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CONICAL GRATE RICE HUSK COMBUSTOR FOR GRAIN DRYING

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ABSTRACT

An experimental conical grate rice husk furnace was designed, fabricated, and tested in Los Banos at the Agricultural Engineering Division of the International Rice Research Institute. Experiments were performed with the furnace under suction from an axial-flow fan. Drying air efficiency of the furnace was found to lie in the range 60 - 80 % . At a rice husk burning rate of 32 - 38 kg/hr, the furnace was compatible with a flat-bed dryer demand of 4 - 6 tons/batch for 6 - 8 hr continuous operation . The furnace has a simple cable-type transmission which provides synchronized fuel feeding and ash discharge, and is lightweight relative to its heat load.

The charred ash from the furnace contained from 6 to 15 % unburnt carbon and was amorphous, as examined by the X-ray diffraction method .

Problems in continuous operation of the gasifier-combustor were identified, the major constraint being rice husk feeding flow at high temperature.

A rice husk gasification equilibrium (RHGE) model was developed to predict gasifier performance. The model used a reactivity factor Rf to account for biomass reactivity relative to that of graphite , and took account of the ash content and the %Unburnt carbon of rice husk in the mass and heat balance equation. Comparison between RHGE model-generated data and published experimental data showed that the model adequately predicted gasifier performance.

Key words : Rice husk, Furnace, Combustion, Gasification, Drying, Modeling.

INTRODUCTION

In South-East Asian countries such as in Vietnam and the Philippines , artificial drying of the crop harvested during the rainy season is both an immediate and a long-term necessity. The percentage of spoiled wet-season rice crop due to bad weather conditions may range from 10 to 30 % . Though there is much drying know-how and technology available, the adoption of mechanical dryers by farmers in developing countries has been very slow. The reason, as pointed out in many economic studies, is drying cost. While sun drying in the Philippines and Vietnam costs about 1% of the value of the paddy, the cost of drying by mechanical dryers is between 4 - 15% . This big difference tends to overshadow the advantages of mechanical dryers over the shortcomings and risk of sun drying in rainy season.

Two ways of reducing drying cost are :

(a) Reduction of depreciation cost : This requires a high capacity yet simple and low-cost installation. This consideration stems from the fact that in actuality farmers do not use dryers more than 40 days/year. This is a vicious circle: The drying cost being high, farmers tend to look at the dryer as a safety device, meaning it is only needed when the rain is continuous for many days, for example during a typhoon, when "All or Nothing" is the case. If they only use the dryer for a few days, the depreciation cost is high, pushing drying cost to an even higher level ...

In Vietnam's Mekong Delta the 4 - 10 ton/batch flat-bed dryers, which are being increasingly adopted by groups of farmers or contractors (the number totaled to about 250 units in 1991) , seem to have met this requirement of reducing depreciation cost. In some way, it is "economy of scale" at work.

(b) Reduction of energy cost : This point can be illustrated by farmers' rejection of dryers using kerosene-fired burners in the Philippines , in spite of government efforts to promote hundreds of them in the past. Consider 1 liter of kerosene containing 36 MJ at 8 pesos and 1 kg of biomass fuel containing 14 MJ at 0.1 pesos * , it is easily shown that one heat unit of kerosene costs 31 times more than that of biomass fuel.

Of the biomass fuels potentially available for rice drying, rice husk is the most abundant. In the Philippines, about 1.6 million tons of rice husk (20 % of paddy production by weight) are produced annually as a by-product of rice milling. In Vietnam, the corresponding quantity is twice that amount (3.2 million tons annually).

Rice husk is commonly considered a no-cost fuel . Huge piles of husk at rice milling plants, or dumped along the highway are commonly seen. In practice, the transportation cost from the rice mill to the drying site must be accounted for (estimated at 0.01 pesos/km-kg 1992 in the Philippines) .

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* Conversion rate: 1 US$ = 25 pesos

So the problem of designing a rice husk furnace which is energy-efficient, matched with the drying requirements, yet simple enough to lower depreciation cost, is still challenging to researchers and was the objective of this study. The design should meet the following general criteria :

(1) Rice husk consumption rate should be compatible with dryer demand, that is, in the range from 20 to 50 kg/h for a 4 - 6 ton/batch dryer.

(2) Capable of about 8 hours continuous operation .

(3) Free of operational problems such as caking or channelling of rice husk.

(4) Simplicity in design so that it can be fabricated by an average metalshop in rural areas (for example in the barrios of the Philippines). . Simplicity in the transmission drive means less risk of break-down, more reliable operation, which is crucial during the short and hectic time of the drying season.

(5) Should be lightweight enough to be capable of being mounted on a mobile dryer, which is a concurrent research topic at IRRI. For example, a combustor coupled with a 4-ton/batch dryer consuming 25 kg of rice husk per hour should weigh less than 300 kg .

(6) Durable and reliable.

An extensive review of the literature (Hien, 1993) revealed the existence of the following rice husk combustion systems (with discussions on the advantages/disadvantages, and design-related characteristics of each system) :

Rice Husk Combustors

- IRRI BD-2 flat-grate rice husk furnace (Fig. 6)
- Inclined grate furnace (designed at the Indian Institute of Technology) .
- IIT horizontal cyclone furnace
- Cyclonic furnace of PADISCOR, a Philippine manufacturer.
- Concentric vortex furnace of SUKUP, a U.S. Company (Fig 1).

Gasifier-Combustors

- IRRI gasifier furnace (Joint project with the Philippine Department of Agriculture)
- ITDI-DOST combustor furnace (designed at the Industrial Technology Development Institute of the Philippine Department of Science and Technology) .

EQUIPMENT DESIGN

After initial work which involved testing of DOST gasifier-combustor, BD-2 furnaces, fabrication of gasifier of the continuous type, the decision was made to develop a conical grate furnace. The final product resulted from 2 consecutive designs:

First design: Concentric vortex combustor

Among existing rice husk furnaces, the concentric vortex furnace seems to hold the most promise in terms of complete combustion. Consulting the Sukup furnace as a model (Sukup, 1989) , the challenge was to simplify the drive without sacrificing performance.

A rice husk combustor with a fuel consumption rate of 25 kg/h was designed in May 1992 (Fig. 2) . Its operation was as follows:

Rice husk was fed to the bottom of the furnace by a screw conveyor which was driven from the dryer fan shaft through a 2-step pulley and belt transmission. Primary and secondary air was supplied tangentially by tuyeres located around the cylindrical furnace wall. The secondary air flowing downward in the outer vortex, was preheated by radiation from the inner flame vortex, and mixed with rising volatile gases until the mixture reached the fuel bed. The downward vortex also caught unburnt particles which were centrifugally separated from the inner vortex, and brought them back to the fuel bed for re-ignition.

The upward inner flame vortex increased the residence time for entrained particles and combustible gases to burn. The product gases exited through a spout and mixed with the ambient air before entering the dryer fan inlet. Ash was removed intermittently by manual raking through the ash door.

Compared to the original Sukup furnace, this design was much simpler in construction. However, it still required a 2-step transmission for the auger; and the ash removal was not automatic. A simpler transmission was designed before a prototype was built to this configuration.

Second design: Conical grate combustor

This design retained all the features of the concentric vortex furnace, except for the primary combustion area. The idea of using a conical grate stemmed from assessments of a small rice husk stove model popularly used in Southern Vietnam and tested at IRRI . The cylindrical combustion chamber was surrounded by a conical hopper, the wall of which slanted 56^{o} from the horizontal for smooth flow (The same angle had been used in the stove with good results) . The conical grate extended from the lower part of the hopper . Air flows through the inclined grate and burns the solid char on the grate. Excess air flowing upward burns volatile gases which evolve from preheated rice husk surrounding the cylindrical chamber. This column of rice husk also serves as an insulation layer.

