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ENERGY FROM RICE RESIDUES

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ABSTRACT

Energy From Rice Residues

This report provides information on commercially available systems that are producing energy from rice residues in the United States, Europe, and various developing countries.

The report reviews the production of several types of energy including industrial process heat in the rice milling industry and other industries, mechanical and electrical power for rice milling, and electric power for the grid. The rice residue systems reviewed in the report include furnaces producing direct heat, boiler systems, steam engine systems, steam turbine/generator systems, gasifier/engine systems, and a gas turbine system.

Most of these systems burn rice husks, but the outlook for producing energy from rice straw is also assessed. In addition, the prospects for the use of energy from husks or straw in the processing of rice bran are reviewed.

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Energy From Rice Residues

1
INTRODUCTION

Developing countries produce millions of tons of rice husks and straw as a byproduct of harvesting rice. Although some of these rice residues are used for fuel or for other purposes, most of the residues are burned for disposal or just dumped. In most rice-growing countries, rice residues represent one of the largest potential fuel supplies for biomass energy projects.

Since the mid-1980's, new rice residue plants have been installed in several countries and a number of others have been planned. Firms in the United States, Europe, and Japan are currently offering major components or complete systems for rice residue utilization, using several types and sizes of combustion or gasification units, boilers, engines, engine/generator sets, and other components.

Information on components and systems and the present use of these systems in rice residue projects has not been widely available. The primary objective of this report is to provide basic information on the present and prospective commercial availability of various types of systems and on present operational projects, along with sources of more detailed information.

The great majority of the present systems and planned projects have been designed to use rice husks, although two large power plants in California are beginning to burn some rice straw along with husks and a plant fired exclusively with straw is planned in India. The use of rice straw as an industrial fuel has been limited by the logistical problems associated with the collection of the straw and by a lower ash melting temperature which can create slagging problems in furnaces. Prospects and problems associated with the industrial use of rice straw are described in section 6.

The report focuses on firms providing complete husk power systems or major husk combustion systems. An effort has been made to include all such firms which are actively involved at present with international projects or sales. No attempt has been made to provide information on firms providing husk combustion systems or equipment exclusively within their own countries.

The inclusion of a system or project in this report is not intended to imply a judgement by the editor or by the U.S. Agency for International Development on the operational capabilities, cost effectiveness, or suitability of the system for any specific application in a developing country.

Descriptions of systems and plants of specific companies are based on information provided by the firms and reviewed by them .

2
CHARACTERISTICS, AVAILABILITY, AND USES OF RICE HUSKS

Characteristics of Rice Husks

The husk surrounding the kernel of rice accounts for about 20% by weight of the harvested grain (paddy). In modern two-stage mills, the husk and the bran layer inside the husk are removed in separate stages; these mills generate about 200 kg of husk for each tonne of paddy.

In most of the very numerous small mills in developing countries, some or all of the bran is removed with the husk in a single-stage milling operation. The resulting husk/bran mixture often represents 25% or more of the paddy by weight.

Since opportunities for husk combustion and gasification systems at present are principally at larger two-stage mills, a husk/paddy ratio of 20% is assumed in the discussion of such opportunities in this report.

The energy content or caloric value of the husks varies somewhat with the rice variety, the amount of bran mixed with the husks, and the moisture content of the husks (usually 8 to 10%). Most of the approximate fuel values cited in the literature on rice husks are close to 6,000 BTU/lb, 3,000 kcal/kg, or 15 MJ/kg. The energy in 3 kg of husk approximately equals that in 1 kg of fuel oil or 1.5 kg of coal. Somewhat higher fuel values have been indicated in tests of husks from small mills in developing countries; the inclusion of some bran with the husks tends to increase the percentage of carbon and dilute the ash in the mixture.

Most rice husks contain between 15% and 20% ash, although even higher ash contents have been recorded in some cases. The ash is 92% to 95% silica. The high ash content and the characteristics of the ash impose several severe requirements on the design of combustion or gasification systems for use with rice husks.

Availability and Use of Rice Husks

In most of the major rice producing countries, the total annual output of husks is very large, but most of the husks are available in relatively small quantities at tens of thousands of small mills.

The patterns of rice milling, husk availability, and husk utilization vary substantially from country to country. Although a review of the availability and uses of husks in all A.I.D.-assisted countries is not feasible, information is presented in the following sections on the availability and use of husks in three countries with quite different patterns. Indonesia, Thailand, and India.

Indonesia

In 1987 a team funded by the A.I.D. Bioenergy Systems and Technology Project studied the potential for private investment in rice residue power generation in Indonesia. The report of the team provided a comprehensive picture of the availability and use of rice husks in that country.

Indonesia produced over 31 million tons of paddy in 1986, as well as an equal tonnage of rice straw and about 7 million tons of husks. Most of the paddy was milled in 60,462 stationary mills which produced 25.7 million tons of milled rice. Half of these mills had capacities of about 1 ton per hour; only 1% of the mills were larger, and 49% of the mills were smaller. The statistical average output of Indonesian mills was only 425 tons per mill per year. About 8.7 million tons of paddy were milled in transient mills or by hand in villages. This small-scale, decentralized rice milling has been encouraged by the Government of Indonesia as a means of increasing rural employment and ensuring food supplies in remote rural areas.

Since the production of parboiled rice is not common in Indonesia, rice husks are not needed as a boiler fuel in Indonesian rice mills. Neither the report of the BST team nor a paper on husk utilization from the Institute of Technology in Bandung (ITB) made any reference to the use of husks as a boiler fuel in the rice milling industry or any other industry in Indonesia.

The BST team estimated that only about 10% of the available husks are used for economically productive purposes such as fuel for brick kilns, filler material for bricks, animal litter, growing medium for mushrooms, and others. Other industrial uses cited in the ITB paper included tobacco curing, small scale paddy drying, and the production of soybean cake.

Some husk is given away to anyone who will remove it from the milling sites. Very low income people who cannot afford or obtain fuelwood burn rice husks in simple vertical containers for domestic cooking. In some areas, husks are used to absorb human wastes and the mixture is then used in the fields as fertilizer. Much of the husk remains unused and is burned on open ground near the mills.

Thailand

Thailand produced 13.86 million tons of milled rice in 1988-89 and generated over 3.465 million tons of rice husks.

An overview of rice milling and of rice husk availability and utilization in Thailand was provided by studies in the early 1980s by the Thailand Institute of Scientific and Technological Research (TISTR) and by Chulalongkorn University.

In that period there were about 40,000 rice mills in Thailand. About 93% of these were small mills processing less than 20 tons of paddy per day. These small mills processed only about one-fourth of the rice crop in Thailand. Most smaller mills were operated

with small diesel engines, although some mills in areas served by the grid had electric motors.

Three-quarters of the Thai rice is processed in larger mills. The Chulalongkorn University study identified 1,450 mills producing from 20 to 40 tons of rice per day and 948 mills producing more than 40 tons/day.

Parboiled rice is not included in the Thai diet, although a few mills in Thailand produce parboiled rice for export. Since steam is not required for parboiling, the larger Thai mills have traditionally used steam from husk-fired boilers in steam engines or turbines to produce mechanical power. All but one of 16 larger mills surveyed by Chulalongkorn University used rice husks as the primary source of power. The Chulalongkorn study concluded that about 80% of the medium-sized and large mills in Thailand used power from rice husks and that about 30% of all the husks generated in the country are used as fuel in the rice milling industry.

