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OPERATION AND APPLICATIONS OF RICE HULL GASIFIER-COMBUSTORS

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ABSTRACT

The gasifier-combustors operate on the principle of the open core, batch type gasifier. The gas generated in the reactor, which has a heating value of 3,900-4,000 kJ/SCM is ignited in the gas exit or piped to a thermal equipment. Two (2) reactors with internal diameters 45.72 cm. (drum-size) and a large (square) unit with 105 cm. x 105 cm. in cross section were used. The drum-size gasifier-combustors were used to fire clay bricks in a small wood-fired kiln. Four (4) drum-size units were also used to fire bricks in a shuttle kiln. The results show that a temperature of 750-850°C within the kiln was attained in 8-hour firing period. The laboratory tests on the fired products revealed that their properties are within set standards.

Initial tests on the use of the drum size units in a food drier (indirect drying) and in a grain drier (direct) show that the gasifier-combustor can maintain the required temperature within the drying chamber or plenum. The economic projections show that it is economically feasible to adopt the gasifier combustor for food and grain drying. Other agrowastes such as coconut husks, corn cobs and coffee hulls were also tested successfully as fuels in the drum-size units.

The large unit which is capable of delivering 1 million kJ/hr will be attached to a 6 cu. m. wood-fired kiln for brickfiring. As envisioned, this type of equipment will be used as heat source of a boiler for power generation and process heat.

INTRODUCTION

Significance

In a developing country like the Philippines, biomass gasification technology is attractive because of the relative simplicity of the process, the abundance of biomass fuels, and a multitude of potential uses. Among the biomass energy resources available, rice hull is an obvious choice as gasifier fuel because of their abundance. (About 1.8 million metric tons were produced nationwide in 1988). The utilization of rice hulls as energy source will not seriously contribute to environmental problems such as soil erosion and depletion of soil fertility, since they are seldom returned to the field after rice milling but instead piled and burned in dumpsites. In their normal form, rice hulls may not require further processing when used as fuel because of their homogenous size distribution and acceptable moisture content.

Despite the potential, gasification of rice hulls is not without problems. The technology in gasifying wood, charcoal and coal cannot be totally adopted in gasifying rice hulls because of their unique properties. The properties which contribute to the difficulty in gasifying rice hulls are low bulk density, high ash content, changing flow properties when subjected to thermal decomposition and the excessive moisture and tar which are carried in the gas during gasification.

Objectives of the Study

The general objective of this study was to evaluate the suitability of the rice hull gasifier-combustor for direct-heat applications. Specific objectives were:

1. To design and fabricate rice hull gasifier combustors for direct heat applications;

2. To assess the technical viability and conduct an economic feasibility of using the abovementioned equipment for brickfiring, food and grain drying applications;

3. To identify other applications of the combustors.

REVIEW OF LITERATURE

Various studies on the gasification of agricultural residues and other biomass fuels for engine application and as a heat source have been conducted since the technology was revived in the early seventies. These works include the gasification of wood (Cruz, 1981; Nandi and Onischak, 1982; Reed and Markson, 1983; Reed, 1984; Vinluan, 1989a, Wallawender and Chern, 1982), corn cobs (Allen, 1982; Payne, 1980b), coconut shells (Cruz, 1975, Cruz, 1976a and Dimagiba, 1969), rice hulls, one of the most abundant agricultural refuse (Tiangco et al., 1986; Kaupp, 1984; Manurung and Beenackers, 1985, and Vinluan, 1989b). An unpublished work of Vinluan (1985), discusses the potential of gasifiers for the rubber industry in Mindanao with specific application for drying.

Vinluan (1989b) conducted an experiment on a 20 cm. diameter batch-type gasifier and found out that a stable flame in the gas exit, which is an indicator of a continuous gas production, was obtained at an air superficial velocity of 6.78 and 12.33 cm./sec. Within this range of superficial velocity, the gas heating value was 3,600-4,000 kJ/SCM. The open flame temperature obtained using a pyrometer was 650-750°C with the carbon conversion of the fuel at 80-85 percent. Considering the gas product composition, the calculated adiabatic flame temperature is about 1,400°C.