The simple cable-actuated vibrating mechanism of the IRRI BD-2 dryer was adapted for rice husk feeding. However, unlike the BD-2 mechanism which vibrates a plate under the hopper

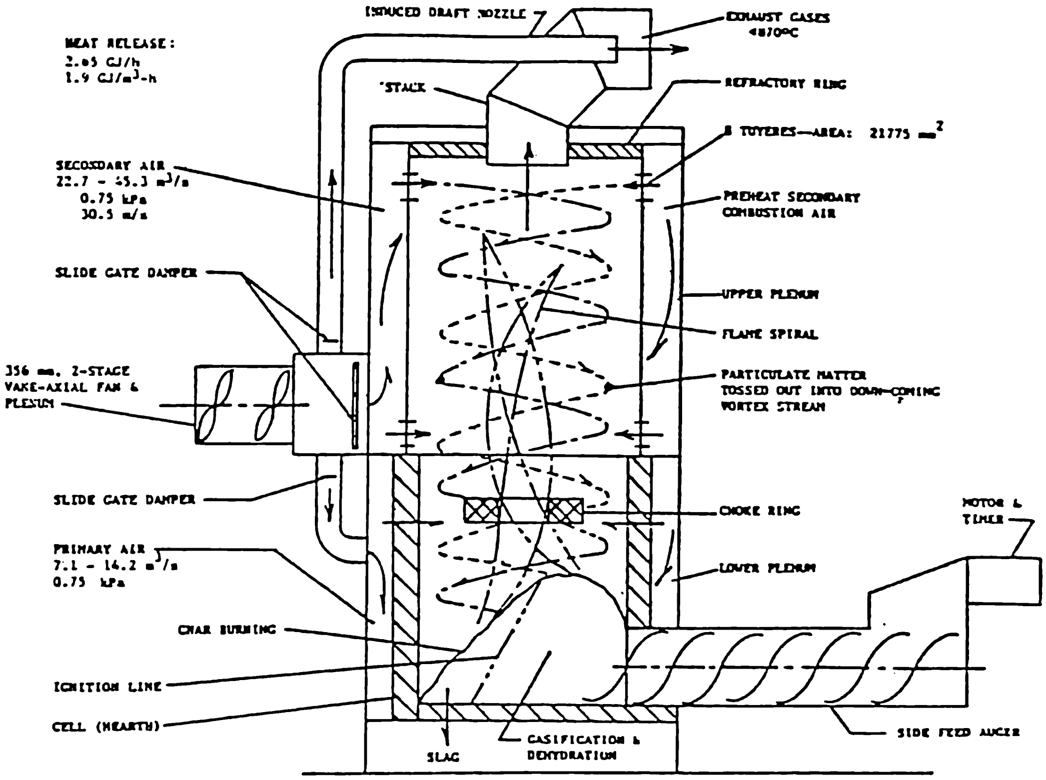

Figure 1. Concentric vortex furnace
(Claar & Bucele, 1981)

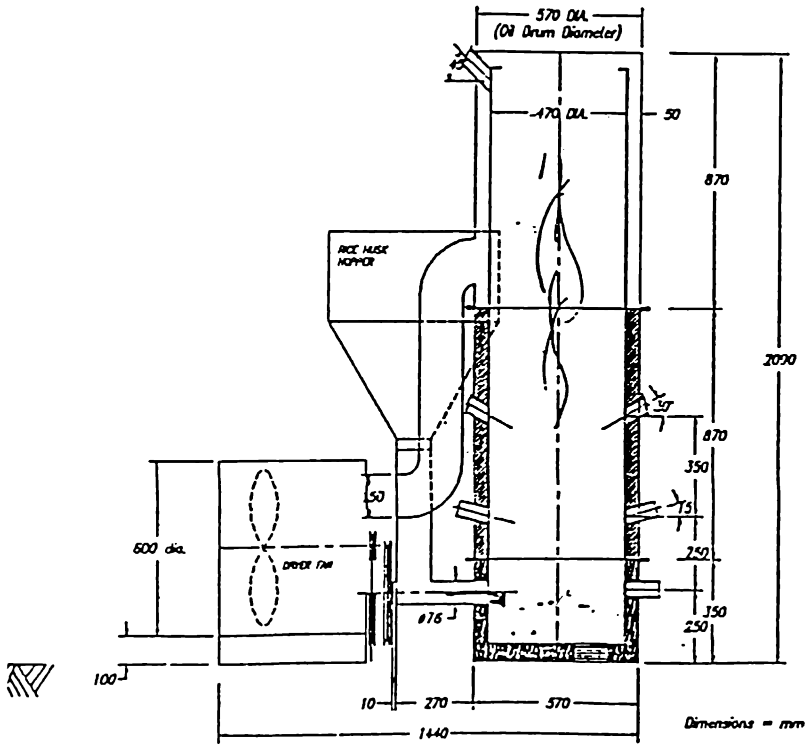

Figure 2. First Design: Rice husk concentric vortex furnace

for feeding (Fig. 6), the design used the ash discharge holder as the vibrating part to control both ash discharge and fuel feeding.

Figures 3 & 4 shows the construction of the designed furnace.

The calculation for the upper cylindrical chamber is similar to the first design (concentric vortex furnace). There was no precedent for design data on the lower conical grate, so some preliminary experiments were performed. First, based on the original rice husk stove dimensions and a burning rate of about 1.5 kg/h, a bigger stove with a burning rate of 3.5 - 4.0 kg/h was designed. The calculations of this medium stove used the design data of the inclined grate (Gherzoi, 1958). Geometrical and thermal similarities between these two stoves were established, from which extrapolations to the 25-30 kg/h targetted furnace size were obtained.

The fabrication of this prototype was finished in September 1992. From observations in several promising preliminary tests, a major design change was made. The stationary grate was cut off and replaced with a vibrating conical grate. This new grate was supported and vibrated together with the ash discharge holder by the same cable-actuated mechanism. The upper edge of the grate was about 3 cm outside the lower edge of the hopper (Fig. 5) so that the vibration of the grate was transmitted to the incoming rice husk mass, thus affecting its feeding . While the stationary grate had 9 mm dia. holes as in the small stoves, the vibrating grate was made of 4 mm dia. screen to prevent unburnt rice husk from falling through.

To adjust ash discharge rate, besides varying the vibrating force with the return spring, a vertical circular ring was installed over the edge of the ash holder. Lowering or raising this ring would decrease or increase the gap for ash discharge.

This was the final design (hereafter refered to as "JB furnace") used for the experimental set-up . It was based on 3 different concepts: a conical grate of the small rice husk stove used in Vietnam, a cable-actuated vibrating mechanism of the BD-2 dryer developed in the Philippines, and a concentric vortex combustion chamber originated from the Iowa State University .

EXPERIMENTAL METHODOLOGY

A test duct was constructed to measure the flow, pressure, and temperature of the air (Fig. 7) from the fan outlet. This simulated the flow at the drying bin inlet. Temperature at various points was measured by type-K thermocouples, and recorded with the Omnidata Polycorder.

A BD-2 axial-flow fan was used but set to run at higher speed (2400 rpm) rather than the designed 2000 rpm in order to produce a compatible flow for the furnace requirement. The calibration curve of the fan is shown in Figure 8a.

Product gas CO_2 and O_2 were measured with the ORSAT apparatus.

The average consumption of rice husk was determined from weighing the total rice husk consumed during a certain burning time. The burning time was counted from one minute after firing to when all the ash was discharged into the ash bin.