The husks are typically burned in traditional furnaces which are custom-built at the mills with fire brick and insulating brick by experienced local furnace builders working without engineering drawings. Most boilers used in these mills are built by local boilermakers.

The TISTR survey indicated that about 20% of the medium and larger mills were operated with electric power, and this percentage has increased as new mills have been built and some of the old mills have been modernized.

Due to the existence of numerous larger mills which need electric power but do not need steam for parboiling, Thailand provides interesting opportunities for the use of relatively large husk gasifier/engine systems. At present it is apparently the only A.I.D.-assisted developing country in which a private firm (Charung Engineering) has sold a number of gasifier/engine systems fueled with rice husks for power generation in rice mills.

Husks are also used as fuel in a number of other industries in Thailand. Examples listed in the Chulalongkorn study included fuel for brick making and charcoal production and boiler fuel for a distillery and for plants producing rice bran, kraft paper, and jute fiber.

Non-energy uses of husks in Thailand include filler for brick, poultry food supplement, poultry bedding, soil additive to reduce salinity, fertilizer, and domestic fuel. The use of husk as a domestic fuel is relatively limited due to the availability of more convenient fuels, the lack of suitable stoves, and, in many cases, the availability of husks only at mills some distance from the village.

India

India is the world's second largest rice producer (after China). The annual output is over 90 million tons of rice, about the same quantity of straw, and over 20 million tons of husks.

There are over 110,000 rice mills in India, the largest number in any single country. About 90,000 of these are small hullers or shellers with capacities below 500 kg/hour. A U.S. Department of Agriculture report in 1981 indicated that only about 15% of the paddy in India was milled in two-stage mills which remove husks and bran separately. In 1985 there were 17,826 "modern or modernized" rice mills in India with capacities from 1 to 3 tons per hour.

Despite the very large supply of rice husks, the extent of the utilization of husks is much higher in India than in any other developing country. Nearly half of the Indian rice is parboiled, and about 40% of the husks generated in India are used as a boiler fuel in parboiling mills. As in Thailand, some of the older non-parboiling mills in India produce mechanical power with rice husks; the typical husk power system includes a rather inefficient step-grate furnace, an old Lancaster-type boiler, and an old steam engine.

Rice mills in India which do not use their husks for parboiling or for mechanical power usually sell the husks to other industries for use in furnaces or boilers. Due to the severe energy and fuel shortage in India, a wide range of Indian industries use rice husks as fuel.

Competition among buyers has driven up the price of rice husks in India. A study for AID indicated husk prices around Rs. 300 ($18) per tonne in Haryana in 1987/88. An Indian agency reported prices in 1988 in Haryana and Punjab ranging from Rs. 300 to 400 ($18 to $23) per tonne. In mid-1989 the Indian Institute of Technology in New Delhi indicated that husk prices in some parts of northern India had reached Rs. 500 ($30) per tonne.

Although rice husks have been widely used as a domestic fuel in India, the increased use of the husk by industries appears to be restricting the use of the husks for domestic purposes.

3
INDUSTRIAL PROCESS HEAT FROM RICE HUSKS

At present the most common industrial use of rice husk is for process heat, including both the direct use of heat from husk-fired furnaces and the generation of low pressure steam in husk-fired boilers. Most of this use of husks is in the rice milling industry, but husks are also burned as a boiler fuel or for direct heat in a number of other industries in several developing countries.

In the rice milling industry, husks are widely used as a boiler fuel in mills producing parboiled rice. In such mills the rice is soaked, cooked, and dried while still in the husk and is then milled to produce white or polished rice. Parboiled rice is less gummy and more stable when cooked than other rice. About 20% of the world's rice crop is parboiled, but the percentage is much higher in some Asian and African countries. Nearly half of the Indian rice is parboiled.

In many of the older parboiling mills in India and elsewhere the husks are burned in very inefficient step-grate furnaces which leave a black ash with a high percentage of unburned carbon. These mills usually have rather inefficient boilers. Even a relatively efficient mill in India uses about 180 kg of husks (80% to 90% of the husks produced from each tonne of paddy) to produce the 600 kg of steam needed to parboil a tonne of paddy. At best, the remaining husks may provide enough heat for drying the parboiled paddy.

This use of husks in rather inefficient furnaces and boilers to provide steam for parboiling and drying has precluded the use of husks in these mills to provide mechanical or electrical power. Eldon Beagle's survey of rice husk utilization for FAO in the mid-1970s revealed no mill in which rice husks were being used for both rice parboiling and the production of mechanical or electrical power. However, research for this report has identified several husk-fired power plants at rice mills which are operating as cogeneration plants.

A cogeneration plant produces both electricity and process heat. Steam at relatively high pressures is used in a turbogenerator or a steam engine/generator set to generate electricity; low-pressure exhaust steam from the turbine or engine is used for process heat.

Until recently, cogeneration has been rare in the rice milling industry in developing countries. Parboiling mills typically use steam produced with husks for parboiling and drying, rather than for electricity generation. Mills in which rice is not parboiled do not have a major demand for process heat, although some of the larger parboiling mills have used steam for paddy drying. In many of the older mills without parboiling, low pressure steam from husks provides mechanical power via steam engines or turbines without the production of electricity.

Experience in recent years in other industries has clearly demonstrated the economic benefits of cogeneration systems at mills in which there is a substantial demand for both electric power and process heat. Exhaust steam from husk-fired power plants is used for process heat in several rice mills in developing countries.

In some developing countries (notably India and Thailand), furnaces and boilers to be fired with husks are built at the site by local firms. Several firms in developing countries manufacture husk-fired combustion units providing direct heat for paddy drying. This report focuses primarily on firms which provide "packaged" (factory-built) combustion/gasification systems that have been specially designed for use with rice husks.

The high ash content of rice husks and characteristics of the ash impose severe requirements on the design of combustion systems to be fired with rice husks: (a) Ash removal devices must be able to remove the high volume of ash without interfering with the flow of combustion air. (b) Furnace temperatures must be carefully controlled to avoid slagging problems which arise if the temperature exceeds the point at which the ash begins to melt (about 1440°C, 2624°F). (c) Systems must be designed to minimize the entrainment of ash in the gas stream and/or to minimize erosion of components by entrained ash as it passes through the boiler tubes and heat exchanges.

The five firms listed below produce combustion and/or gasification units which have been used in developing countries with rice husks to provide direct process heat and/or low pressure steam.

Gariboldi Engineering Company

Gariboldi Engineering was associated until recently with a large, century-old rice milling company in Milan, Gariboldi S.N.C. The engineering firm provides several types of power systems for rice mills including burners, boilers, heaters, and complete power plants.

The Gariboldi line of husk burners can be used with air heaters for paddy drying or with firetube boilers for steam generation. The design combines features of grate burners and suspension burners. Combustion begins on a grate and is completed in suspension after the partially burned husks are entrained in the air/gas stream. The ash is also entrained and is removed in one or more cyclones after the gas leaves the boiler or air heater. Gariboldi offers these husk burners in five sizes with capacities of 500 to 2500 kg (1,101 to 5,507 lb) of husks per hour. When used with an air heater for drying, the smallest burner uses the hourly husk output of a 2.5 ton/hour mill.