Despite the numerous studies conducted there are no gasifiers that are widely adopted in agriculture or industry.

The Gasification Process

In conventional producer gas theory, the reactions take place in different zones of a deep fuel bed, namely, drying and distillation, oxidation and reduction zones. The principal chemical reactions that take place in the oxidation, reduction and distillation zones are discussed in serveral references (Cruz, 1985; Desrosiers, 1979; Gumz, 1950; Kaupp, 1985; Kaupp and Goss, 1981). In moving-bed gasifiers the rate of consumption of carbon is controlled by the flow rate of the blast. Under normal operating conditions, an excess of carbon will be available. Equilibrium will almost be obtained, provided that the bed temperature is sufficiently high and blast evenly distributed (Buekens and Schoeters, 1982). In fluid-bed and lean phase gasifications, the flow of carbon and that of blast can be varied independently, therefore, an excess of carbon cannot be guaranteed under all operating circumstances. For biomass materials, the reactivity is such that comparable gasification rates for wood chars are obtained at temperatures 100°C to 200°C lower than those required for coal (Graboski, 1979). Reed and Markson (1983) mentioned that biomass charcoal is very reactive and that at normal operating temperatures the reaction rate is only limited by internal surface, and that biomass charcoal is 25 times more reactive than coke.

Mathematical Modelling of Gasifier Systems

The most common method of modeling a gasifier is by the equilibrium composition based on the laws of thermodynamics. The method allows us to determine the equilibrium state of a chemical reaction by using enthalpies, entropies and equations of state. On the other hand, kinetic calculations produce information about the composition of the system as equilibirum is approached with time. With relatively rapid reaction, these intermediate compositions and the time required to achieve them are of little importance, hence, thermodynamic calculations become very useful. The equilibrium composition was used in a number of studies, programs and nomograms (Allen, 1982; Cruz, 1985; Reed, 1984). The work of Vinluan (1989a) applies equilibrium modeling for downdraft and a CUSD gasifier. The model was used in optimizing the operation of the gasifier-combustors. A computer software in BASIC language was prepared to run the model. Various types of agricultural wastes can be used as input fuel in the computer program.

DESCRIPTION AND OPERATION OF THE GASIFIER-COMBUSTORS

The Gasifier-Combustors

Two sizes of gasifier-combustors were used. These are shown in Figs. 3.1, and 3.2. The specifications of the units are shown in Table 3.1.