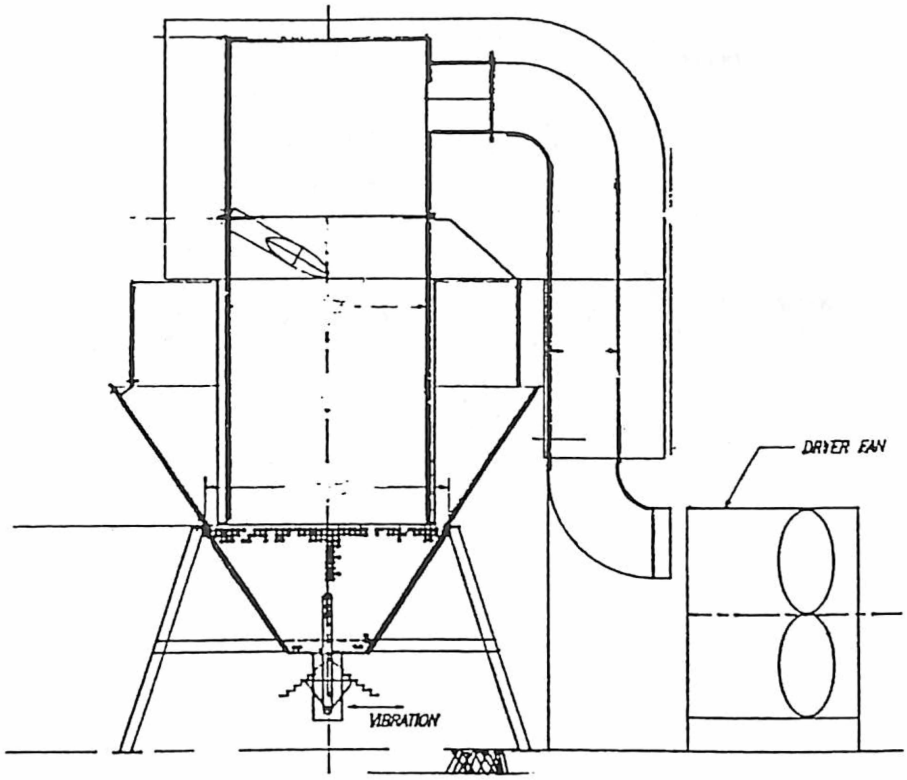

Figure 3. Conical grate rice husk furnace (JB furnace) (Hien, 1993)

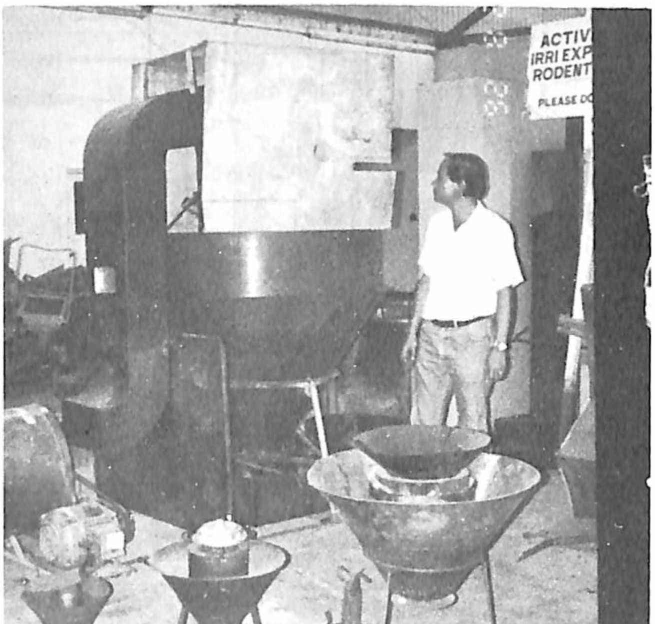

Figure 4. Rice husk combustor for crop drying. In foreground, rice husk stoves of modified Vietnamese design

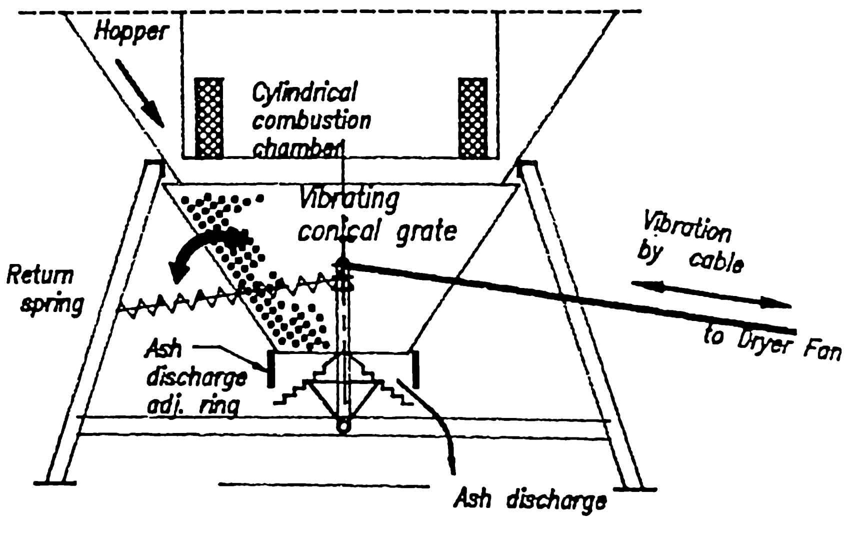

Figure 5. Conical grate with its vibrating cable mechanism (Hien, 1993)

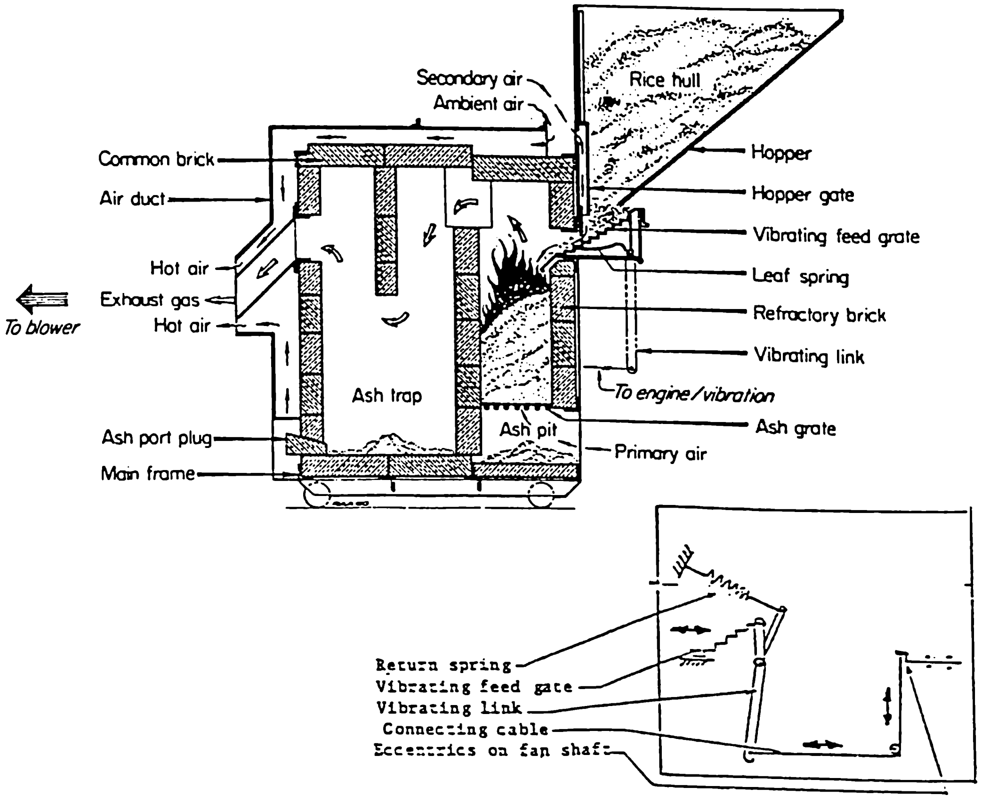

Figure 6. IRRI BD-2 furnace with its vibrating cable mechanism (IRRI, 1979)

