Adaptation of an automatic downdraft rice husk furnace for use with commercial paddy dryers[1]

M Gummert,[2] V Chandrasekar,[3] Phan Hieu Hien,[4] Nguyen Thanh Nghi,[4]
Le Van Ban,[4] E Aquino,[2] P. Borlagdan[2], and JF Rickman[2]

Around 115 million tons of rice husk are produced worldwide every year as a by-product of the rice-milling process. Although considered waste in many countries, rice husk, with a calorific value of 11–15.3 MJ/kg, could be a cheap renewable energy source. There are no net CO_2 emissions into the atmosphere when rice husk is burned.

The adoption of rice husk furnaces for paddy dryers in Southeast Asia is low because of feeding and conveying problems. Existing options include complex and expensive automated plants using mechanical or pneumatic conveyors often combined with a continuous flow dryer of high capacity or simple manually fed and thus labor-extensive furnaces for smaller-scale dryers. Small- to medium-scale or re-circulating batch dryers with capacities between 4 and 10 t per batch become increasingly more important for maintaining paddy quality since, with increasing income, consumers demand better-quality rice.

In the mid-1990s, a small-scale downdraft rice husk furnace with a mechanical ram for automatic feeding and ash removal was developed in cooperation between Hohenheim University, Germany, and IRRI, Philippines, for use in small-scale low-temperature dryers. After initial testing in Vietnam, the furnace was modified at Nong Lam University, Ho Chi Minh City, for use with different dryer types available in the Mekong Delta. In the Philippines, the furnace was modified for use with flat-bed dryers of 4–6-t capacity. In response to increasing market potential for carbonated rice husk (CRH) as a bio-fertilizer additive in the Philippines. initial experiments were conducted using reduced combustion to identify the potential to produce CRH as a by-product of the heating process.

This paper describes the evolution of the furnace in Vietnam and the Philippines and presents findings from adaptive research conducted in the Philippines for matching the furnace with commercially available flat-bed dryers.

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[2] Agricultural Engineering Unit, International Rice Research Institute, Los Baños, Philippines

[3] Post Harvest Technology Centre, TNAU, Coimbatore 641 003, India

[4] Center for Agricultural Energy & Machinery, Nong Lam University, Ho Chi Minh City, Vietnam

Background

With the increase in the standard of living in Southeast (SE) Asia, consumers become more health and quality conscious with respect to the rice they are purchasing. The traditional postproduction systems that still predominate in most SE Asian countries are, on the other hand, characterized by inefficient postharvest operations, resulting in combined qualitative and quantitative losses that can reach 25–50% of the rice value at market.

One of the major causes of qualitative and quantitative loses in the postharvest chain is traditional drying practices, which involve exposing the grains in thin layers in the open under the sun (sun drying). Especially in double-cropping systems, where one harvest falls in the wet season characterized by high relative humidity and frequent rain, quality deteriorates very quickly. Under those conditions, only mechanical dryers can help save the crop and maintain high quality for optimum returns. In the early 1970s, the University of the Philippines Los Baños (UPLB) and IRRI adapted a simple flat-bed dryer with 1–2-t capacity for drying paddy and successively similar dryers with up to 10-t capacity were introduced in most SE Asian countries with varying degrees of impact. With the increasing demand for better-quality rice, a result of national economies moving toward exporting rice, various other fixed-bed batch dryers were developed and other, more sophisticated re-circulating batch dryers were increasingly imported, for example, from Taiwan and Korea. Nevertheless, dryer adoption is still very low. Vietnam is leading in dryer use with an estimated 20% of the rice crop produced in the Mekong Delta being dried in dryers. In the Philippines and Indonesia, an estimated 2% of the rice production is mechanically dried, and Cambodia, Laos, and Myanmar still rely exclusively on sun drying. But, as recent developments in Vietnam show, where around 15 years ago only a few dryers were used, export-oriented rice production as well as increasingly quality-conscious consumers in local markets will increase the pressure to produce better quality. It is therefore anticipated that demand will increase for mechanical dryers.

Drying is an energy-intensive operation. Depending on the dryer model, it takes from 8 to 16 L of kerosene to dry 1 ton of paddy in commercially available dryers from 24% to a safe moisture content of 14%. Consequently, one of the major reasons for the low adoption of dryers is the high cost of fuel used for heating the drying air, whereas energy for sun drying is free. Currently, we also observe a steady increase in fossil fuel prices and, with emerging economies increasingly competing in the world market for energy resources, crude oil prices are likely to remain at high levels or even increase.

A key to increasing the acceptability of mechanical dryers is therefore to reduce the variable cost component to which fuel prices contribute the most. Rice husk seems to be an ideal fuel since it is cheap and readily available in villages and at rice mills where drying usually takes place.

Rice husk as energy source

Around 115 million tons of rice husk are produced worldwide every year as a by-product of the rice-milling process. Often considered as waste in countries such as the Philippines or Indonesia, rice husk, with a calorific value of 11–15.3 MJ/kg, can be a cheap and renewable energy source (Chandrasekar 2005). In 2004, 2.8 million t of rice husk were produced in the Philippines (FAO 2004), with an energy content equivalent to about 930,000 m³ of kerosene. The major constraints to using rice husk as fuel on a larger scale, such as for the generation of electricity, are its low bulk density of around 70–140 kg/m³ in loose form or 180 kg/m³ as compressed pellets and its decentralized production. This makes any transport over longer distance for use in a large plant uneconomical. It is more feasible to use rice husk at or in the proximity of the rice mills where it is produced. Since rice husk is available almost free of charge at the mills, it can reduce the energy cost for mechanical drying by 95% (Berggötz 1990).