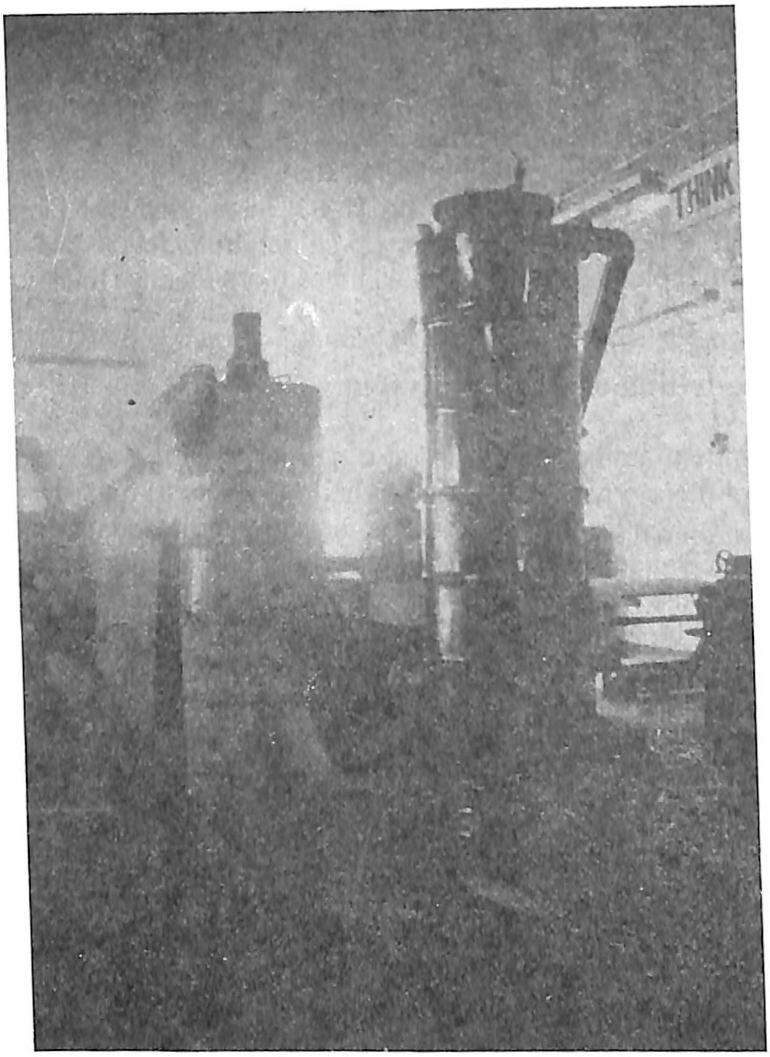

Fig. 3.1 The drum-size reactor.

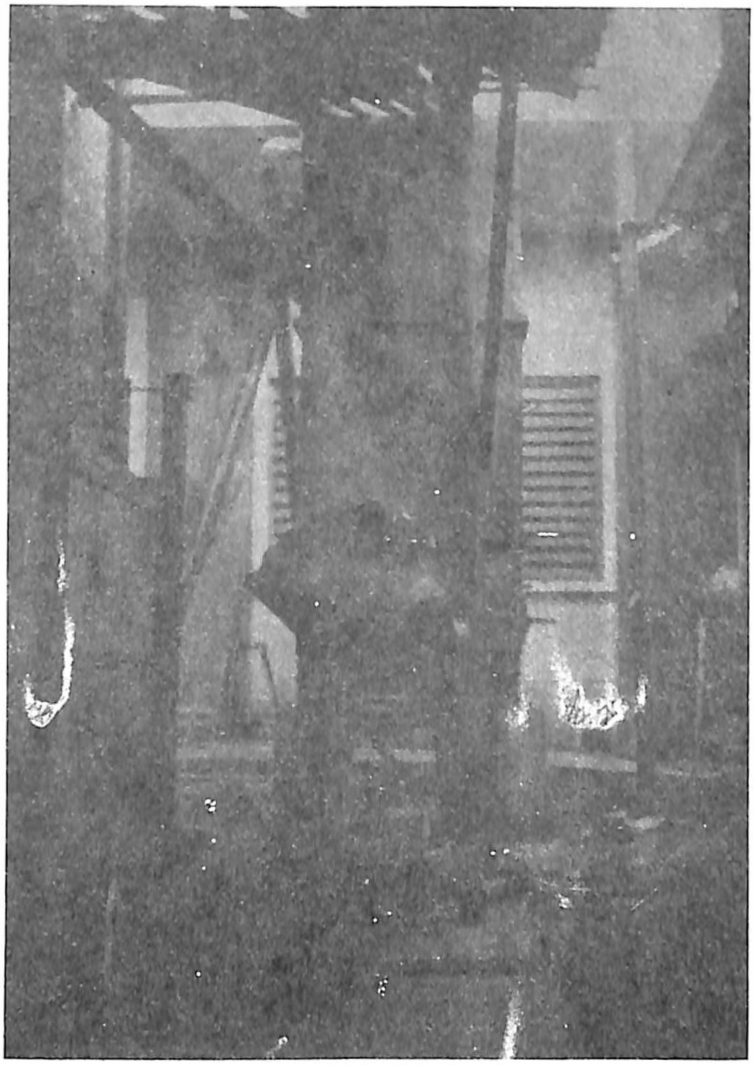

Fig. 3.2 The large rectangular reactor with a thermal output of 1 million kJ/hr.

