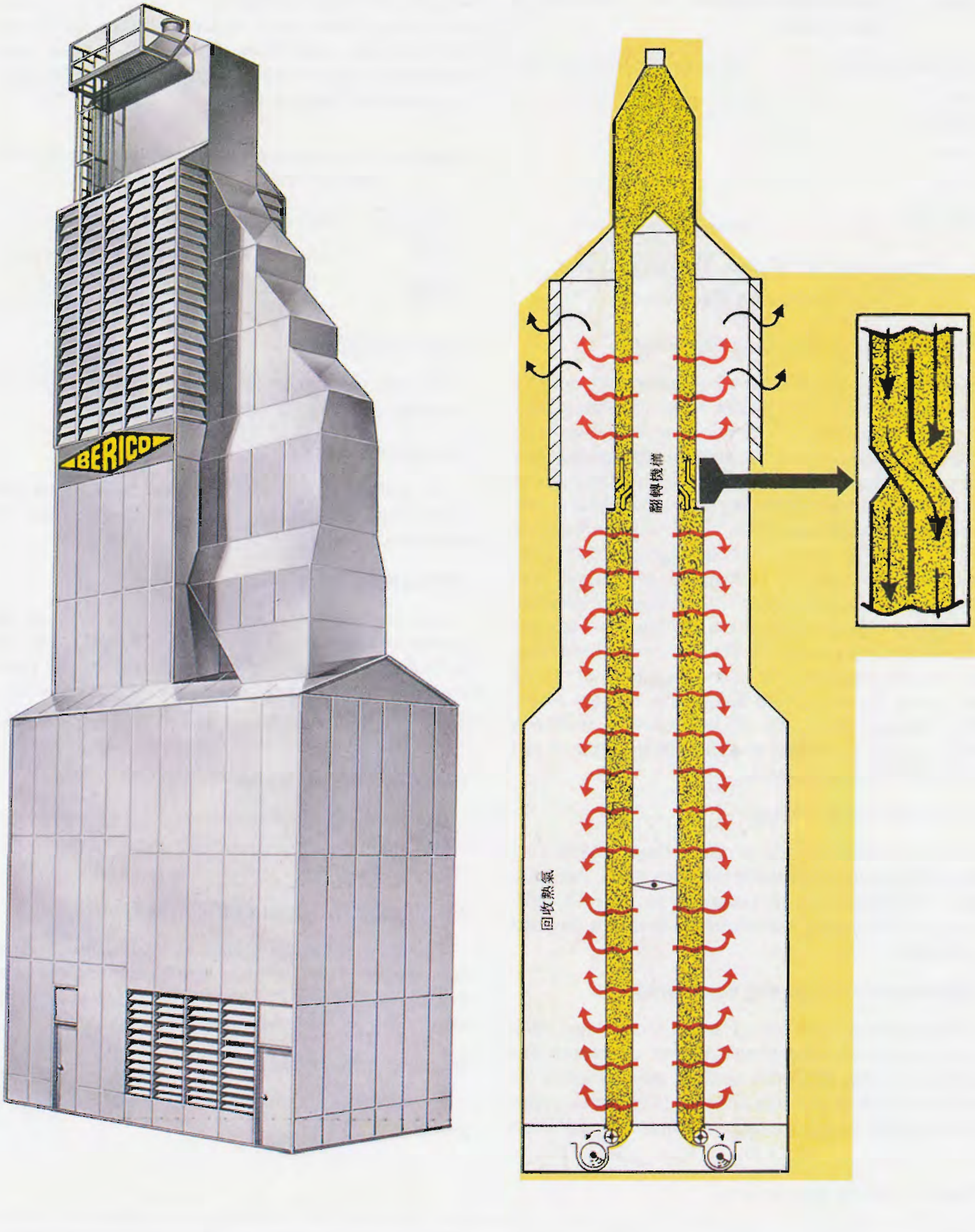

Figure 1. Crossflow grain drying machine.