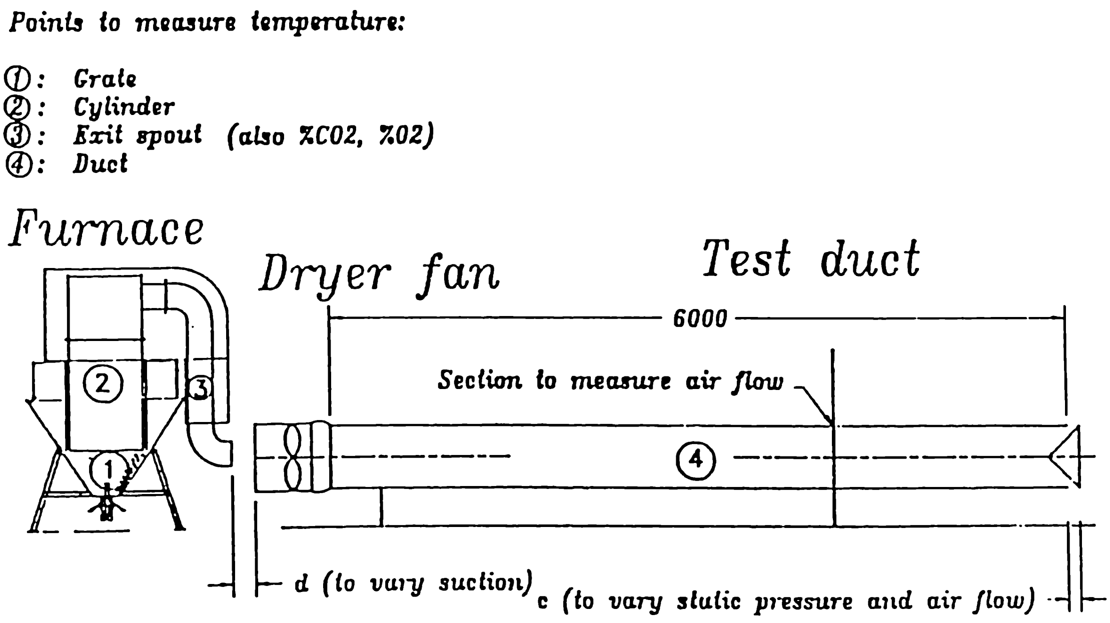

Figure 7. Test rig for JB furnace

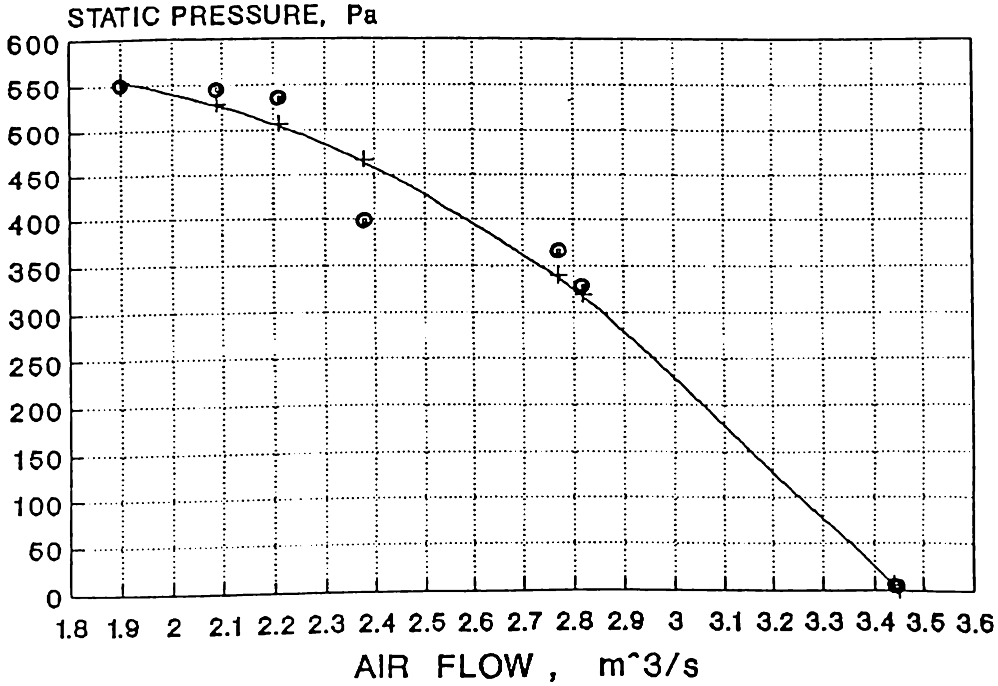

Figure 8a. BD-2 fan calibration curve (2450 rpm)

Thermal efficiency %Eff is defined from the first law of thermodynamics

$$HR + Q_{loss} = HP$$

where H_R = enthalpy of the reactants
H_P = enthalpy of the products (including solid components: Ash, considered as SiO_2, and Unburnt carbon, considred as having same specific heat as graphite)

Q_{loss} = heat loss from furnace

and $$\%Eff = [1 - (Q_{loss} / Lhv)] * 100$$

where Lhv = Lower heating value of fuel

The first law equation can be rewritten in terms of the variables under study, namely, %Excess air E_x, %Unburnt carbon U_c, %Heat loss $\%Q_{loss}$, and Reaction temperature T_r

$$f (E_x , U_c , Q_{loss} , T_r) = 0$$

or $$Q_{loss} = f (E_x , U_c , T_r)$$

The reaction temperature was from actual measurement, the excess air was derived from $\%CO_2$ and O_2 of the Orsat analysis. The %Unburnt carbon is a function of reaction temperature and time, derived from experimental data of Singh et.al. (1981) fitted with a second-order equation, which is :

$$Y = 55.265445 + -0.076530 * X_1 + -0.172297 * X_2 + 0.0000301 * (X_1)^2 + 0.0005356 * (X_2)^2 + 0.0000350 * X_1 * X_2$$

$$[R^2 = 0.77]$$

where X_1 = Combustion temperature , K
X_2 = Combustion residence time, minute
Y = %Unburnt carbon .

The residence time was estimated in two ways: (1) by calculating from the rice husk flow rate over the grate distance, (2) by observing the difference between the time the last rice husk particles entered the grate to the time all the ashes were discharged. Both methods lead to a residence time between 10 and 15 minutes.

Programs using QuickBASIC 4.5 were written to speed up calculations .

Drying air efficiency : In actual use of the furnace for drying, the final concern is the quantity of heat transferred to the drying air. Thus, the drying air efficiency is defined as:

$$\%Eff_{dry} = \frac{M_{air} * C_p * (T_d - T_0)}{M_f * L_{hv}}$$

where

M_{air} = mass flow rate of air , kg /s

M_f = mass flow rate of fuel = average burning rate , kg /s

T_0 = air initial temperature (range = 25 - 30 ^oC)

T_d = air final temperature (range = 40 - 70 ^oC)

C_p = average specific heat = 1.006 kJ /kg K for the above range.

L_{hv} = Net heat of combustion of as-used rice husk = 11350 kJ /kg (calculated from H_{hvDry} = 13900 kJ/kg and 10% moisture content)

Four drying experiments were conducted on November 5, 10, 13, 19,1992 with a 1.5-ton bin to test the furnace capability of 6-hr operation as required by the flatbed dryer.

RESULTS AND DISCUSSION

Effect of Excess air

(a) The cylinder temperature decreases as excess air increases (Fig.9)

The linear regression equation adequately represents the data:

$$T_{cyl} = 1245.8 - 2.2476 * X_e \quad [r^2 = 0.85]$$

(b) Excess air affects %Carbon conversion efficiency (Fig.10)

[Definition: $\%C_{convert}$ = 100% - %Unburnt carbon]

The first-order regression is

$$\%C_{convert} = 95.30 - 0.03964 * X_e \quad [r^2 = 0.85]$$

The results were in the range of unburnt carbon as analysed after the test run.