Table 3.1 Specification of the gasifier-combustors

Type	Inside Diameter (cm.)	Average Heat Output (kJ/hr.)	Rice Hull Capacity kg.	Outer Shell	Insulation	Ash Removal System	Intended Use
Small	20.00	40,000	7	B.I. plate	Refractory SK-32	movable grate	Laboratory
Drum-size (Model A)	45.72	200,000	35	200 li. drums	Concrete	tilting grate, side ash port	Brickfiring, Palay drying
Drum-size (Model B)	45.72	200,000	35	200-li. drums	Soil bricks	tilting grate, bottom ash port	Food drying
Large-size (Model A)	(square) 105 cm. x 105 cm.	1 million	210	B.I. plate	Soil bricks	tilting grate, bottom ash port	Conversion at wood-fired kiln
Large-size (Model B)	(square) 105 cm. x 105 cm.	1 million	210	None	Soil bricks	tilting grate, bottom ash port	Brickfiring shuttle kilns, conversion of wood-fired kiln

The Components of the Gasifier-Combustors

Air Delivery and Metering System. Air is supplied from an electric centrifugal blower and conveyed to the gasifier reactor by pipes of 8 cm. in diameter. Air entering the reactor is measured by a square-edged orifice installed in each pipe inlet.

Fuel Inlet and Hopper. The topmost section of the reactor is composed of the cover, fuel inlet and hopper assembly. A handle is attached to the center of the cover. One end is hinged to the cylindrical hopper. The opposite end has a lock and screw which set the cover properly into place.

Grate and Ash Removal System. Ash is removed after each batch by tilting the grate and scraping the ash in the ash port. In the drum-size (Model B) and the large unit, ash is discharged in the bottom part which is opened after each operation.

Starting the Gasifier

The gasifier-combustors were fired by dropping burning charcoal on top of the grate. Rice hulls were then loaded into the reactor until it is full. Initially, a noncombustible gas was generated, however, after 3-5 minutes a combustible gas was produced.

APPLICATIONS OF THE GASIFIER-COMBUSTORS

Brickfiring

Test runs were conducted using the drum-size gasifier-combustor for firing bricks in a small wood-fired kiln. The set-up is shown in Fig. 4.1. The average firing time was 8 hours with a kiln temperature of 750-850°C. Physical tests conducted on fired bricks showed that the strength and water absorption were within set standards for fired structural clay products.

The use of the drum-size gasifier-combustor for firing bricks in a shuttle kiln is being implemented in San Jose City (Figs. 4-2). The shuttle kiln, which has a capacity of about 500 pieces bricks with dimension of 5 cm. x 10 cm. x 20 cm., utilizes, four (4) drum size combustors as heat source. The runs show that the required firing temperature of 800-850°C can be attained in 8 hours. Another application of the gasifier-combustor for brickfiring is for the kilns of ITDI for its housing project in Molino, Bacoor, Cavite. A total of four (4) gasifier-combustors with a total energy output of 4 million kJ/hour.

Food Drying

An application of the gasifier-combustors which will have a significant impact in the country's postproduction programs is for food drying. The drum-size unit is attached to a