There are many alternative uses for rice husk and rice husk ash but some are still under investigation in the laboratory stage or are not applied widely (Chandrasekar 2005). In agriculture, for example, rice husk is used in fields as bedding material for seedlings, as soil conditioner, and as a pest control agent. In animal husbandry, rice husk can be added to feedstuff and litter material but it has very low nutritional value and high silica content, which makes it a poor feed. Industrial uses include additives for hollow blocks, ground drainage and insulation materials, binder for bricks, and particle boards. But, in general, only a very low percentage of the annual rice husk production goes into those applications. The biggest percentage of rice husk is deposited at dump sites or burned in the open (Philippines) or in furnaces for dryers or in brick kilns (Vietnam).

Rice husk ash can be used in the steel industry as tundish powder for producing high-quality steel and in the cement industry as an additive for high-quality cement. Carbonized rice husk (CRH), which is generated by carbonization or partial combustion of the rice husk, is porous and bulky and contains micronutrients such as phosphorus, potassium, calcium, and magnesium vital for crop growth. It is becoming increasingly popular in the Philippines as a soil conditioner, and can be used as a base material for microbiological inoculants, a pest control agent, charcoal for fuel, medicine, and water purification (Asis 2004). If a rice husk furnace could be designed for incomplete combustion, it could provide additional income through the production of CRH.

Rice husk furnaces for mechanical dryers

A rice husk furnace has functional components for feeding the husk, providing air for combustion, burning the husk, removing ash, separating fly ash from flue gas, and conveying heat to the dryer. Each of these components needs to be optimized for an even and clean combustion and for high furnace efficiency.

An analysis of existing rice hull furnaces showed that their specific fuel consumption (hourly rice hull consumption per ton dryer capacity) ranges from 3.5 to 95 kg/h/t, where 6.2 kg/h/t is a typical value for an average direct-fired furnace found in commercial dryers and 95 kg/h/t represents an Indonesian furnace with a heat exchanger that relies on natural draft from a chimney for moving air through the furnace.

The flue gas of a rice husk furnace can be mixed with ambient air and then used directly as drying air for paddy drying without using a heat exchanger. Burning the rice husk does not generate polycyclic aromatic hydrocarbons (PHA) as poorly adjusted kerosene burners do (Braunbeck 1998). In addition, pollutants from the burning process will accumulate on the husks of rice grains, which are removed in the milling process. For rice husk furnaces, heat exchangers are therefore not needed, which keeps investment down.

Problems with existing furnaces

Tumambing (1984), Phan Hieu Hien (1993), Braunbeck and Gummert (1994), and Braunbeck (1998) have evaluated existing commercial rice husk furnaces in the Philippines. Chandrasekar (2005) assessed rice hull furnaces in the Philippines and in Vietnam. The problems with the existing furnaces that prevent a more widespread application can be summarized as follows:

- The physical properties of rice husk, especially the high angle of repose of 35–50°, low flow ability, and the tendency to form bridges and clog when gravity fed, make constant feeding of rice husk with simple gravity feeding devices difficult. Its abrasiveness due to high silica content wears mechanical feeding devices quickly.
- Most small-scale rice husk furnaces are labor-intensive because they are either batch type or semi-mechanized. In Vietnam, most furnaces need attention from the operator every 10 minutes. But, the increasing labor shortage during the harvest season makes labor a more significant cost factor.
- Automated furnaces with low labor requirement, for example, with pneumatic feeding systems, have a high capital cost and require a certain size for economical operation. They are feasible only for large-scale drying plants with continuous flow dryers, which are not very popular in SE Asia.
- Because of the intermittent feeding of batch-type furnaces, the rate of husk fed into the burning chamber and consequently the temperature can vary largely over time. This often exceeds the maximum allowable temperature for paddy drying. Too-low temperatures increase drying time and drying cost.

- Intermittent feeding also causes an uneven combustion process, which often results in smoky operation and flue gas with high carbon monoxide levels.
- The drying air often has high fly-ash contents because most furnaces are updraft furnaces where the drying air is sucked through the rice husk bed into the dryer. Some of the lighter ash particles are conveyed with the air into the air distribution system.
- One way to prevent fly ash is to use a heat exchanger, but this increases capital cost and decreases furnace efficiency. Without a heat exchanger, the combustion air is moved through the furnace by suction from the fan of the dryer. This means that the rate of airflow through the furnace and thus the combustion process can be easily controlled. With a heat exchanger, additional devices such as a chimney or an auxiliary fan are needed for moving the air through the furnace. Controlling the airflow rate and thus the burning process then becomes more difficult, especially when free convection is used.

There is a need for a small-scale furnace for rice dryers with batch capacities up to 10 t that is free of fly ash, has an even burning process and temperature pattern, and does not require much labor for operation.