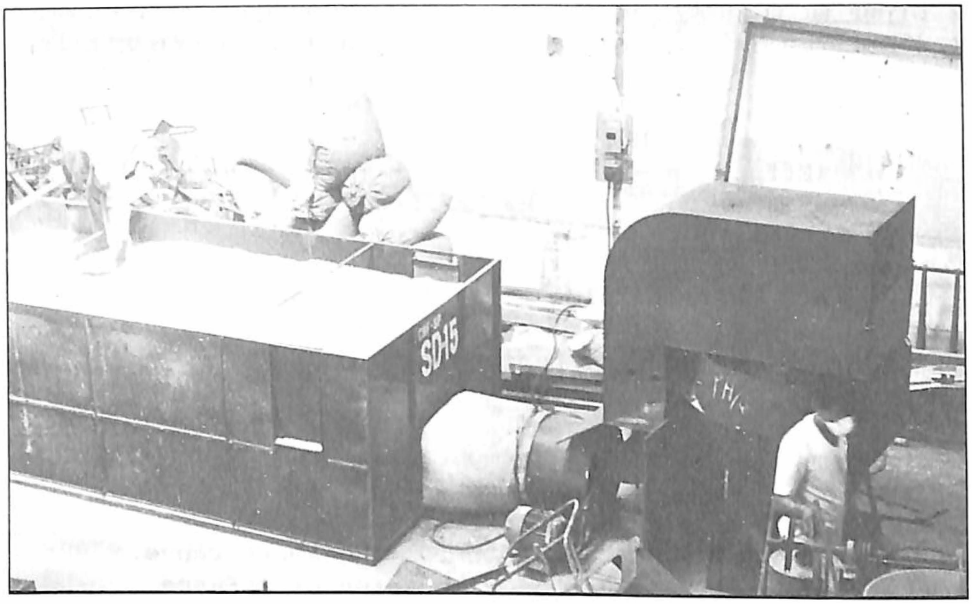

Figure 8b. Drying experiment using the conical grate rice husk furnace

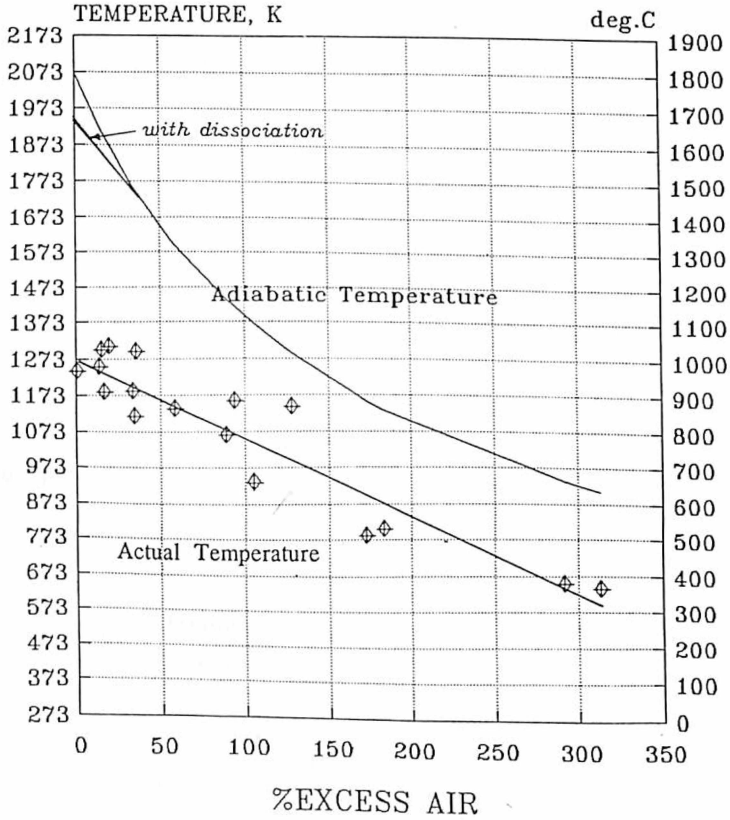

Figure 9. Adiabatic & Actual temperature as a function of Excess air

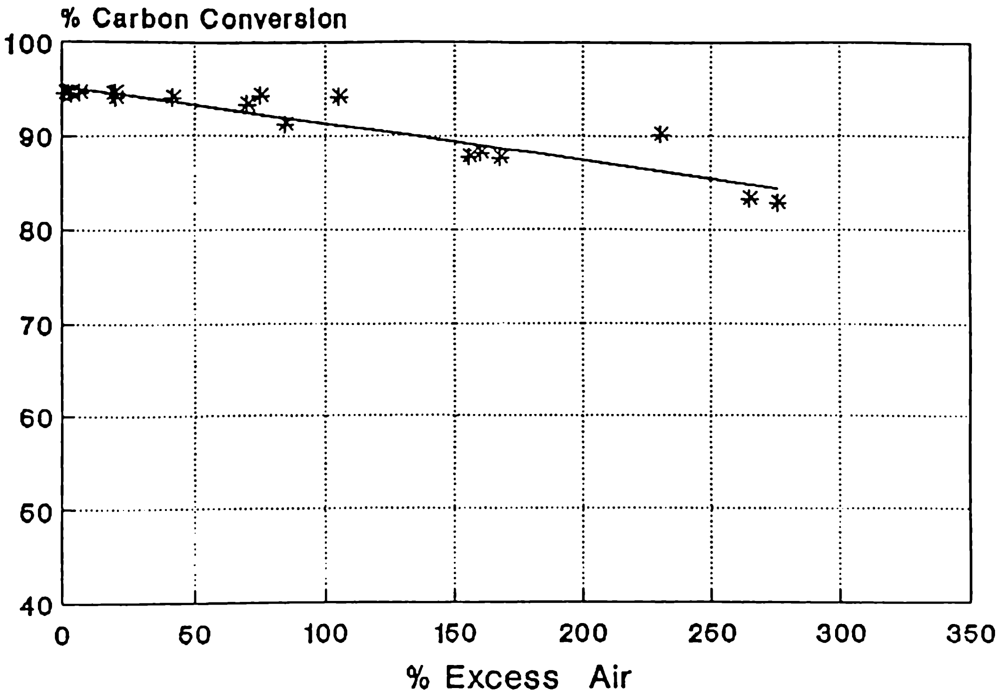

Figure 10. % Carbon conversion efficiency versus
% Excess air

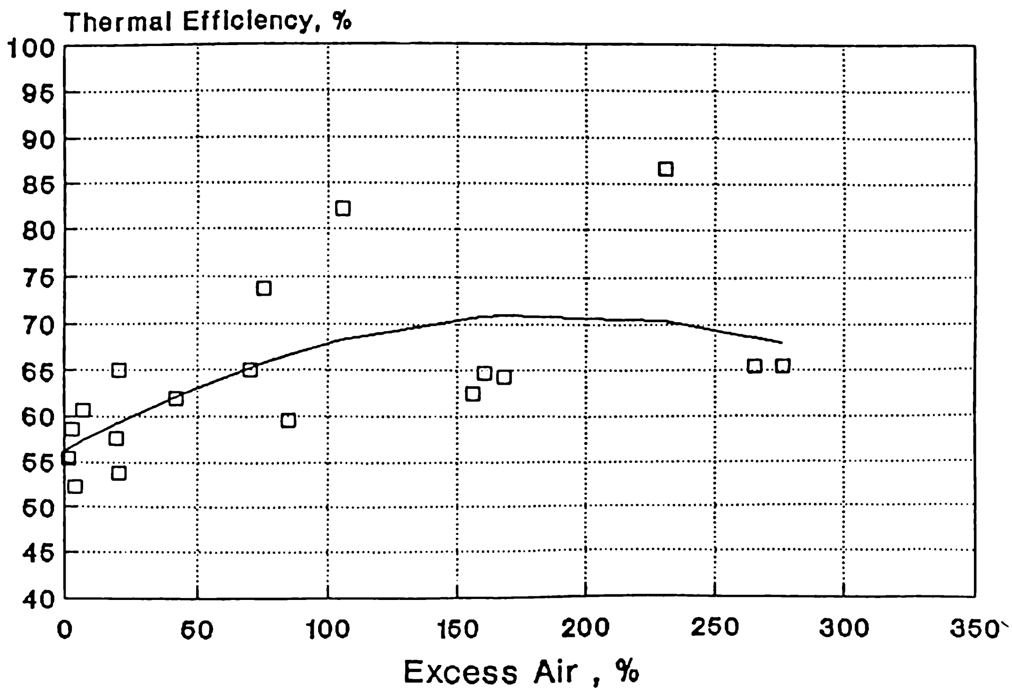

Figure 11. Thermal efficiency versus % Excess air

(c) Plot of %Efficiency versus %Excess air shows a scattered trend of increasing efficiency with excess air up to about 150%.The second order regression is as follows :

$$\%Eff = 56.32 + 0.15730 * X_e - 0.00004172 X_e^2$$

$$[r^2 = 0.39]$$

It is well known in boiler operation that additional excess air results in more heat loss in the flue gas and thus decreases efficiency. But for the furnace in this study, all the combustion products are passed to the drying air; thus the heat in the excess air is utilized, and may not necessarily decrease efficiency. Secondly, for biomass burning, some excess air is needed for better mixing with fuel for complete combustion. However, too low a temperature resulting from large amount of excess air would cool and slow the combustion reaction. If a minimum temperature of 700 ^{o}C (973 K) is prescribed for good combustion to take place (Rensfelt, 1978 ; Payne 1981), then from Fig. 9 , the excess air should be below 150%. This is consistent with the trend shown in Fig. 11 . Thermal efficiency increases with excess air up to about 150% level.

(d) A close examination of the 3 graphs of Temperature, %Carbon conversion, %Efficiency versus %Excess air with data split into 2 ranges reveals a similar trend. Above 50% excess air, the increasing or decreasing trend is readily observed. But below 50% excess air, it seems that no relationship can be established. The implication is that within this range, the combustion characteristics are affected by other variables. Obviously, one of these variables is the degree of mixing between fuel and oxygen for combustion. All research results in biomass have recommended an excess air level above 50% for good mixing and complete combustion. It seems that no theory exists so far to explain the turbulent mixing of oxidants and biomass fuel.

From the above considerations, it can be summarized that the proper operating range of excess air for this JB furnace is 50 - 150%

Drying air efficiency