Gariboldi produces two types of heater/dryer systems. In systems to be used for drying grain or other foodstuffs, clean air is heated in a heat exchanger (fig. 1). Seven of these models produce from 120,000 to 1.4 million kcal/hour (476,000 to 5.55 million BTU/hour). For other industrial drying applications, the flue gas is mixed with ambient air and used directly for drying. Six of these models produce from 500,000 to 3 million kcal/hour (2 to 11.9 million BTU/hour).

Gariboldi provides both firetube and watertube boilers for use in husk-fired systems. In the more widely used firetube boilers, the tubes pass through the water three times before the gas stream leaves the boiler.

The smallest firetube boiler system requires 392 kg of husks per hour, the equivalent of the husk output of a 2-tonne/hour mill. It produces 1666 kg/hour (3671 lb/hour) of steam at 15 bar (213 psi). The largest model requires 2.3 tonnes of husks per hour, the husk output

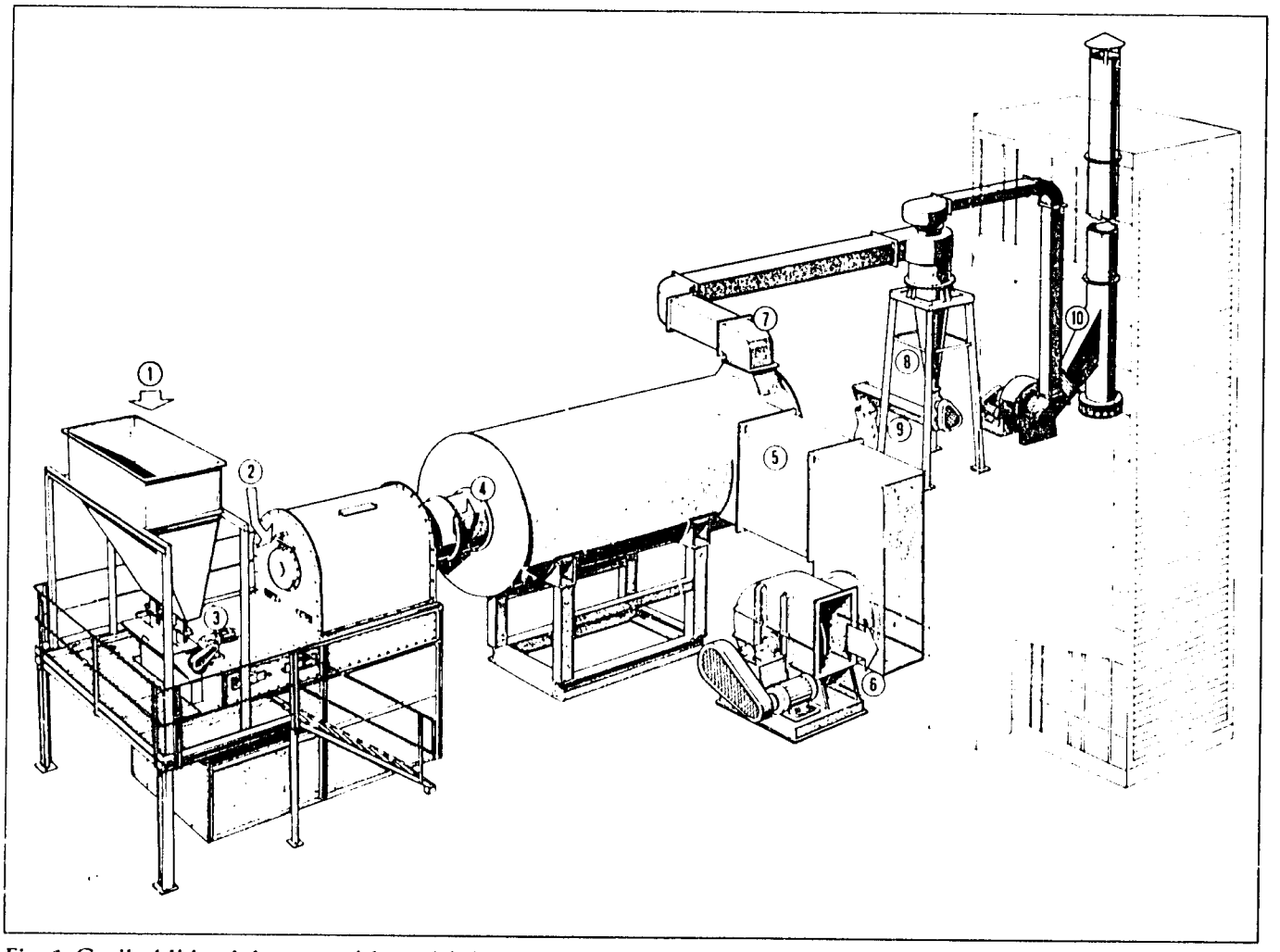

Fig. 1. Gariboldi husk burner with gas/air heat exchanger, Italy (Source: Gariboldi Engineering, Milan).

of a 12-tonne/hour mill. It produces 10,000 kg/hour (22,026 lb/hour) of steam at the same pressure.

Gariboldi's firetube boilers have been used in rice mills in Italy and in various developing countries including Egypt, Mali, Burma, and the Philippines.

PRM Energy Systems

PRM Energy Systems (PRME) offers a combustion/gasification system which was developed for use with rice husks at the large Producers Rice Mill in Stuttgart, Arkansas. The units have been used for rice drying, process steam, and power generation. They will also be used soon in husk-fired power plants in India and Malaysia.

Husks are burned in a reactor which resembles an updraft gasifier. The vertical steel cylinder is lined with castable refractory. Husks are fed to a proprietary burner by a manual or computerized flow/weigh scale which admits a measured weight of husks and avoids variations in the BTU level of the fuel which can occur with volumetric fuel metering

A mechanical fluidizer moves the hulls and ash through the reactor. The systems operate with a relatively low primary air velocity so that very little ash is entrained in the gas stream. At the top of the narrowed gasifier, secondary air is introduced to crack hydrocarbons and raise the gas temperature to 1800 to 2000°F (982 to 1093°C).

Ash is removed through ash discharge screws at the bottom of the reactor. A water cooling jacket around the screws permits safe handling of the ash by pneumatic conveyors which carry it to an ash packaging station.

Two of the PRME systems have been used since 1982 in the production of parboiled rice at the Producers Rice Mill in Arkansas. A 12-foot (3.6m) diameter reactor burns 5,000 lb (2268 kg) of husk per hour and produces hot gas at 1800°F (985°C) which is used for the direct firing of a rotary dehydration system and gravity driers in the final drying of parboiled rice. This system is shown in Figure 2. Another 12-foot reactor burns 4500 lb (2040 kg) of husk per hour and produces 24 million BTU/hour; it is coupled to a firetube boiler which produces 17,000 lb/hour (7711 kg/hour) of steam at 125 psig (8.5 bar).

The husk combustion/gasification system provides all the heat, steam, and hot water requirements for the parboiling process at the PRM mill. Exhaust steam is used in a backpressure turbine to generate 160 kW of electric power for use in the mill. The PRME reactors replaced burners fired with natural gas and resulted in savings in fuel costs of approximately $1.3 million per year. The payback period on the initial investment was only about 6 months.

In the summer of 1988 PRME Energy Systems installed units at three 5-ton/hour rice mills in Malaysia operated by the National Paddy and Rice Authority at Simpang Lima in Perak, Sekinchan in Selangor, and Parit Puteh in Kelantan.