Design specifications

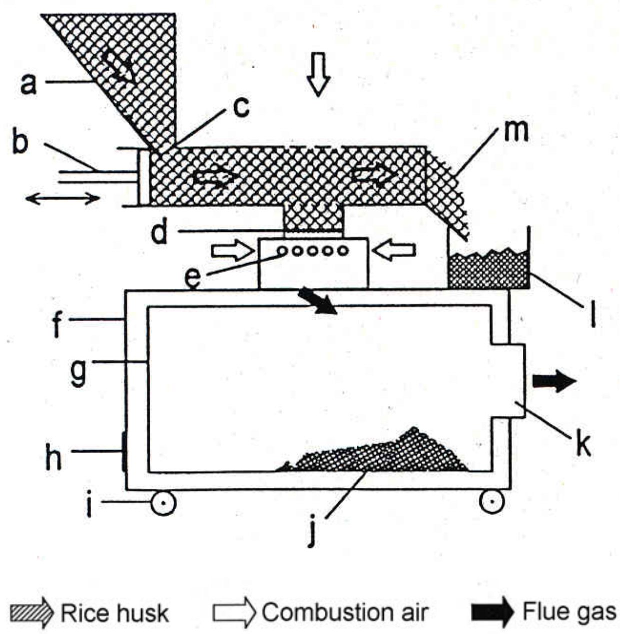
Following the evaluation of existing rice husk furnaces in the field, an analysis of the requirements of commercial dryers, and an extensive literature survey, the following design specifications for an improved rice husk furnace were drawn up:

- A simple design for a machine that can be easily produced in local workshops using locally available and inexpensive materials.
- A temperature rise from 6 °C for low-temperature drying up to 15 °C for heated-air drying at an average rice husk consumption of 6 kg/h per ton dryer capacity.
- Automatic feeding of the rice husk with a constant feed rate for even temperature for at least 4 hours without operator assistance and with provisions to prevent clogging of rice husk in the feeding mechanism.
- Smokeless and odorless combustion with high furnace efficiency and low carbon monoxide contents.
- Easy ignition within 5 minutes and a short time to reach steady smokeless combustion. The flue gas needs to be free of fly ash.
- Automatic ash removal from the burning chamber.
- Forced (??) convection for provision of the combustion air by using the fan of the dryer for a controlled and clean combustion process.

- Safe and easy operation, including fire hazard protection during power failure.
- Low capital and running cost.

Rice Husk Furnace Development for Low-Temperature Drying

A novel design for a semi-automatic downdraft furnace was developed at Hohenheim University as part of the GTZ-funded collaborative IRRI-UAF project using a design process that focused on previously identified problems in relation to the individual functional components of the furnace (Figure 1).



a	Feed hopper	e	Secondary air holes	i	Ash bin
b	Ram	f	Housing	j	Fly ash
c	Flap	g	Combustion chamber	k	Flue gas outlet
d	Grate	h	Inspection hole		

Figure 1: Schematic diagram of the Hohenheim furnace prototype (adapted from Braunbeck 1998).

Automatic feeding system

Constant and automatic husk feeding is achieved with a simple mechanical device using a piston (b) that pushes the husk in adjustable time intervals from the feed hopper (a) through the charging duct and over the grate (d), where combustion takes place. The feed rate is set by adjusting the piston frequency. The up- and downward motion of a flap (c) at the bottom of the feed hopper, which is activated by the piston movements, stirs the rice husk in the feed hopper and thus prevents it from bridging and clogging. This also serves as a barrier against the fire burning into the hopper in case a power failure occurs during operation.

Controlled and clean combustion

The furnace employs the downdraft principle to minimize fly ash. Combustion happens on top of a grate (d) that is below the level of the charging duct. Rice husk ash accumulates on top of the grate and serves as a filter to prevent new ash from falling into the combustion chamber (g). The suction of the dryer fan provides a constant flow of the combustion air, thus ensuring proper control of the combustion process. Secondary air holes (e) provide sufficient secondary air for complete combustion of the combustible gasses, thus ensuring low CO levels.

Even heat transfer

A constant and even heat generation is guaranteed by the automatic feeding system. The flue gas outlet (k) is placed at the inlet of the blower of the dryer. The combustion air volume and thus the temperature rise can be set by varying the distance between the flue gas outlet and the blower. The constant forced airflow allows optimizing the burning process for complete combustion.

Ash separation

Because of the downdraft principle, only very little fly ash occurs. This can be easily separated by gravity in the combustion chamber and removed occasionally through an inspection hole.

Automatic ash removal

No separate devices are needed for ash removal since the ash is simply pushed out of the discharge opening and falls into an ash collection container.

Performance of the Hohenheim prototype

The first prototype was designed for a small low-temperature in-bin drying system with 6-t capacity. The thermal output of the furnace ranged from 8.7 to 16.7 kW at a rice husk feed rate of 2.6 to 5.7 kg/h. Experiments conducted over 4 hours showed that the feed rate, and thus the temperature, decreased in the first 2 hours until a steady-state feed rate of around 3 kg/h with a thermal output of around 10 kW was reached. The reason for this is that the husk gets increasingly compressed in the charging duct, which increases friction and decreases the volume fed to the burning section. This effect is more significant at higher initial feed rates. Although this was seen as the major shortcoming of the prototype in actual drying operation, this might not constitute a big problem since, at the beginning, the wet paddy can be dried using higher temperatures than at the final stage of drying. The long-term experiments also showed that, after the initial firing, the temperature fluctuation over time was minimal with ±1 K (see also Figure 2) and automatic feeding could be maintained over 4 hours without operator assistance.