Records of drying air efficiency of 16 test runs from October 1 to December 9, 1992 are graphed in Fig. 12. High efficiency was obtained in a test run with uniform ash discharge (Oct.13, Nov.13, Dec.8) and another with adequate air supply from the dryer fan (Nov.24). A distance of 130 - 150mm between the furnace exit spout and the dryer fan inlet was found to be sufficient for the suction.

Furnace capacity for drying

Test runs on Nov. 24 and Dec.7,1992 with the test fan at its maximum capacity of 3.4 m^3/s raised the drying air to 57 ^{o}C above the ambient temperature of 29 ^{o}C at a burning rate of 37 kg/h (average values). If a fan of double air flow capacity (6.8 m^3/s) is used and positioned so that its suction induces the same air supply to the furnace for the same burning rate, then the drying temperature T_d is calculated by:

$$3.4 * (57 - 29) = 6.8 * (T_d - 29)$$

$$===> \quad T_d = 43\ ^oC$$

The drying air temperature of 43 ^oC is widely recommended for flat-bed type drying of paddy (Brooker, 1974; De Padua, 1973; IRRI, 1979; Hien , 1991). This temperature results in high head rice recovery in general, and high germination percentage in case of seed drying.

The above references also recommended a specific air flow rate of about 1.0 m^3 /s/Ton of paddy. Thus it can be derived that the furnace heat (at 37 kg/h burning rate) can match the requirements of a 6-ton/batch dryer, using 6.8 m^3/s airflow .

Matching the furnace heat load with other type of dryers with known specific air flow rate can be similarly derived.

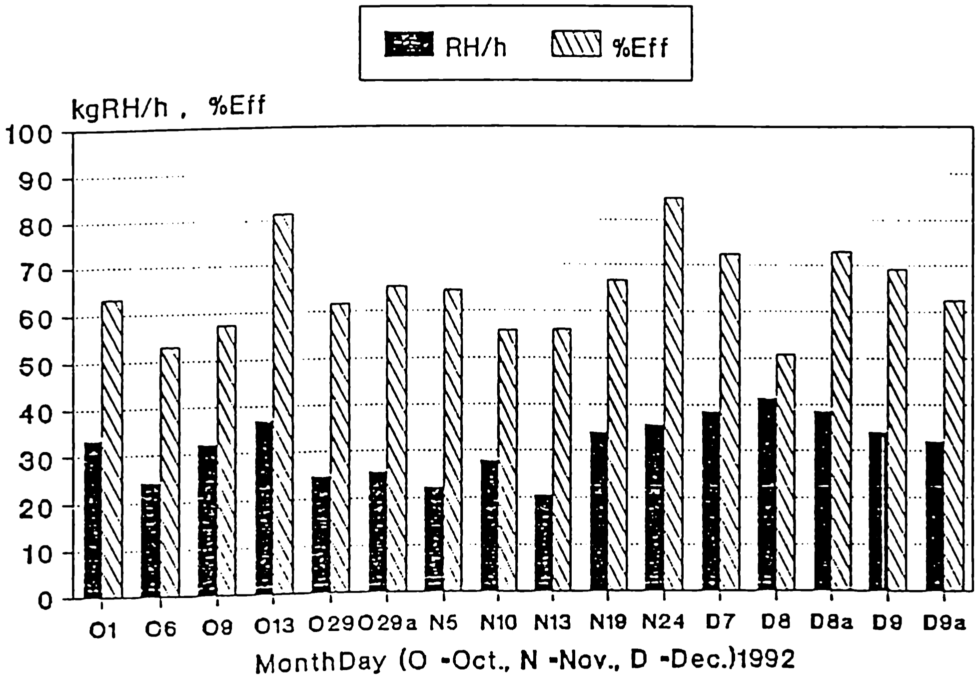

Figure 12. Records of JB furnace tests
(Drying air efficiency & Rice husk burning rate)

Particulates emission

During the 6-hr test on October 13, 1992, 48.5 kg of charred ash was collected from the ash discharge bin, and 1.5kg of flyash was gathered in front of the test duct . Thus, the flyash was 3% by weight of the total ash output or 570 mg /MJ heat input. This was rather high compared to 160 - 210 mg /MJ particulates emission from biomass furnaces (using wood or corn cob) reported in the U.S. (Barret , 1983). Anderson (1985) quoted 390 mg /MJ as the maximum particulates emission level allowed by Iowa State law for furnaces, but added that "...furnaces used for on-farm grain drying are, in most cases, exempted from this law".

The high flyash emission of this JB furnace is one of its drawbacks and is one point to consider for future improvement.

Grain Drying Tests

The furnace was found adequate as a heat source for matching a dryer, as shown by the moisture reduction curve Fig. 13. With 1 - 1.5 ton of paddy in the bin, the drying rate was 2.4 - 3.6 percentage point (wet basis) per hour, depending on the initial moisture content and the drying temperature.