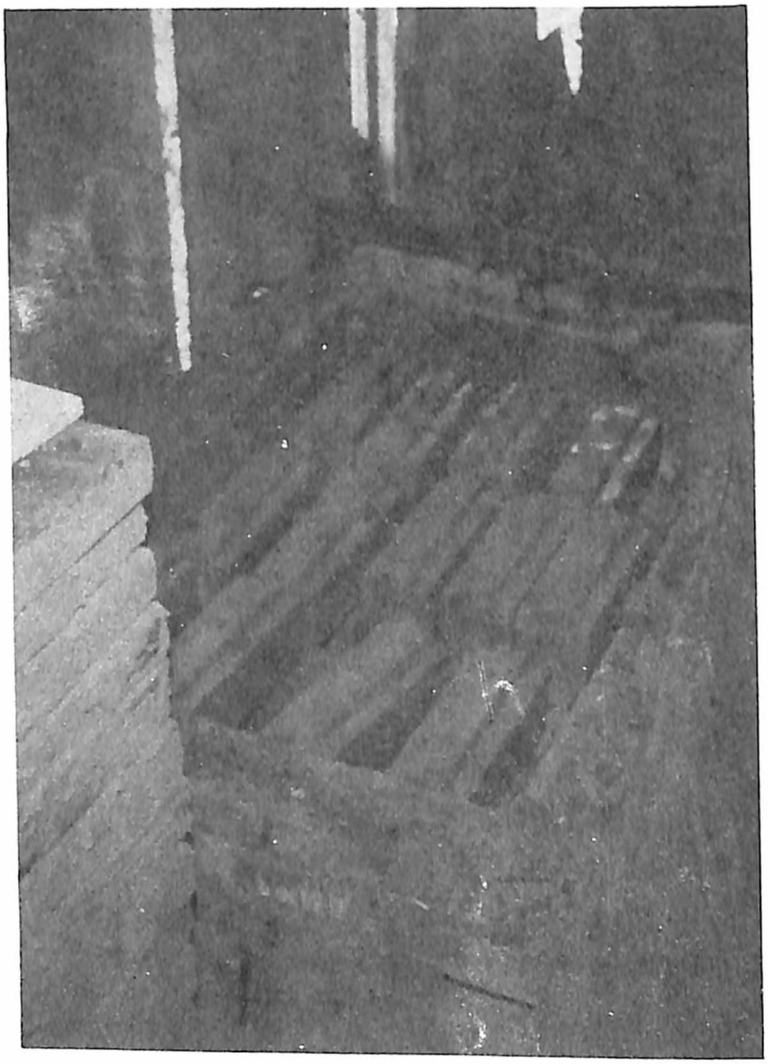

Fig. 4.1 The small wood-fired kiln which utilizes a drum-size combustor as heat source.

Table 4.1 Cost Comparison of Different Thermal Systems

System	Initial Investment per 1,000 kJ/hr. Output	Type of Fuel (Cost)	Estimated Fuel Cost per 1,000 kJ/hr. Output
GEMCOR Direct Heat Gasifier	₱ 120.00	Wood (₱ 840/T)	₱ 0.07
ITDI Rice Hull Gasi-fier-Com-bustor	₱ 39.00	Rice Hull (₱ 90/T) Hauling Cost	₱ 0.02
Kerosene Burner	₱ 7.00	Kerosene (₱3.70/li)	₱ 0.13
Biogas	₱1,100.00	Pig Manure Zero Value	0

Fig. 4.2 The shuttle kiln for brickfiring at San Jose City.

Table 4.2 Economics of Using the Rice Hull Gasifier-Combustor in an Existing Food Drier (Added Cost Analysis)

Fuel System	Additional Component	Additional Investment (₱)	1 Cost of Fuel and Electricity ₱/cycle	2 Depreciation Cost ₱/cycle	Operating Expenses (1 + 2) ₱/cycle	Annual Savings ₱/year	Payback Period /year
Wood-Fired	None	0	₱68.18	-	₱68.18	-	-
Rice Hull Gasifier-Combustor	Combustor	₱7,000	₱21.64	₱8.97	₱30.61	₱5,860.92	1.19 years

Assumptions:

1. One (1) drying cycle is equal to 8 hours of continuous operation. Three (3) drying cycles per week or 156 cycles per year.

2. Rice Hull is a waste, as such, only the hauling fee will be paid at ₱0.50/sack.

Table 4.3 **Economics of Using the Rice Hull Combustor in Rice Drying for an Existing Flat Bed Drier (Added Cost Analysis)**

Fuel System	Additional Component	Additional Investment (₱)	1 Cost of Fuel ₱/cycle	2 Cost of Labor ₱/cycle	3 Depreciation Cost ₱/cycle	Operating Expenses (1 + 2 + 3) ₱/cycle	Annual Savings ₱/year	Payback Period /year
Kerosene	None	0	₱118.40	-	-	₱118.40	-	-
Rice Hull Gasifier Combustor	Combustor	₱7,000	₱ 20.33 (incl. electricity)	₱20.00	₱17.50	₱57.83	₱4,845.60	1.44 years