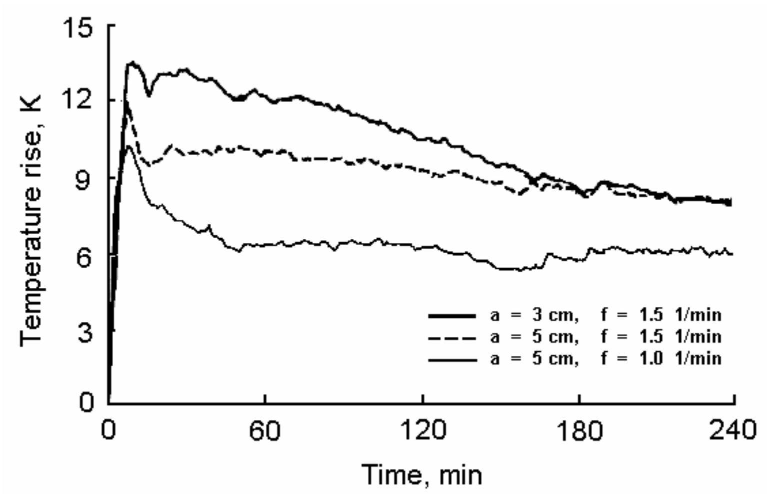
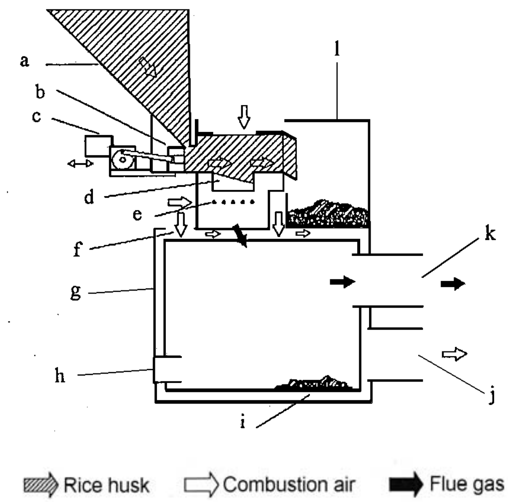


Figure 2: **Temperature rise of the drying air in long-term operation at different piston strokes (a) and frequencies (b) (Braunbeck 1998).**

Further work focused on optimizing design parameters, combustion efficiency (99%), furnace efficiency (from 30% to 70%), and carbon monoxide contents of the flue gas (from 0.4% down to 0.05%). An economic assessment with data from the Philippines indicated the economic feasibility if the furnace were made from local materials.

Practical evaluation in Vietnam

Considering the results of the furnace optimization conducted at Hohenheim, an improved prototype (Figure 3) with shorter charging and discharge ducts for reduced friction of the rice husk was constructed at the University of Agriculture and Forestry in Ho Chi Minh City, Vietnam, using locally available materials. The work was conducted in connection with a thesis project by a Hohenheim student (Bojarkski 1998). Other modifications included a shorter, double-layer burning chamber for better insulation and a declining grate.



a	Feed hopper	e	Air inlet	i	Fly ash
b	Ram	f	Heat exchanger air inlet	j	Heat exchanger air outlet
c	Motor	g	Combustion chamber	k	Flue gas outlet
d	Grate	h	Inspection hole	l	Ash container

Figure 3: The first Vietnamese prototype (Bojarkski 1998).

Optimization trials resulted in an optimum performance at a piston stroke of 50 mm and a piston frequency of 40 seconds. Using these settings, an initial rice husk feed rate of 4 kg/h was reached in continuous operation. Even with the modifications made to reduce internal friction, the feed rate dropped to 3.5 kg/h when the operation was continued (Figure 4) and to 2.5 kg/h after 18 hours. The targeted temperature rise of the drying air of 12 K was nevertheless achieved.

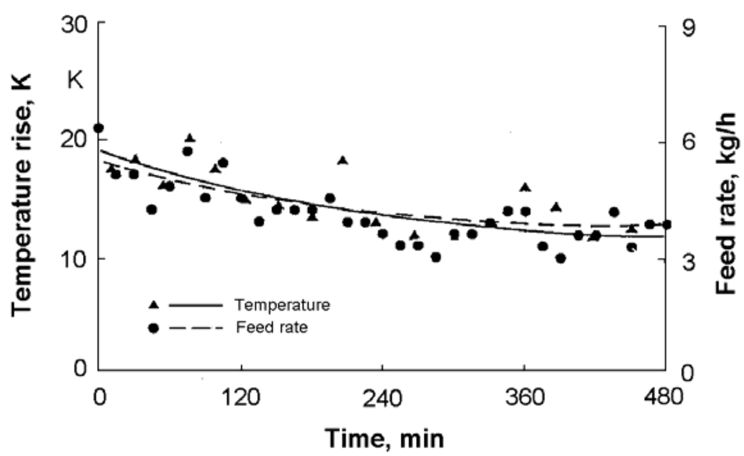


Figure 4: Temperature and feed rate over time, Vietnamese prototype (Bojarkski 1998).