At present the 8 foot (2.4m) diameter reactors are used to provide hot gas for paddy dryers which previously operated with fuel oil. The gas temperature, which is 1800°F (982°C) when it leaves the reactor, is reduced to 675°F (357°C) by mixing with ambient air in a blending chamber and is reduced to 150°F (65°C) by

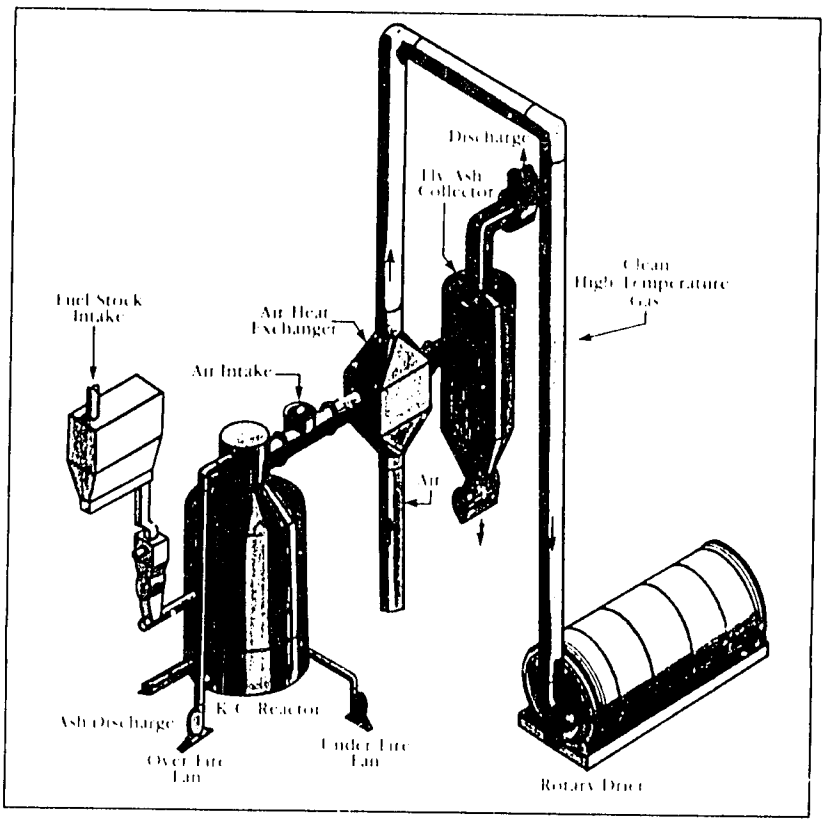

Fig. 2. Rotary drying system for parboiled rice with PRME reactor, U.S.A. (Source: PRM Energy Systems, Stuttgart AR USA)

further blending with ambient air in the dryers. Each unit is capable of drying up to 15 tons of paddy per hour, using about 1 ton of husks and replacing about 80 gal of fuel oil.

Plans are being developed to add a boiler and generator to the unit at the Sekinchan mill. The new system will produce 225 kW, and exhaust steam from the turbine will be used in the paddy dryers.

Universal Energy International

A rotary kiln combustor/gasifier developed by Universal Energy International (UEI) of Little Rock, Arkansas, operates about 6 months a year on rice husks at the Laterite Products Company's facility at Pak Chong in Thailand. About 60 tons of husks per day are purchased from local rice mills during the rice milling season when husk prices are lowest; the husks are burned to provide direct heat to a large vertical lime kiln. The UEI unit replaces an oil burner.

The large refractory-lined horizontal combustor is 7 ft (2.1m) in diameter and 17 ft (5.2m) long. A controlled quantity of primary combustion air is distributed in the kiln through an air tube with a proprietary UEI design. The husks are dried, pyrolyzed, and burned as they tumble inside the rotating combustor. The energy-rich gases pass into a vertical secondary combustion chamber and are mixed with secondary air to complete combustion. The hot gases pass from the top of the chamber directly into the vertical lime kiln.

The secondary chamber has a conical bottom and acts like a cyclone; ash drops to the bottom of the cone and is continuously removed by a screw conveyor through a rotary airlock. The ash, which is 95% silica, is used by the firm as about 10% of the ingredient mix for the manufacture of concrete blocks.

Rice husks will also be burned during a part of the year in a larger UEI combustor which is being installed at the Consunji lumber mill in Zamboanga (Mindanao) in the Philippines. The 8-foot (2.4m) diameter rotary kiln will fire a boiler producing 20,000 lb/hour (9072 kg/hr) of process steam at 400 to 450 psi (27 to 30 bar) which will be used in the lumber mill.

Another 8-foot UEI kiln is being used for electric power generation in Malaysia. It burns 100 tons per day of urban wastes, producing steam at 600 psig (41 bar) and 650°F (340°C) which is used in a condensing turbine to generate about 1 MW of power for sale to the local grid.

F. H. Schule GmbH

Schule, a large German manufacturer of rice milling machinery, provides large furnace/boiler systems for firing with rice husks.

The husks are burned on an inclined step grate furnace which is built under or above the floor of the plant; husks can be fed manually or automatically. The three-pass firetube boilers have capacities ranging from 1000 to 17,000 kg/hour (2205 to 27,485 lb/hour), pressures up to 24 bar (348 psi), and temperatures to 400°C (752°F).

The units have large combustion chambers and large diameter firetubes to minimize ash deposits on the boiler surfaces. These Schule systems produce about 2.5 kg of steam for each kg of husk. They are used in a number of Schule-built rice mills to provide process steam for parboiling.

Charung Engineering Company Ltd.

The two largest models of rice husk gasifiers produced by Charung Engineering of Thailand, described in section 4, have also been used to produce direct heat for paddy drying. The gas is cleaned in a dry filter before use in the dryers.

Charung's 2.3m diameter model burns 400 kg of husks per hour and replaces 80 liters of fuel oil. The 3.0m diameter model burns 600 kg/hour of husks and replaces 120 liters of fuel oil per hour.

4
MECHANICAL AND ELECTRICAL POWER FOR RICE MILLING

Overview of Power Use and Husk Power Systems at Rice Mills

Power requirements of rice mills

The great majority of the rice mills in developing countries are small mills processing 1 ton of paddy per hour or less. The power requirements of these mills are quite modest.

A survey in Thailand indicated that 30,000 rice mills had engines with 30 hp or less. A Philippine agency stated that a gasifier/engine system producing 24 hp would be suitable for 16,000 rice mills in the

Philippines. A recent Indian report indicated that about 80,000 simple huller mills in India require only from 5 to 10 hp, while about 12,000 sheller mills need from 10 to 30 hp. Modern or modernized 1-ton/hour mills in India need 40 to 60 hp.

In rural areas not served by the electric power grid, the small mill is typically powered by a diesel engine. If the mill is on the grid, mechanical power is usually provided by electric motors. Many rice mills in India have electric motors which are powered by diesel engine/generator sets during the substantial periods in which power is not available from the grid.

Data from several developing countries indicates that the average power requirement for a small mill operated with electric motors is 18 to 20 kWh per tonne of paddy.

The power requirements of medium-sized and large rice mills per ton of paddy are usually substantially higher, although power needs vary widely from mill to mill. Some of the older mills have rather inefficient power systems, machinery, and/or line drive hookups. The modern mills require power for a larger number of machines for cleaning, husking, separating, grading, polishing, etc.