Assumptions:

1. The existing Flat Bed Drier has a capacity of 40 cavans (2 metric tons).
2. Estimated drier usage is 40 drying cycles per season (wet and dry). One drying cycle is 8 hours.
3. Additional investment of the combustor adopted is ₱7,000.
4. The drier operator will be trained to operate the gasifier-combustor and will be given an additional compensation of ₱20.00/cycle.
5. Cost of rice hull is estimated at ₱0.50 per 6-kg. sack. This cost is for hauling fee because rice hull is free.
6. The fuel of the existing system is kerosene at ₱3.70 per liter.

Table 4.4 Economics of Using the Rice Hull Gasifier-Combustor in an Existing Wood-Fired Kiln (Added Cost Analysis)

Fuel System	Additional Component	Additional Investment (P)	1 Cost of Fuel P/cycle	2 Depreciation Cost P/cycle	3 Maintenance Cost P/cycle	Operating Expenses (1 + 2 + 3) P/cycle	Annual Savings P/year	Payback Period /year
Wood Fired	None	0	P1,320	-	-	P1,320		-
Rice Hull Gasifier-Combustor	2 units Large Combustor (Model B	P55,000	P310.00 (incl. electricity)	P220.00	P25.00	P555.00	P765.00	1.43 years

Assumptions:

1. There are 50 firing cycles per year.

2. One (1) firing cycle consumes 8 m^3 of wood with a price of P180/m^3.

3. No additional labor is required in shifting from wood-fired to gasifier-combustor.

furnace and heat exchanger assembly where clean hot air is generated and forced to a drying chamber. The set-up is shown in Fig. 4.3. Initial runs show that a hot air temperature of 50-68°C within the drying chamber is easily met.

Grain Drying

In grain drying application, the gasifier-combustor will be used as substitute for a kerosene-fed burner in a flat-bed drier (Fig. 4.4). The experiments are being conducted jointly with the National Food Authority (NFA) and the International Rice Research Institute (IRRI). Initial results show that the required temperature for rice drying is easily attained using the gasifier-combustor. The thermal output of the drum-size unit has been proven to be more than enough to supply the heat requirement of the drier. A Kongskilde columnar drier of the NFA at Cabanatuan City will also be retrofitted to a rice hull gasifier-combustor.

Comparative Analysis and Economics of Using the Gasifier-Combustor

Shown in Table 4.1 is a comparative analysis of the different energy sources and thermal systems. It can be noted that the biogas system, despite its very low operating cost, is not as attractive compared to the gasifier-combustor because of the very high initial cost involved. Hence, for small users where there is limited capital the gasifier-combustor becomes more attractive. Shown in Tables 4.2, 4.3 and 4.4 are the economic analyses of using the gasifier-combustor for food drying, grain drying and brickfiring, respectively. It is apparent in the tables that adoption of the system for these applications is economically justified.

Use of Other Agrowastes as Fuel

Other types of agricultural residues such as coconut husks, corn cobs and coffee hulls were used as fuel for the drum-size unit. The results show that these agrowastes are equally suitable as fuel. This further proves that the gasifier-combustor technology could be adopted in localities where these fuels are abundant.

CONCLUSIONS

Considering the results of the brickfiring experiments in a small wood-fired kiln and in a shuttle kiln, it can be concluded that a rice hull gasifier-combustor is suitable for firing clay bricks. The foremost requirement, a temperature of 750-850°C within the kiln, was attained in most of the tests. The results of the strength and water absorption tests on the products would mean that their properties are within set standards.