The furnace was then successfully tested in combination with a batch dryer with 2-t capacity for providing supplementary heat for low-temperature drying. Drying time was 48 hours, during which the furnace was operated for a total of 32 hours during nighttime.

In 1997, the GTZ-funded IRRI-UAF project on the evaluation of low-temperature drying systems for the humid tropics came to an end and with it the further development of the rice husk furnace for low-temperature drying.

Adaptive Research for Heated-Air Drying

As a result of the increasing cost for fossil fuels, the furnace design was re-visited in 2002 in Vietnam as an alternative to existing furnaces and in 2004 in the Philippines with the objective of replacing kerosene with rice husk as fuel for commercially available heated-air dryers. In a cooperative effort between the International Rice Research Institute (IRRI) and Nong Lam University in Ho Chi Minh City, Vietnam, the design was adapted to the needs of a flat-bed dryer with 4-t capacity since this kind of dryer is widely used in Vietnam and has gained some popularity in the Philippines.

Adaptations in Vietnam

At NLU, several design iterations from 2002 to 2005 led to a furnace with a 25-kg/h feed rate (Figure 5). The furnace was tested with a fan test duct with an airflow rate of 3.1 m^3/s at a static pressure of 300 Pa.

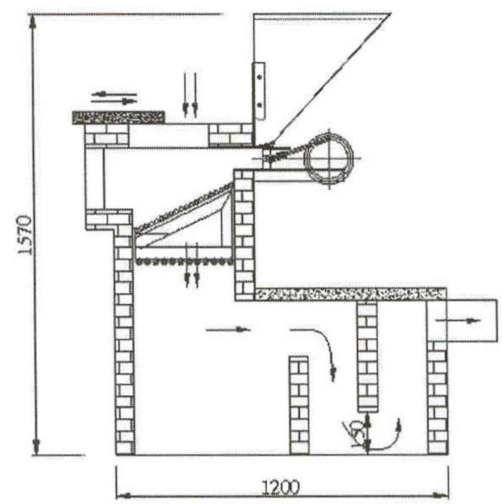


Figure 5: Vietnamese furnace with 25-kg/h feed rate (Phan Hieu Hien 2005-I).

The heated air was clean, without fly ash or smoke. The furnace efficiency was 48–80% depending on the ram frequency and ram stroke. Although further work is needed to optimize these settings, at this stage the furnace fulfilled the requirements of a 4-t flat--bed dryer. As a next step in commercialization of the design, a similar furnace was installed and tested at a peanut station in Tay Ninh for peanut drying (Figure 6). This latest design incorporated a microprocessor- controlled timer (assembled from available electronic parts), which controls the start and stop timing of the ram motor (Figure 7). The controller is reliable, accurate, and yet cheap enough, with a price tag of around US$40.

Figure 6: Furnace installed at Tay Ninh for peanut drying (Phan Hieu Hien 2005-II).

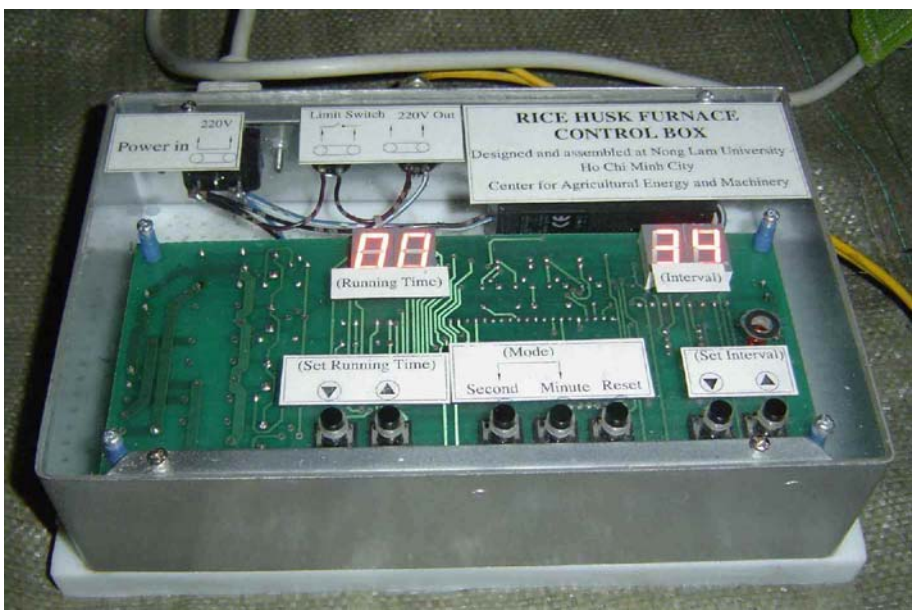


Figure 7: Microprocessor-controlled timer for the ram drive (NLU).

In the initial testing, the furnace was operated for a total of 64 hours and maintained a drying temperature of 43 °C, with a variation of around ±2 °C over this period (Figure 8) against more variation in the ambient temperature (average 29.5 ^{o}C ± standard deviation of 3.6 ^{o}C). The steel rods of the grate bend from the heat and consequently the grate was replaced with a cast-iron grate for better heat resistance.