A mill in Mali uses only 80 kW (around 30 kWh/tonne) to process 2.25 to 2.75 tons of paddy per hour. A 5-ton/hour mill in the Philippines with only two electric motors requires only 150 kW (30 kWh/ton), while a new state-of-the-art mill of the same size in Brazil requires 350 kW (70 kWh/ton).

The total power requirements of the largest rice mills often include power for offices, housing, water pumping, and other infrastructure. A paper from Twente University in the Netherlands indicates that large rice mills processing from 12 to 24 tons of paddy per hour need from 500 kW to 1 MW of installed power.

Availability of husk power systems

At present, most of the commercially available equipment and systems for the production of mechanical and electrical power with rice husks is only suitable for use in larger rice mills.

Research for this report has not identified any commercial firm which offers systems which appear to be both technically and economically feasible for the most common type of rice mill in developing countries, the mill processing about 1 ton of paddy per hour. The only identified manufacturer of traditional steam engines, Mernak of Brasil, produces a steam engine/generator system which could be operated with the husk output of a 1-ton/hour mill, but it is doubtful that such a large system would be cost effective for a mill of that size.

The smallest rice mills with husk power systems which were identified during research for this report were a 2-ton/hour mill in India with a Grain Processing Industries gasifier/engine system, a 3-ton/hour mill in Malawi with a Spilling steam motor system, and several 3-ton/hour mills in Thailand with Charung gasifier/engine systems.

The smallest mills in which husks have provided steam for turbine/generator systems were 5-ton/hour mills in Malaysia. The smallest combustor/gasifier offered by PRM Energy Systems requires the output of a 5-ton or 6-ton/hour mill. Satake's smallest husk power system is designed for a 7-to 8-ton/hour mill.

Electricity generation at rice mills

Experience at rice mills with the use of steam from husks to generate electric power is still rather limited. Appropriate systems have not been available which matched the fuel supply and power requirements of the small mills. In many of the larger mills, all of the husks are burned to provide low pressure steam for the parboiling and drying of rice.

The power output of a husk-fired steam power plant per ton of husks depends primarily on the efficiency of the boiler system and on the steam pressure. Most present or planned systems at rice mills in developing countries have been designed to operate at pressure between 150 psi (10 bar) and 250 psi (17 bar). Most of these low pressure systems produce between 275 and 350 kWh of net electric power per ton of husks (300 to 375 KWh/tonne), but some smaller plants have lower output rates.

In general, a mill that uses most or all of its husk output in a low pressure power plant produces about the amount of net power which is needed to operate the mill, leaving little or any surplus power for export. Net power output of 275 to 350 kWh per ton of husks is equivalent to 55 to 70 kWh per ton of paddy. This level of output may be close to, and can be less than, the power consumption of the large mill per ton of paddy.

For example, a husk power plant built at a 15-ton/hour mill in Suriname in 1974 was rated a 1.2 MW

but met only about two-thirds of the maximum requirement of the large mill complex which exceeded 100 kWh per ton of paddy.

Research for this report has identified only two cases in developing countries in which substantial power has been exported for a considerable period by a husk-fired power plant at a rice mill. A 1.9 MW plant at a 25-ton/hour mill at Tacurong (Mindanao) in the Philippines sold about 500 kW of power to a local cooperative for about 15 years beginning in 1970. Surplus power from a 2.8 MW husk-fired plant at the large Mah Boon Krong mill in Thailand is exported to an adjacent marble-cutting facility. In addition, about 30% of the power generated by a new 10.5 MW plant in the Punjab in India will be exported to the adjacent community.

Several husk-fired power plants in developing countries have failed to operate satisfactorily because the severe requirements for the combustion of rice husks were not fully met in the design of the system. These included a 315 kW plant at a large rice milling facility at Cabantuan in the Philippines, two 350 kW plants of different designs at 4- to 5-ton/hour mills at Jerlun and Telok Kechai in Malaysia, and a 2.1 MW plant at a large mill at Iloilo City in the Philippines.

Since the firms which built these plants are apparently no longer offering power plants for rice mills, detailed information on these plants has not been included in this report. Typically, a biomass combustion system that had operated well with low ash fuels was installed at a rice mill without sufficient concern for the problems arising from the use of rice husks. The failure of these plants has clearly demonstrated the importance of the very careful design of the combustion air system, temperature controls, ash removal equipment, and boiler surfaces to meet the special requirements of rice husk combustion.

Steam Engine Systems for Rice Mills

During the last decades of the 19th century and the first decades of the 20th century, most of the rice mills around the world were operated with steam engines using steam from husk-fired boilers. The use of steam engines in rice mills and other industries declined steadily after about 1925 due to the increased availability of two more convenient forms of power, electricity from the grid and diesel systems (engines and engine/generator sets). By the mid-1970s, when increased oil prices created renewed interest in many biomass energy systems, there were only a few remaining manufacturers of steam engines.

Research for this report has identified three commercial manufacturers of steam engines suitable for use in rice mills. These include traditional heavy steam engines by Mernak of Brazil, modular "steam motor" systems by Spilling of Germany, and new compact multi-cylinder steam engines being developed by Skinner in the United States.

Mernak S. A.

Mernak, located in Brazil's rice growing region, has provided husk power systems with steam engines to Brazilian rice mills for over 40 years.

The firm produces seven models of boiler/engine systems with outputs ranging from 40 to 240 hp and 33 to 200 kVA; larger outputs can be obtained by using two or three units. The two smallest systems operate at 10 kg/cm^2 (142 psi), but most of the other models use steam at 12 kg/cm^2 (170 psi).

Husks are fed to the boiler manually, by a gravity feed, or by an automatic auger. They are burned on a fixed inclined grate with minimal underfire air to reduce ash entrainment in the gas stream. Ash is removed from a pit under the grate.

The large steam engines are similar to models that were widely used for industrial purposes early in the 20th century. The generator is powered by a belt drive from one of the engine's two large flywheels. The smallest boiler/engine/generator system weighs 7 tonnes, while the largest system weighs 27.2 tonnes.

The largest Mernak models operating at about 200 psi (13.6 bar) and 550°F (287°C) require only 6 lb (2.72 kg) of husks per kilowatt-hour which is equivalent to 333 kWh per ton of husks (367 KWh/tonne).

Mernak is represented in several Asian countries by Osage Steam Power Systems, Columbia, Missouri. Osage provides turnkey installation of steam power systems and other power plants up to 20 MW.