The quality of dried grain follows well established facts in rice drying technology. By keeping the drying temperature below 43 ^{o}C, high head rice recovery could be obtained, as in the Nov.13,1992 test.

Ash test

The ash content in the charred ashes were analyzed and the corresponding %Unburnt carbon based on the fuel analysis was calculated .

Low unburnt carbon content from 10 to 16 % (or high carbon conversion efficiency) resulted in tests with proper adjustment of ash discharge and enough air suction.

X-ray diffraction analysis ash was done at the Material Sciences Laboratory of the Philippine Department of Science and Technology. Graph of the sample obtained from combustion of rice husk in the conical grate was found to be amorphous (Fig. 14). In contrast, the graph of charred ash from rice husk combustion with the DOST gasifier-combustor revealed the presence of other crystalline silica as well as other crystalline minerals such as phosphorous oxide. The amorphous or crystalline state is consistent with the temperature profile of the equipment (Fig. 15) and published results. If the ash attains and held at 800 ^{o}C for 1hr the transformation from amorphous to crystalline form takes place.

Amorphous ash can be used as a cement substitute in proper proportion, to make low-cost concrete (Cook, 1981).

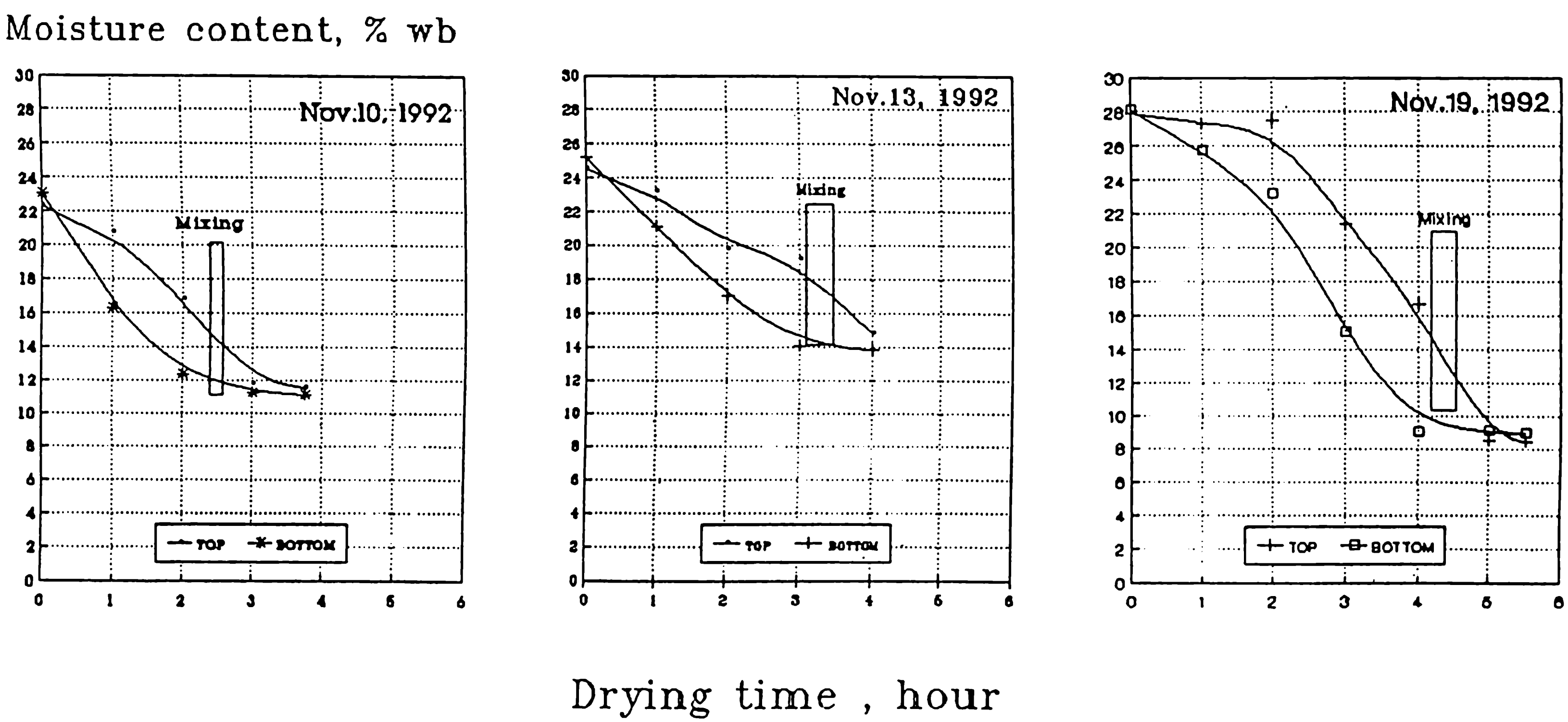

Figure 13. Moisture reduction curves

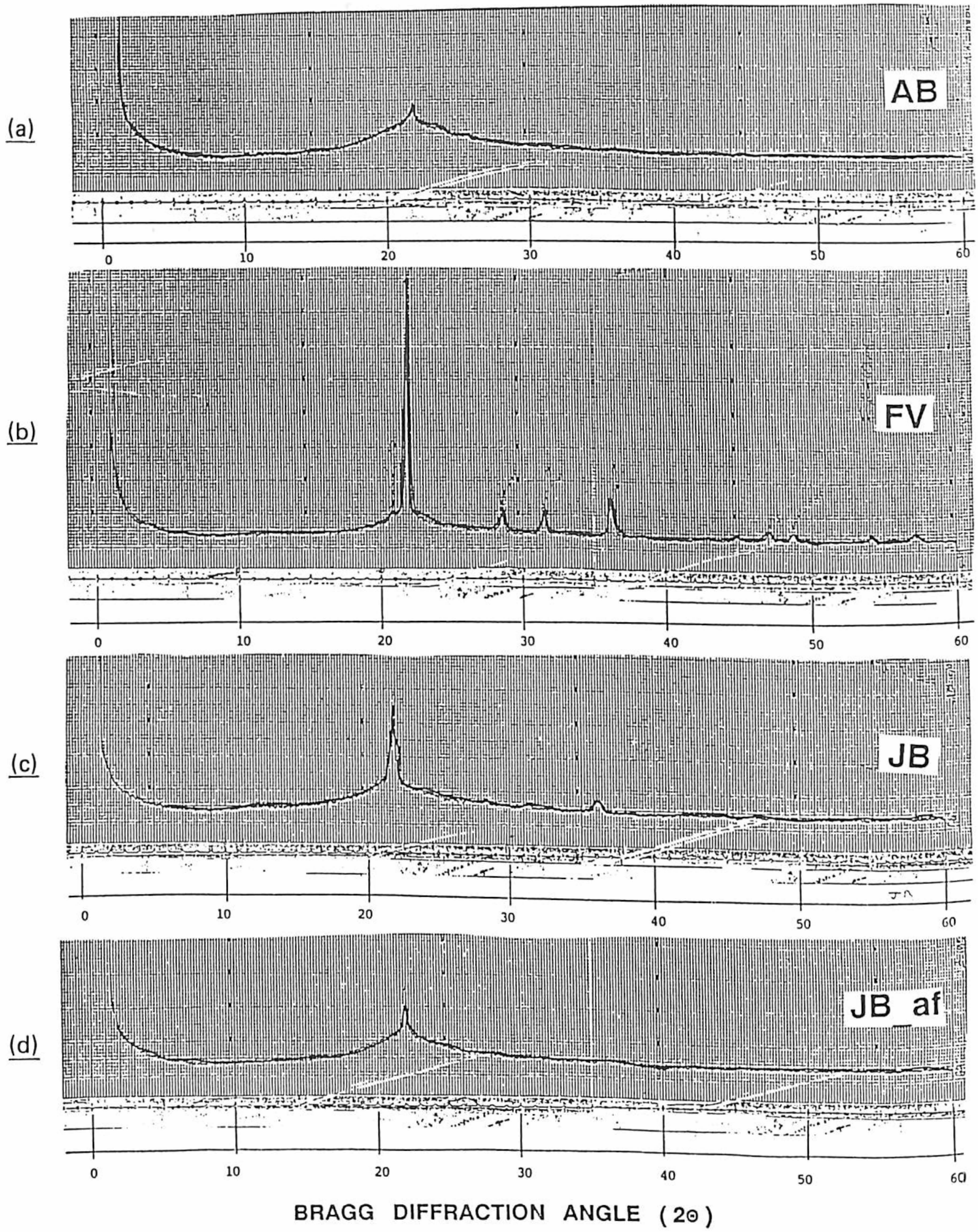

Figure 14. X-ray diffraction charts of rice husk ash.
(a): "Tube-in-basket", (b):DOST gasifier-combustor, (c) & (d): JB furnace.