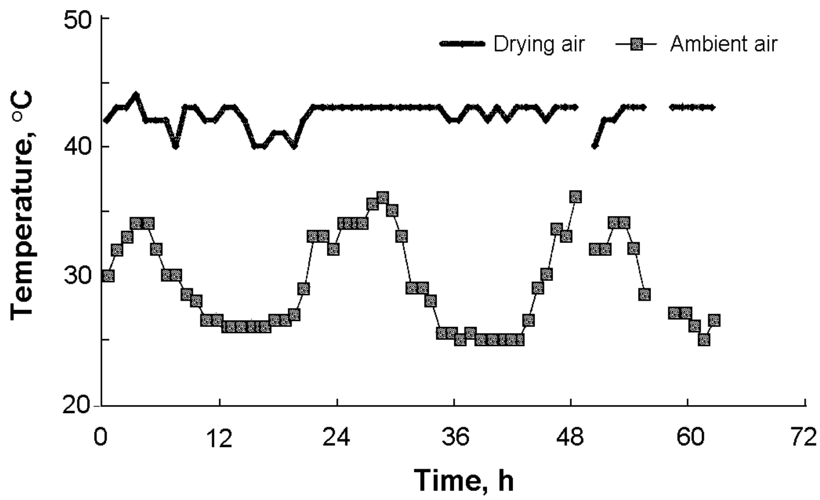


Figure 8: Test results of the furnace at Tay Ninh in long-term operation (Phan 2005-II).

It is planned to include the new furnace in new flat-bed dryer installations replacing the common inclined-grate furnaces in rice mills that need more automated operations. NLU is also working on a furnace with a rice husk feed rate of 150 kg/h, which is intended for use with brick kilns. A large percentage of the rice hull produced in the Mekong Delta is used for burning bricks (Phan Hieu Hien 2003).

Adaptations at IRRI and in the Philippines

The objective of the adaptive development in the Philippines was to establish dimensions and operating parameters for a furnace that can be used with flat-bed dryers with around 4-t capacity. Some trials also focused on the question whether the furnace can also be used to produce marketable CRH if the degree of combustion is reduced through an increased feed rate. Based on the experience gained in Vietnam, a mobile concept prototype with a ram width of 600 mm and a husk feeding rate of 18 kg/h was designed with the following adaptations (Figure 9):

- Reversed flow of rice husk with respect to the burning chamber to create more space for ash collection and to obtain a longer traveling time of the flue gas inside the burning chamber for better prevention of flames coming from the outlet and for improved fly-ash separation.
- Shorter grate and reduced feed and discharge ducts for less internal friction and reduced compression of rice husk during operation.
- Declining grate and a higher discharge duct to accommodate volume expansion of the ash.
- Inclusion of two baffles in the burning chamber for separation of the remaining fly ash and to prevent flames at the flue gas outlet.
- Usage of an electronic timer to control ram frequency.

The double-layer combustion chamber of the first Vietnamese prototype was maintained for determining how much it contributes to high furnace efficiency.

Figure 9: Concept prototype of a mobile rice husk furnace, test setup of a 4-t flat-bed dryer with a temporary ash collection container. On the left is the conventional manually fed inclined-grate furnace with the same capacity.

The prototype was evaluated and optimized in the IRRI laboratory using a blower test rig that can be used to adjust different air flows. Practical tests with a 4-t flat-bed dryer installed at the Philippine Rice Research Institute (PhilRice) in Nueva Ecija, Philippines, followed. Parameters evaluated included effect of furnace dimensions, feed rate (as a function of feeding interval and pitch of the ram), and secondary air on drying-air temperature, furnace efficiency, degree of combustion, and CO content.

Furnace dimensions: For the desired heat capacity, the following critical dimensions were determined: the grate area was 0.64*0.23 m, the maximum depth of the husk bed was 0.1 m, and the combustion chamber had a volume of 0.21 m^3.

Temperature: The feed rate was constant over time and can be adjusted between 15 and 25 kg/h by setting piston frequency and stroke. For a given setting, it declined slowly over time because of compression of the rice husk and ash as was also observed in previous furnace models. The furnace could easily generate heat to increase the ambient temperature to 43 °C as required for seed drying. The peak temperature was reached after 10–15 minutes and from then on it slowly decreased but was always within acceptable limits. The short-term temperature changes were minimal within +/- 2.5 °C (Figure 10).

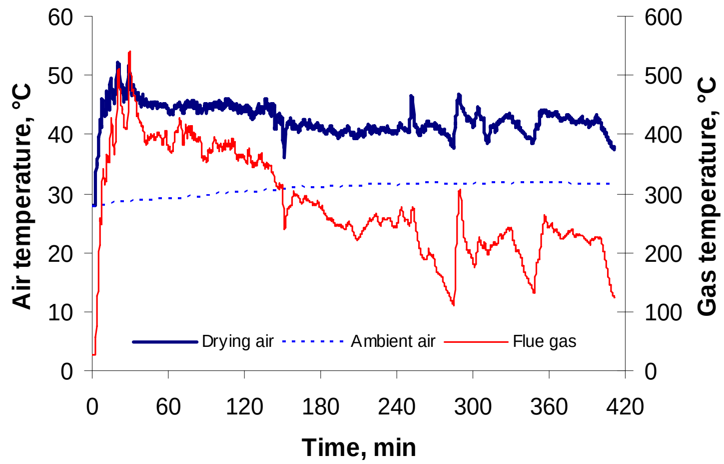


Figure 10: **Temperature of drying air, ambient air, and flue gas over time (data from Chandrasekar 2005).**