Spillingwerk Hamburg GmbH

Since 1950 Spilling has produced a "steam motor" which combines characteristics of a piston-type steam engine with some characteristics of a diesel engine. Spilling manufactures three sizes of one-cylinder motor modules. The steam motor required for a specified

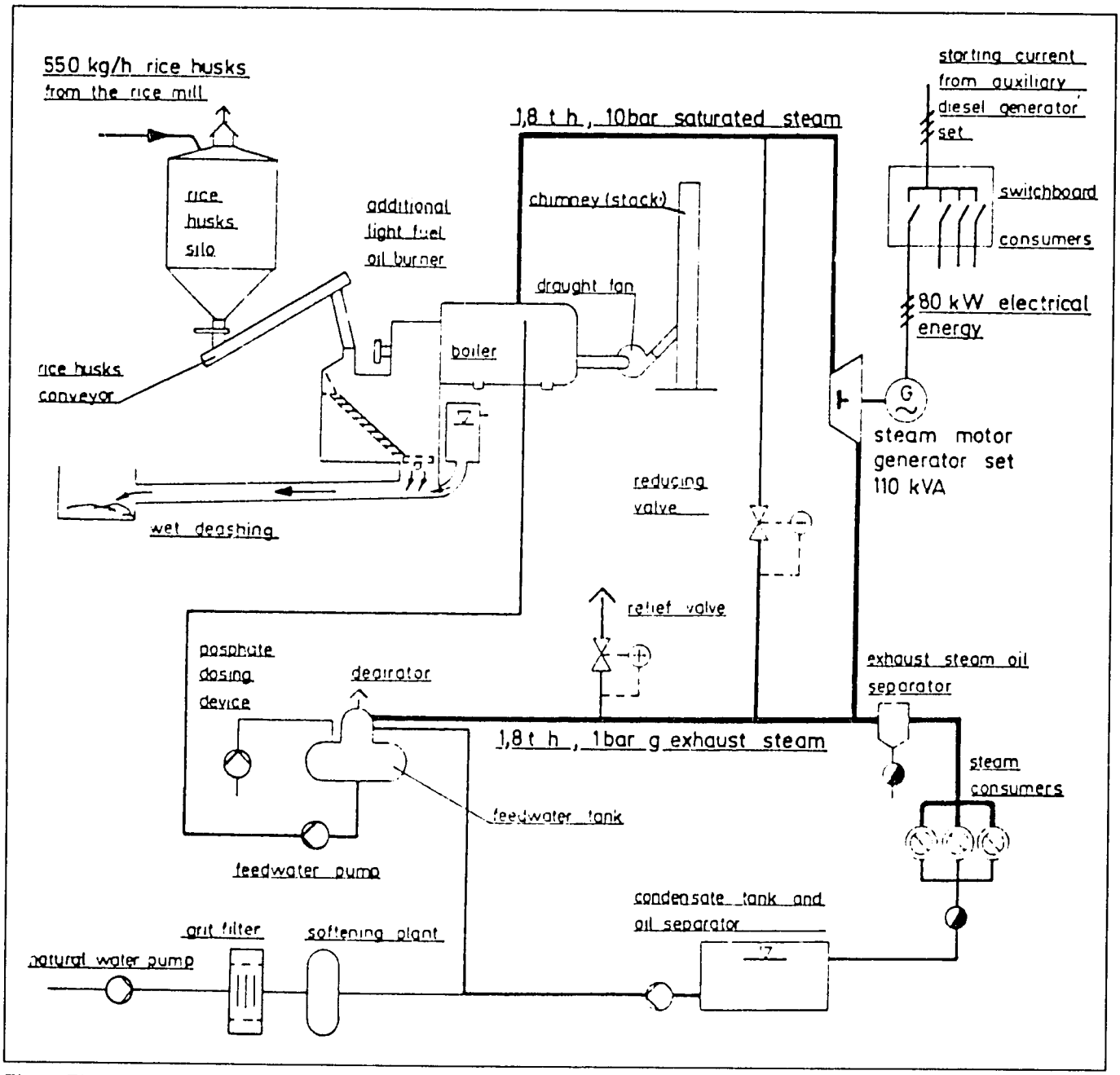

Fig. 3. Eighty-kilowatt husk power plant with Spilling steam motor, Malawi. (Source: Spillingwerke, Hamburg)

power output may consist of a single module or up to six modules linked to a common driveshaft. By using the appropriate size and number of modules, a steam motor system can be tailored to fit the fuel supply and power requirements of a specific mill.

Compared to traditional steam engines, the Spilling systems are relatively compact and lightweight. The smallest motor module weighs 500 kg; the largest module weighs 2 tons.

Spilling offers installation on a turnkey basis of a complete power plant designed for a specific rice mill including furnace, boiler, a properly-sized Spilling steam motor (or motors), generator, controls, and other necessary equipment. Spilling power plants have been installed in 1970 at a large mill in the Philippines and in the mid-1980s at three rice mills in East Africa (Malawi, Madagascar, and Somalia).

The smallest Spilling plant is at a 2.75-ton/hour mill in Malawi (Fig. 3). About 0.55 tons of husks per hour are burned in a step grate furnace. The small boiler produces 1.8 tons/hour (3600 lb/hour) of steam at 11 bar (161 psi). The steam is used in a single Spilling motor

module with only one cylinder. Net output is 80 kW (about 145 kWh per ton of husks or 159 KWh/tonne). Exhaust steam at 1 bar (14.5 psi) is used for parboiling and drying. A larger Spilling system is installed at a 4-ton/hour mill in Somalia. At this plant 0.8 tons of husks per hour are burned on an inclined step grate to produce 2.8 tons per hour of steam at 25 bar (362 psi) and 300°C (572°F). The steam is used in two of Spilling's medium-sized motor modules to produce 270 kW of gross power; net output is 235 kW (293 kWh per ton of husks or 322 KWh/tonne). Exhaust steam at 0.5 bar (7.25 psi) is used for paddy drying.

About 1.5 tons of husk per hour are burned in another Spilling plant at a 7.5-ton/hour mill in Madagascar. The husks are burned on a moving step grate. The boiler produces 5.4 tons per hour of steam at 25 bar (362 psi) and 330°C (626°F). It is used in four of Spilling's largest motor modules to drive a generator producing 580 kW of gross power. Net output is 500 kW (333 kWh per ton of husks or 366 KWh/tonne). Exhaust steam at 0.25 bar (3.6 psi) is used in the mill.

The largest Spilling husk-fired plant operated for about 15 years in a large rice mill in the Philippines. The 25-ton/hour mill and a 2.0 MW power plant were built in 1969/70 at Tacurong (Mindanao).

Up to 5 tons per hour of husks were burned in two Lambion inclined grate furnaces feeding two 9-ton/hour Sillers and Jarmat boilers. They produced a total of 18,000 kg/hour (40,000 lb/hour) of steam at 26 bar (382 psi) and 360°C (680°F).

The steam was used in three Spilling steam motors, each consisting of four motor modules and each linked to a 666 kW generator. The net power output was around 1725 kW (345 kWh per ton of husks or 379 KWh/tonne).

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The installation of a steam condensing system was avoided by using the exhaust steam from the motors in ejector systems which provided combustion air to the furnace without the need for electrically-driven induced draft fans. Some of the exhaust steam was also used for paddy drying.

Rice production in the area around the Tacurong mill did not reach the level that had been expected at the time the mill and power plant were built. The mill operated for a decade and a half, usually at substantially less than full capacity. When the mill was in full operation it required about 800 kW or about 32 kWh per ton of paddy. Up to 500 kW of power was sold to a power cooperative for use in the adjacent community. Economic problems forced the closing of the mill around 1985.

Skinner Engine Company

The Skinner Company, which has built steam engines for more than 120 years, is currently developing a new generation of compact multi-cylinder steam engines which utilize designs and many standard parts from internal combustion engines. The new Delta engines will be available in both in-line block and V-block designs and will operate at steam pressures ranging from 150 to 350 psi (10 to 23 bar).

Depending on the steam pressure, the smallest engine will produce 60 to 70 hp or 40 to 45 kW of electric power. Dimensions are 450 x 1070 x 760 mm (18 x 42 x 30 inches); the engine weighs 180 kg (400 pounds).

Six larger models will provide 100 to 520 hp at 150 psi, 150 to 800 hp at 250 psi. If used for power generation, these models will generate from 60 to 550 kW.