Initial tests runs on the use of the gasifier-combustors in a food drier show that hot air temperature of 50-68°C within the drying chamber is easily met. In the test runs on the

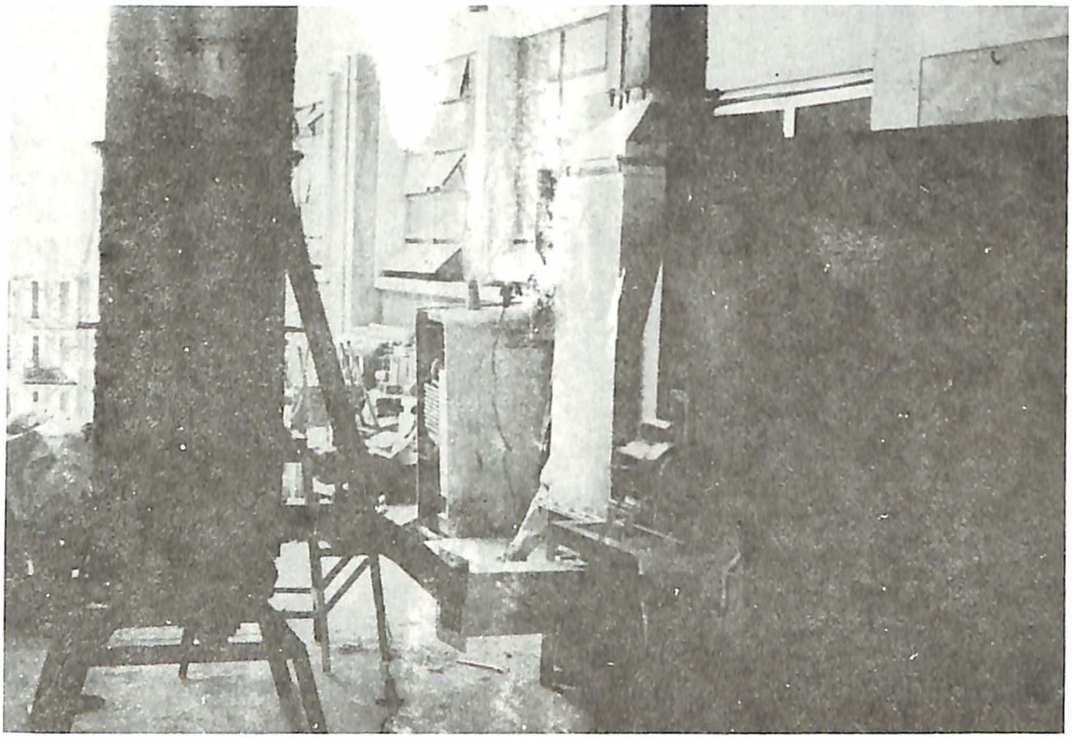

Fig. 4.3 The drum-size gasifier-combustor attached to a food-drier.