Combustion efficiency and furnace efficiency: Because of the continuous burning process with an even feed rate, combustion efficiency was high, within a range of 93–98% (Figure 11). A clear relation between feed rate and combustion efficiency could not be established. Furnace efficiency reached 48–63%, with a falling tendency at higher feed rates. This indicates that the major heat loss comes from incomplete combustion and from heat still contained in the ash that was partly still glowing when it fell into the ash collection bin. This effect increases with increasing feed rate. The double-layer burning chamber proved to be unnecessary since it only increased the drying-air temperature by less than 1 °C, indicating that the heat loss from radiation of the furnace body is small compared with the heat loss from the hot ash disposal.

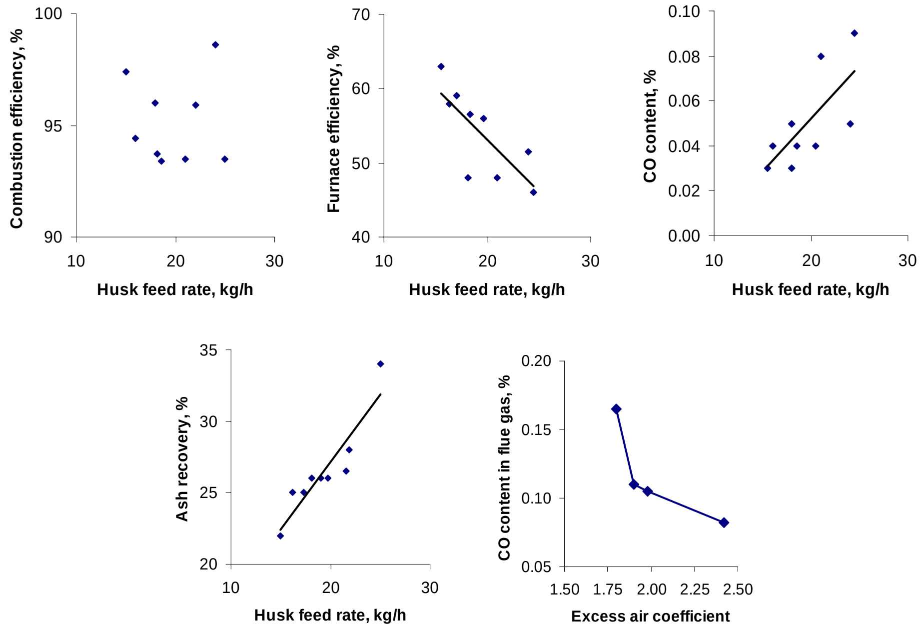


Figure 11: **Results of furnace testing: effect of feed rate on combustion efficiency, effect of feed rate on furnace efficiency, effect of feed rate on CO content, effect of secondary air, and degree of combustion.**

<u>Effect of feed rate:</u> A higher feed rate reduces retention time of the rice husk inside the furnace and thus causes more incomplete combustion and higher heat losses, which both reduce furnace efficiency. Increasing the feed rate from 15 to 25 kg/h increases ash recovery (defined as weight of ash in percent of the initial weight of the rice husk) from 22% to 34% and decreases furnace efficiency from 63% to 45%. The ash from experiments with a higher feed rate had fewer gray ash particles, which increases its market value as CRH in the Philippines.

<u>Effect of secondary air:</u> The secondary air mainly affected combustion cleanliness. An increase in the excess air coefficient from 1.8 to 2.4 reduces CO content from 0.17% to 0.08%; both values are well within acceptable limits and don't constitute any health risk.

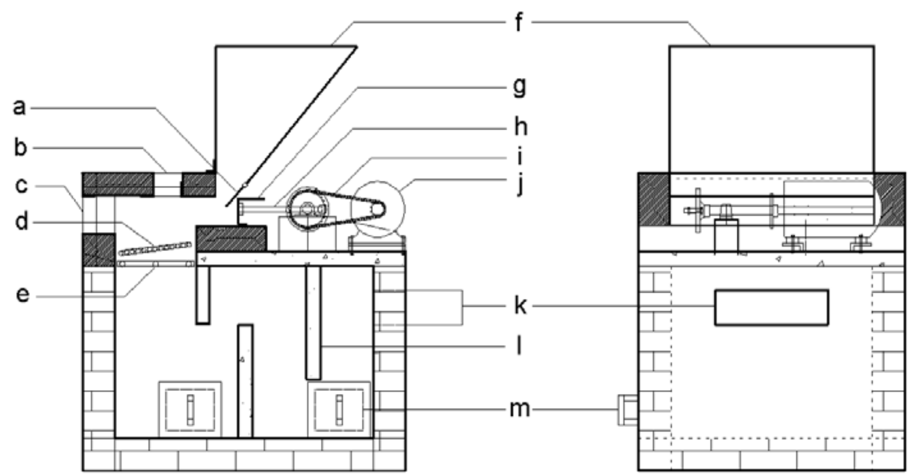
<u>Other observations:</u> When the furnace was placed too close to the fan, suction increased and flames occasionally exited the flue gas outlet.