Skinner expects the costs of the new steam engines will be roughly comparable to those for heavy duty diesel engines with the same power ratings. Advantages cited by Skinner of the Delta steam engines over steam turbines include lower initial cost, lower life cycle costs, less demanding maintenance skills, and sharply reduced risk of catastrophic failure.

Steam Turbine/Generator Systems for Rice Mills

The three firms listed in this section provide husk power systems for rice mills in developing countries using generators driven by steam turbines.

Satake Engineering Company Ltd.

Satake provides four models of complete husk-fired power plants with net outputs ranging from 288 to 1200 kW. The plants are designed for rice mills processing from 7 to 20 tons of paddy per hour. The firm has installed husk-fired plants in Burma, Malaysia, Thailand, and the Philippines.

In earlier Satake plants unground husks were burned on a grate in a factory-built three-pass boiler with both a horizontal fire tube and waterwall tubes. Satake now provides watertube boilers with all plants. Ash is removed from under the grate as well as from the cyclone dust collector. The two smaller models produce steam at 16 kg/cm^2 (227 psi, 15 bar); in the two larger models the steam pressure is 22 kg/cm^2 (312 psi, 21 bar). Turbine exhaust steam is cooled in a condenser, using cooling water from a pond or river or recycled water from a cooling tower.

At startup, combustion of the husks is initiated by burning heavy fuel oil. If the plant is not connected to the grid, an auxiliary diesel generator is needed as a power supply for start-up. About 20% of the gross power is needed to operate the plant.

The smallest Satake plant requires 1.3 tonnes of husks per hour, and is suitable for a mill processing 7 to 8 tonnes of paddy per hour. The net output of this plant is 288 kW (221 kWh per tonne of husks or 200 KWh/ton). The largest Satake plant requires 3.9 tonnes of husks per hour and is suitable for a mill with a capacity of 15 to 20 tonnes of paddy per hour; the net output is 1200 kW (308 kWh per tonne of husks or 279 KWh/ton).

The smallest plant produces about 40 kWh of net power per tonne of paddy processed, while the largest

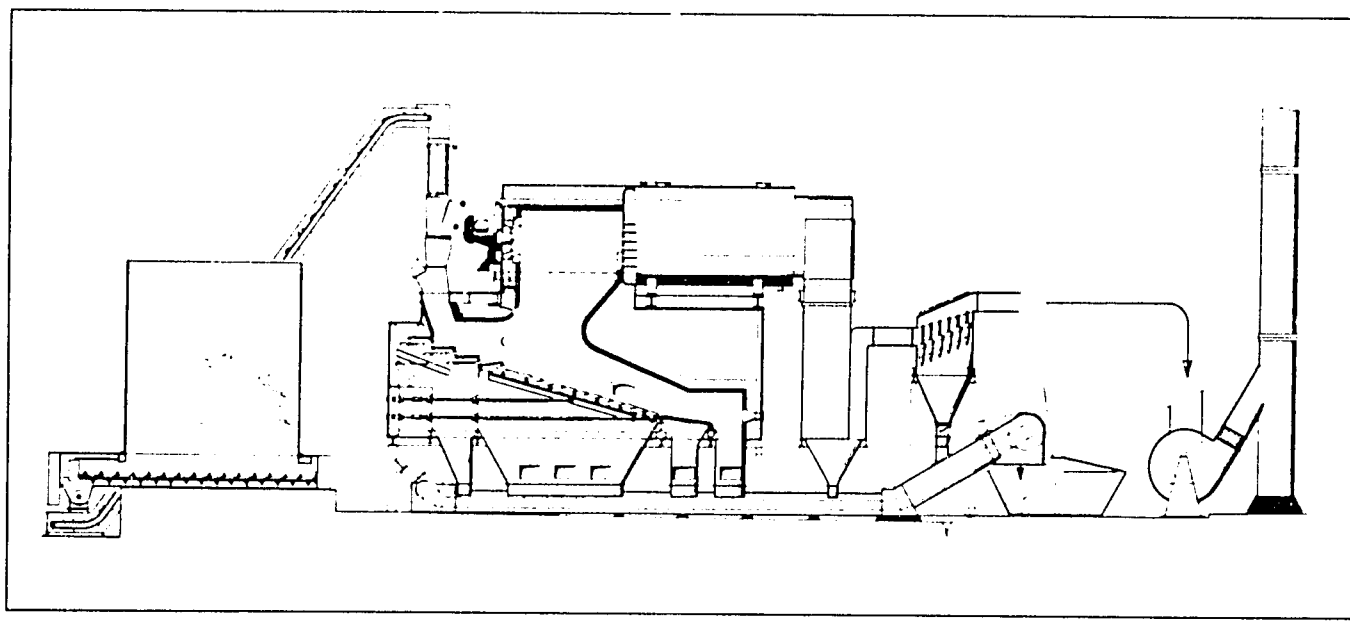

Fig. 4. Lambion inclined grate furnace similar to furnaces in Standard Kessel 10.5 MW husk- fired steam power plant, India (Source: Maschinenfabrik A. Lambion, Arolsen- Wetterburg, Germany)

plant produces about 60 kWh per tonne of paddy. These power output figures are about equal to the typical total power requirements of rice mills producing sufficient husk fuel for these power plants.

Standard Kessel

Standard Kessel has recently completed the largest husk-fired power plant to be built in any developing country. The 10.5 MW plant has been installed at a new 200-ton/hour rice milling facility, which may be the largest rice mill in India and perhaps the largest in the world. The mill was built by Buhler-MIAG of Germany for Oswall Argo Furane Ltd. near Ludhiana in the Indian state of Punjab.

Only one furnace and boiler was operated in the 1988/89 milling season (October-May), but the second furnace/boiler unit was scheduled for operation in the 1989/90 season. In full operation with both boilers the power plant will burn nearly 10 tonnes (9894 Kg) of husks per hour. The two inclined-grate furnaces, shown in Figure 4, were built by Maschinenfabrik A. Lambion of Germany.

The new plant is the first husk-fired steam plant in a developing country to produce high pressure steam. Each of the Standard Kessel boilers produces 36 tonnes/hour of steam at 72 bar (1044 psi) and 130°C (266°F), which is superheated to 505°C (941°F). Power is generated in a two-stage AEG-Karies extraction turbine generator rated at 10.5 MW. The gross power output will be about 1060 kWh per tonne of husks (961 kWh/ton).

From 60% to 70% of the power will be used in the operation of the rice mill; the remaining 30% to 40% will be exported to the adjacent community. Exhaust steam from the turbine at 15 bar (225 psi) will be used for process heat in an associated furfural plant. The power plant will operate only during the October/May milling season.

PRM Energy Systems

Although the husk combustion/gasification units developed by PRM Energy Systems (PRME) have been used primarily to produce process heat, they are also appropriate combustion units for use in turbine/generator systems including both low-pressure and medium-pressure systems.

Low pressure steam from one of the units installed at the Producers Rice Mill in Arkansas has been used in a back pressure turbine to produce 160 kW for the mill. Plans are being made to generate 225 kW using a PRME unit already installed at a rice mill in Malaysia. Potential power output in low pressure steam systems has been calculated by PRME for each of its models.