(a)

(b)

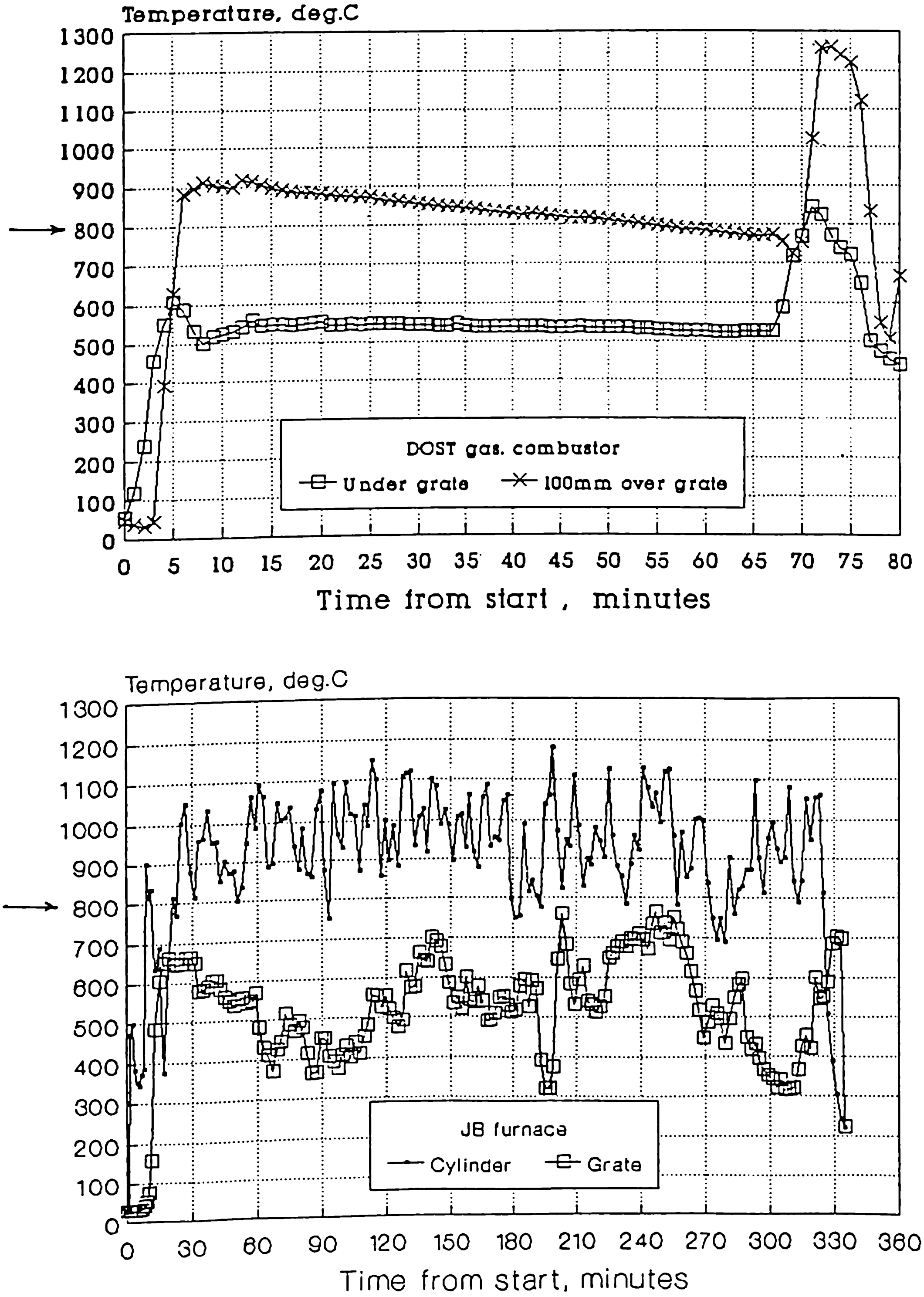

Figure 15. Temperature profiles:
(a) DOST gasifier-combustor (October 16, 1992)
(b) JB furnace (October 13, 1992)

Comparative Features of the JB Conical Grate Furnace

The main tests were concentrated on the conical grate JB furnace, and not on direct comparison with other systems. Nevertheless, from a few firings and operation of the DOST gasifier-combustor and the "BD-type" furnace, and from published reports, some features of these systems can be compiled as follows:

Table 1. Comparison between rice husk combustors

	DOST gasifier-combustor	BD-type flat-grate furnace	Conical grate JB furnace
Weight, kg	350	290	320
Rice husk consumption,kg/h	20-23 for 1.5 hr.	10 continuous	30-40 continuous
Drying air efficiency %	80	70	60-80
Estimated cost pesos US$	 15000 600	 12000 480	 15000 600
ADVANTAGES	+ Simple Construction + High Efficiency + Clean flame	+ Simple Construction + High Efficiency	+ Simple Construction + High Efficiency + Lightweight & low-cost, relative to the heat load + Automatic synchronized ash discharge and fuel feeding + Amorphous ash
DISADVANTAGES	- Need onne extra fan for air supply - Batch type (1/2 hr interruption of drying for refueling every 1.5-2.5 hours) - Crystalline ash	- Flyash sucked into dryer fan - Manual ash discharge every 5-10 minutes for even combustion	- Flyash sucked into dryer fan

CONCLUSIONS

Several systems of rice husk combustion were studied. Consideration of the advantages and drawbacks of each resulted in the selection of a conical grate combustor with cylindrical chamber, which was designed, fabricated, and tested successfully.

The following conclusions can be drawn:

- The conical grate furnace, with its burning rate of 25 - 40 kg/hr, is compatible to a batch dryer with demand of 4 -6 tons/batch. It is capable of the 6 - 8 hrs of operation needed by the flat-bed type dryer.

- The furnace is extremely simple in its cable-type transmission for synchronizing fuel feeding and ash discharge . One single fan provides both drying air for the dryer and combustion air for the furnace.

- The furnace is lightweight (320 kg) relative to its heat load, so is capable of being used on a mobile dryer.

- The drying air efficiency of the furnace is in the range 60 - 80 % . High efficiency (70 - 80%) can be obtained when the air supply corresponds to the burning rate of 32 - 38 kg/hr to reduce heat loss. Lower efficiency occurs at lower burning rate and insufficient air suction.

- The charred ash from the furnace contains 6 - 15 % unburnt carbon. The ash is amorphous and thus could be used as cement substitute in proper proportion to make low-cost concrete.

RECOMMENDATIONS FOR FUTURE WORK

As follow-up activities, it is recommended that the following be undertaken:

* Modification of the exit spout to reduce the flyash level of the conical grate furnace..

* Matching the furnace with other drying bin configurations and sizes to assess its versatility.

* Economic assessment of the furnace-dryer system before its actual field use and propagation .

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