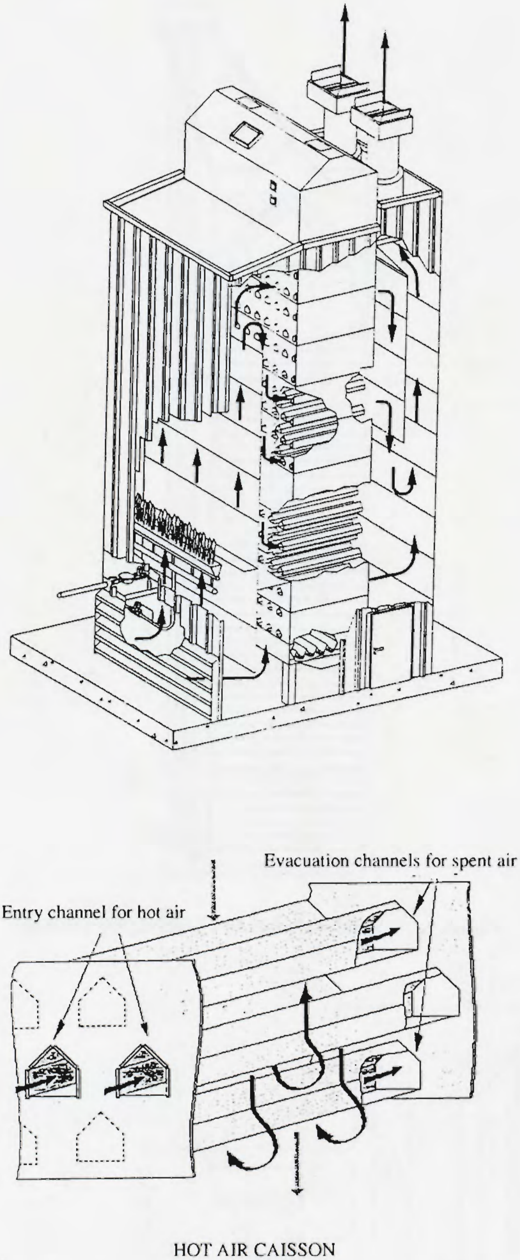

Figure 2. Mixed flow grain drying machine.

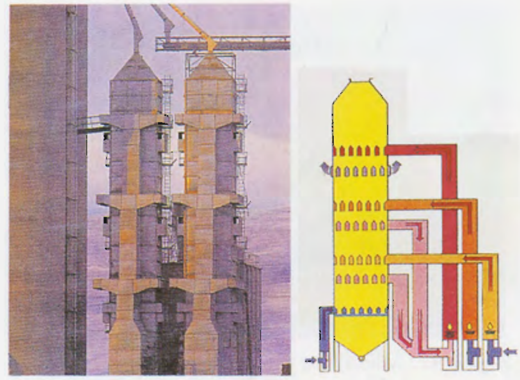

Figure 3. Counter-current grain drying machine.

Figure 4. Multi-pass mixed flow grain drying machine.

Figure 5. Mixed flow grain drying machine.

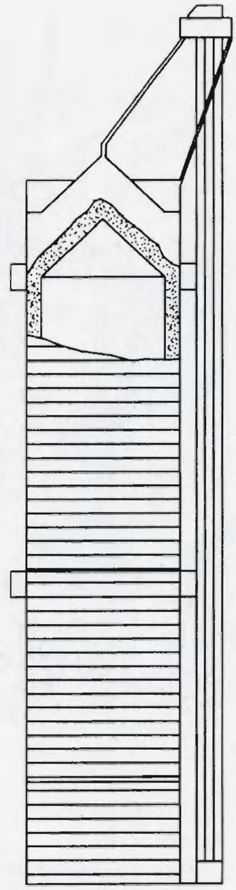

Figure 6. Cylindrical crossflow grain drying machine.

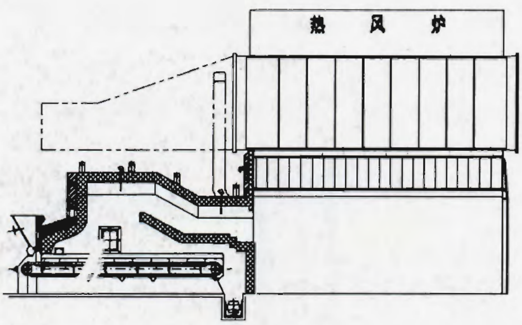

Figure 8. A new type of coal-fired hot-air stove.