The experiments showed that the furnace concept is feasible for providing the heat required for a 4-t flat-bed dryer. As a next step, some improvements were incorporated into the design and a final commercial prototype was constructed at PhilRice. The design changes included (see Figure 12):

- Adaptation to local materials: The combustion chamber was made from ordinary bricks for low investment cost. The burning chamber that contains the grate is made from fire bricks.
- Considering that at higher feed rates both the rice husk compression effect and CO production increase while furnace efficiency decreases, the piston width was increased by 10 to 70 cm for higher maximum feed rates.

The furnace can then be operated at a lower feed rate with increased performance.

- The volume of the combustion chamber was also increased to 0.38 m^3, which allows more time for the flue gasses to burn completely. The number of baffles was increased to 3 for improved fly-ash separation and eliminating flames at the flue gas outlet.



a	Flap	f	Feed hopper	k	Flue gas outlet
b	Primary air inlet	g	Ram	l	Baffles
c	Ash outlet	h	Connecting rod	m	Inspection hole
d	Grate	i	Speed reducer drive		
e	Secondary air holes	j	Electric motor		

Figure 12: The commercial prototype installed at PhilRice (modified from Chandrasekar 2005).

The furnace was initially tested in the off-season, with the drying bin being only half loaded with 1.8 t of paddy. Because of the low amount of (??) air, the airflow rate through the dryer was much higher than specified. Nevertheless, a temperature rise of 11 K was achieved with a 40-second feed interval, resulting in a rice hull feed rate of 28.7 kg/h. Some problems occurred as can be seen in the temperature patterns of Figure 13.

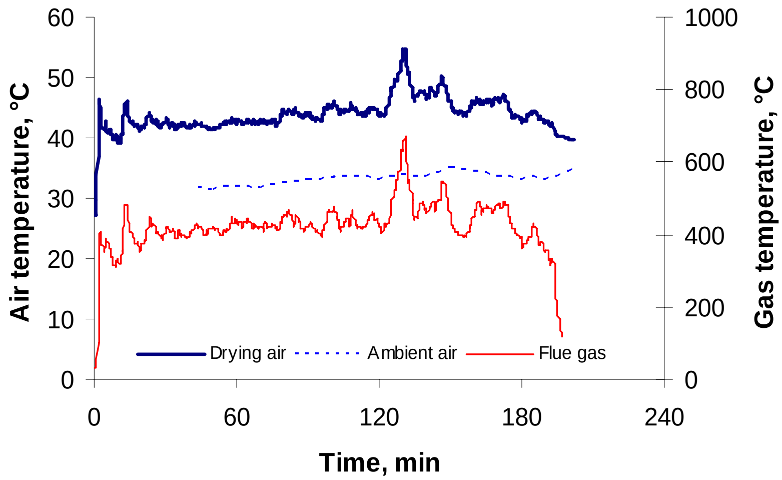


Figure 13: Temperature rise generated by the commercial prototype; the peak at 124 minutes was caused by overfeeding due to a breakdown of the electronic controller.

Because of a lack of experience with the new furnace, it took around 20 minutes to adjust the feed rate to the required drying-air temperature. Afterward, the temperature varied approximately ± 2 K for 100 minutes until the analog electronic controller failed, resulting in continuous operation of the ram. The temperature increased until the problem was fixed after another 10 minutes.

The test was repeated with a higher feed rate of 36 kg/h, resulting in a temperature rise of 16.6 K without further problems with the electronic controller. The tests showed that the furnace is operating well and can provide the required heat easily. Increasing the width of the ram by 10 cm provides sufficient capacity reserves that allow adjusting the operation to various conditions such as optimum furnace efficiency or the production of CRH. As a next step, the furnace operating parameters need to be fine-tuned to suit the needs for seed-drying operation at PhilRice.

Conclusions

The semi-automatic downdraft furnace principle has good potential to overcome the problems of existing small-scale rice husk furnaces, namely, the high labor requirement, uneven temperature, and high levels of pollution. After the furnace was initially developed for a rice husk consumption of 3–4 kg/h for small-scale low-temperature drying systems, it was successfully up-scaled to a rice hull consumption of 15–36 kg/h for use with various heated-air dryers with a batch capacity of around 4 tons. The next steps include long-term evaluation and commercialization of the design. Further up-scaling to fit larger dryers can easily be done. Future R&D work needs to address the following issues:

- The effect of the decreasing feed rate observed in all furnaces is not necessarily a problem. On the contrary, wet paddy can be dried with higher temperatures than paddy that is already partly dried. The decrease in feed rate and temperature might even have a positive effect on the drying process by shortening drying time. This should be quantified.

- The electronic timer used for setting the ram frequency could be easily modified to include a temperature-sensor input that could be used to adjust the ram frequency and thus (federate to) moderate?? the temperature at the flue gas outlet.
- The market potential of CRH in the Philippines and the economics of running the furnace at higher feed rates for more incomplete combustion, which will cause a higher labor requirement for feeding and lower furnace efficiency, need to be assessed.
- A long-term study of performance and durability of the components.
- An economic assessment of operations with various commercially available dryer types in comparison with kerosene-fired dryers.

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