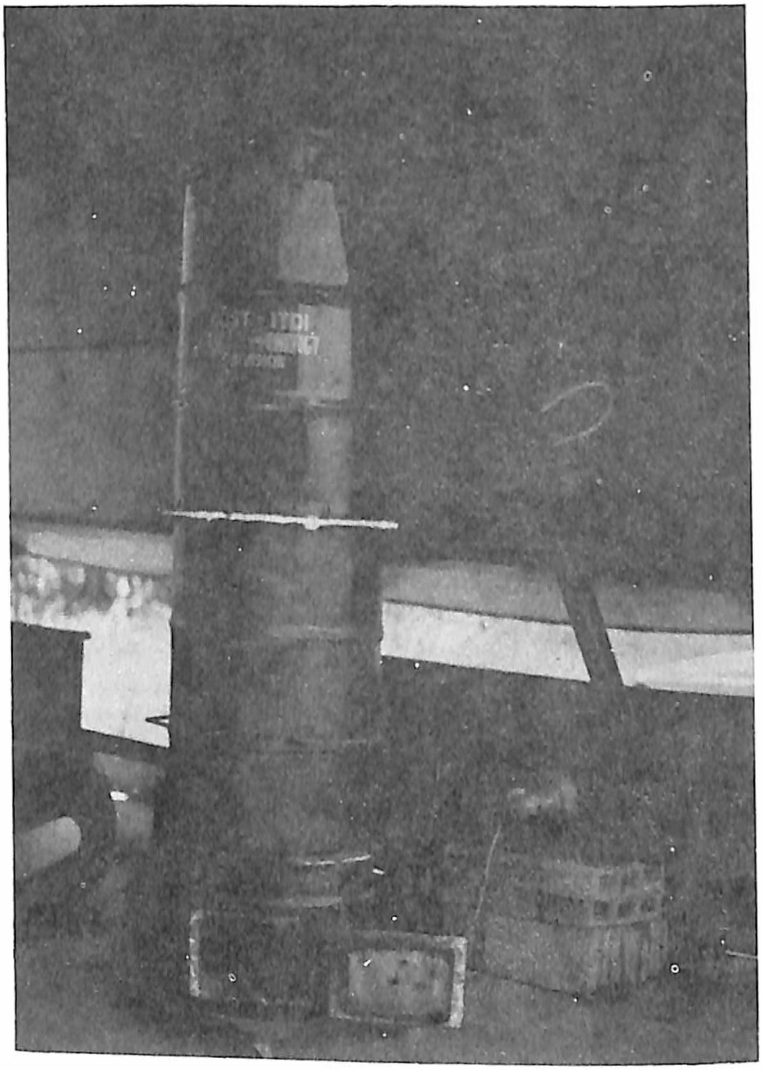

Fig. 4.4 The drum-size gasifier-combustor attached to a flat-bed grain drier.

flat-bed drier, the thermal output of the drum-size unit has been proven to be more than enough to supply the heat requirement of the drier. The economic projections show that it is economically viable to adopt the gasifier-combustor for food and grain drying.

The economic analyses show that it is feasible to use the large gasifier-combustor in a shuttle kiln and in converting a wood-fired kiln to rice hull-fed system.

FUTURE ACTIVITIES

Heat Source for Boilers

An application of the gasifier-combustor which will have a strong impact in the country's rural industrialization program is for boilers. The generated steam can be used for electric power generation and for process heat. This is significant in areas far from the power grid and where the price of fuel oil is prohibitive because of high transport cost from the distribution centers.

In the drawing board is the installation of an experimental boiler fired by multi-fuel gasifier-combustors at the DOST Compound in Bicutan, Metro Manila. The 300 KW power plant of the NFA is also being planned for conversion into a gasifier-combustor system.

Engine Application

By using the gas from the reactor as fuel for internal combustion engines, cheap power (shaft and electrical) for various farm operations can be generated. A very important application is for water pumping for crop irrigation in areas where there is distinct dry season. In post product systems, possible applications involve threshing, milling and refrigeration.

SOCIAL AND ENVIRONMENTAL DESIRABILITY OF THE TECHNOLOGY

Effective utilization of various agricultural wastes offers solution to disposal problems. Thermal conversion of agricultural wastes is one of the most environmentally desirable energy sources because of the absence of SO_2 emissions which is inevitable in the combustion of petroleum-based fuels. Agricultural wastes such as rice hulls, corn cobs or coffee hulls are seldom returned to the field, hence, their use would not seriously contribute to erosion or depletion of soil fertility. The extensive use of these resources would result to the displacement of wood which is the most common fuel for processes such as food drying, tobacco curing, pottery kilns, brickmaking kilns, etc. The conversion of the MSD-ITDI wood fired kiln to rice hulls would displace about 60 tons of fuel wood annually. Considering the thousands of brick pottery kilns, tobacco curing barns and dries throughout the country, the agrowaste-fueled gasifier-combustor if fully implemented, would have a significant contribution to the conservation of the country's wood resources. On the other hand, the

CO_2 emission during the thermal conversion process is converted to O_2 by the succeeding crop.

The technology is not only suitable for post-harvest systems (grain and food drying), infrastructure (bricks for rural housing and crop storage) but also for power generation. The use of the gasifier for engine application is another field of research which has the potential of increasing production by providing cheap power for irrigation, post-harvest system, refrigeration, etc. Hence, the successful dissemination of this technology in the countryside would be of great help in increasing productivity and in accelerating the rural industrialization program.

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