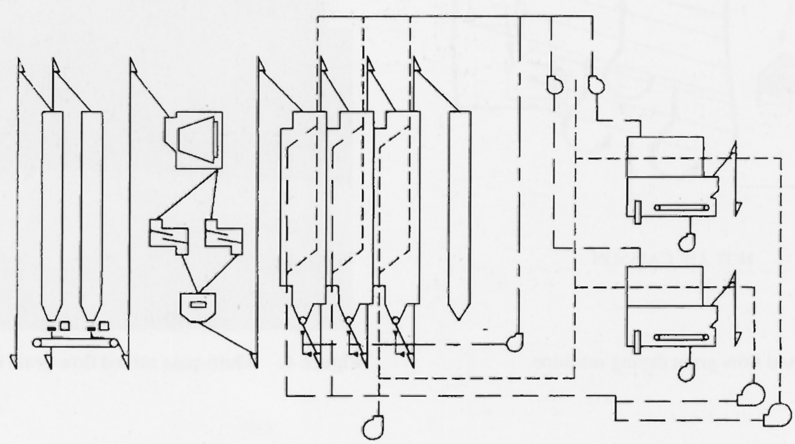

Figure 7. Process diagram for grain drying machine.

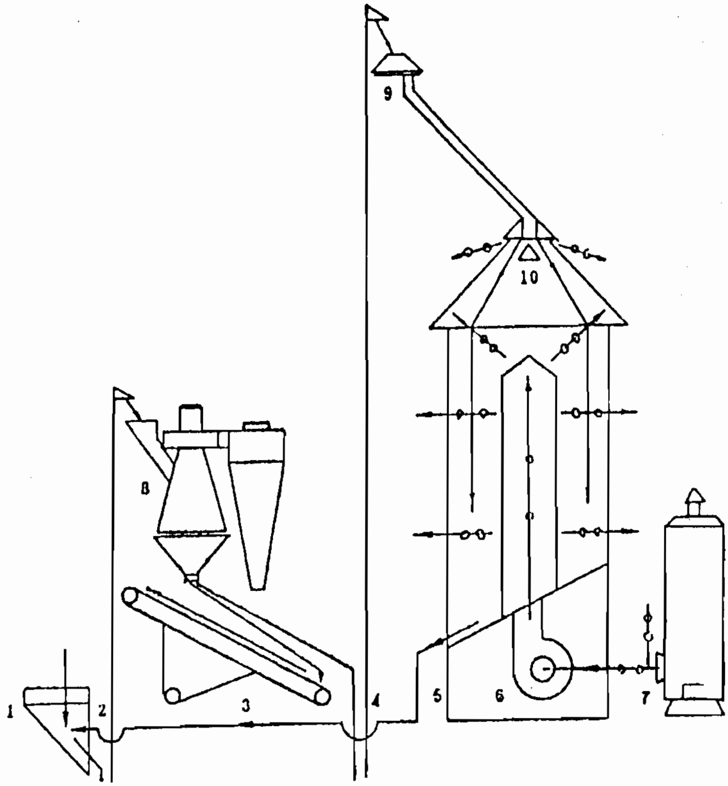

Figure 9. Radial type mechanical ventilation drying granary.

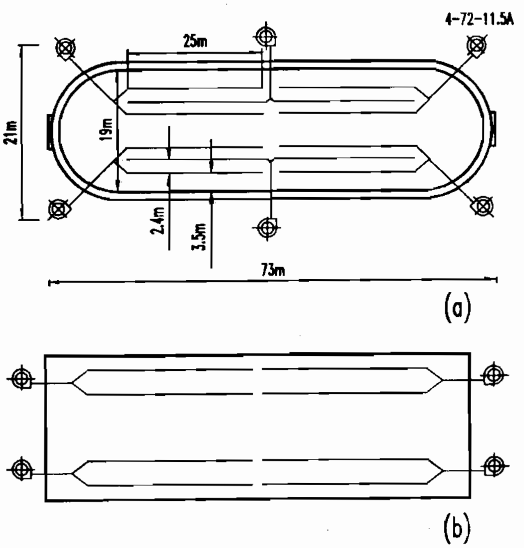

Figure 10. Plan view of ventilation ducting for (a) arch grain house, and (b) storehouse.

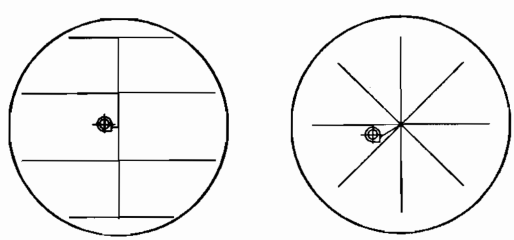

Figure 11. Plan view of ventilation ducting for cylindrical grain stores.