A power plant using PRME's smallest reactor with a diameter of 6 ft (1.8 m) would consume 1543 lb. (700 kg) of husks per hour, produce 6000 lb/hour (2700 kg/hour) of steam at 150 psi (10 bar), and generate 230 kW of net power (295 kWh per ton of husks or 325 kWh per tonne). The hourly consumption of husk by this plant would equal the husk output of a mill processing about 3.8 tons of paddy per hour.

A plant with a 10-foot (3 m) diameter PRME reactor would consume 4400 lb (2000 kg) of husks per hour and produce 17,000 lb/hour (7711 kg/hour) of steam at 150 psi (10 bar). The net electric power output would be 650 kW (295 kWh per ton of husks or 325 kWh/tonne). The hourly husk consumption would match the hourly husk output of a 10-ton/hour mill.

Two large PRME reactors will be used in a 3.0 MW medium-pressure rice residue power plant to be built soon in India. The plant will be located at a new 60-ton/hour rice milling complex at Khanna in the Punjab operated by a large parastatal organization, the Punjab Agro Industries Corporation (PAIC). The power plant will be built and operated by a joint venture corporation including PRM Energy Systems, PAIC, and ICB, a local engineering and construction company which will provide local fabrication and erection.

Financing of the $6 million project has not yet been finalized. Up to 40% of the cost will be funded by the U.S. Agency for International Development's mission in New Delhi under a "Pacer" project which supports scientific and technological innovation in the private sector in India.

The project combines commercially proven combustion technology with an experimental fuel collection and processing system. The plant at Khanna will be the world's first electric power plant to be fueled primarily with rice straw. Rice straw will be purchased from local farmers within a 7-mile radius; the baled or unbaled straw will be brought directly to the power plant without passing through intermediate processing stations. Fuel costs for the plant are estimated at around $780,000 per year or approximately $15 per tonne.

The power plant will include two of PRME's largest reactors, each with a diameter of 16 ft (4.9m). The plant will consume about 6.5 tons of straw per hour or a total of 52,000 tons per year. The facility and power plant will operate 24 hours per day for 330 days per year.

Hot gas from the two reactors will flow into a medium-pressure watertube boiler built in India which will produce 47,760 lb/hour (21,700 kg/hour) of steam at 640 psi (43 bar) and 750°F (400°C). The imported 2.5 MW turbogenerator will use 44,000 lb/hour (19,900 kg/hour) of the steam. About half of the turbine exhaust steam at 150 psi (10 bar) will be used for soaking and cooling in the parboiling process. The remaining steam will be condensed in a cooling tower.

The power plant will produce about 1.3 tonnes of ash per hour or about 10,500 tonnes per year. An ash conveyor and elevator will carry the ash from both reactors to a large vertical ash bin with an ash bagging apparatus. Annual income from ash sales has been estimated at over $650,000.

The plant is expected to generate about 18 million kWh per year. Depending on the timing of the completion of the power plant, the power will be used in the rice mill and/or sold to the grid.

Following the completion of the Khanna plant, the joint venture plans to build a number of additional straw-fired power plants in the Punjab. The total surplus of rice straw in the state has been estimated as sufficient to fuel plants generating a total of 1000 MW. The Electricity Board of the states of Punjab and Haryana have indicated strong interest in the purchase of power from such plants.

Gasifier/Engine Systems for Rice Mills

In a gasifier/engine system, an energy rich gas called producer gas is generated by the partial combustion of biomass with a limited amount of oxygen. The producer gas contains hydrogen, carbon monoxide, and methane as well as inert gases. After most of the particulates, tars, and moisture have been removed from the gas, it is used as fuel in an internal combustion engine. A spark ignition engine can operate on 100% producer gas; a diesel engine needs some diesel fuel for ignition of the gas.

In the first half of this century, between 75 and 100 large husk gasifier power systems were built by Italian and British firms and installed in rice mills in Italy and in several countries in Asia and Africa. These were updraft gasifiers that produced gas with a large fraction of uncracked hydrocarbons. Although the gas cleaning equipment did not remove all of the tars, the heavy industrial engines in use in that era had a greater tolerance for tar than most modern engines.

In the later 1970s several research institutions attempted to use rice husks in the narrow-throat downdraft gasifiers similar to those which had been widely used with wood and charcoal in Europe during World War II. Due to the high ash content of the husks, severe ash fouling and slagging problems were encountered.

An effective modern design for a husk gasifier system has emerged as a result of development work over the past two decades in China, the United States, the Netherlands, Indonesia, and Thailand. The evolution and characteristics of this design have been described in detail in "Rice Husk Energy Systems" (Bioenergy Systems Report, April 1986).

The modern design (Fig. 5) uses a cylindrical gasifier with an open top but no narrow throat or air intake nozzles. Air enters through the top of the gasifier and is pulled down through the husks by suction from the system's engine. Ash falls through a slowly rotating grate and is removed by an ash auger. The gas exits from the bottom of the gasifier and is cleaned in a train typically consisting of a cyclone, a wet scrubber, and a dry filter.

Despite the large potential market the use of husk gasifier systems in rice mills is limited at present to about 100 units at mills in China, at least 34 units in Thailand, a few of the Chinese and Thai units in other countries, and one unit of a somewhat different design in a small mill in India.

The limited commercialization of these gasifier systems has been due to a combination of technical and economic factors. The remaining major technical problems are further optimization of the design of gas cleaning trains and matching the gasifier, engine, and generator to the specific power needs of the rice mill. Commercialization is also inhibited by uncertainties concerning capital costs, the operational life of the gasifiers, the power output with producer gas, and (when gasifiers are used with diesel engines) the percentage of the liquid fuel which is replaced with gas fuel.

An economic analysis of the commercialization of a 20 to 25 kW husk gasifier power system has been prepared for A.I.D. by International Development and Energy Associates Inc. The IDEA study examined the cost and benefits of the use of husk gasifier systems of the design discussed above, as perfected at the Institute of Technology in Bandung, Indonesia. The study assumed that the gasifiers would provide gas fuel to existing diesel engine generator sets which were widely used at rice mills in India.

IDEA's analysis indicated that the critical parameters affecting the financial and/or economic viability of the investment in a husk gasifier system are the percentage of the engine's normal requirement for diesel fuel which is replaced with producer gas, the annual number of operating hours of the gasifier, and the difference between the price of diesel fuel and the price (or opportunity cost) of husk.

A sensitivity analysis showed that the net present value of the gasifier investment would increase (or decrease) by 6.6% for each 1% increase (or decrease) in the percentage of diesel fuel displaced or in the cost of diesel fuel. The NPV varied by about 3% with each 1% change in the operating hours or in the cost of the husks. Within the range of values considered in the study, the capital cost of the gasifier was comparatively less important than the parameters just listed.

Similarly, an analysis by Twente University (Netherlands) and the Institute of Technology of Bandung (Indonesia) found that a husk gasifier system would not be economically attractive for a 1.5 ton/hour rice mill in Indonesia operating less than 2000 hours a year if the gasifier replaced only 60% of the diesel fuel and it cost only $0.12/liter as at present. However, savings become much more significant if there are substantial increases in mill capacity, annual operating hours, diesel fuel prices, and/or the percentage of diesel fuel replaced by producer gas.

To date there have been only a few experiments with small husk gasifiers in small rice mills, and none of these have led to the commercialization of the units by private firms. A scaled-up version of the Bandung husk gasifier power system, with a capacity of 35 to 40 kW of electric power, is now providing power to a 1 tonne/hour rice mill in Java; detailed information on the operation of this unit is not yet available.

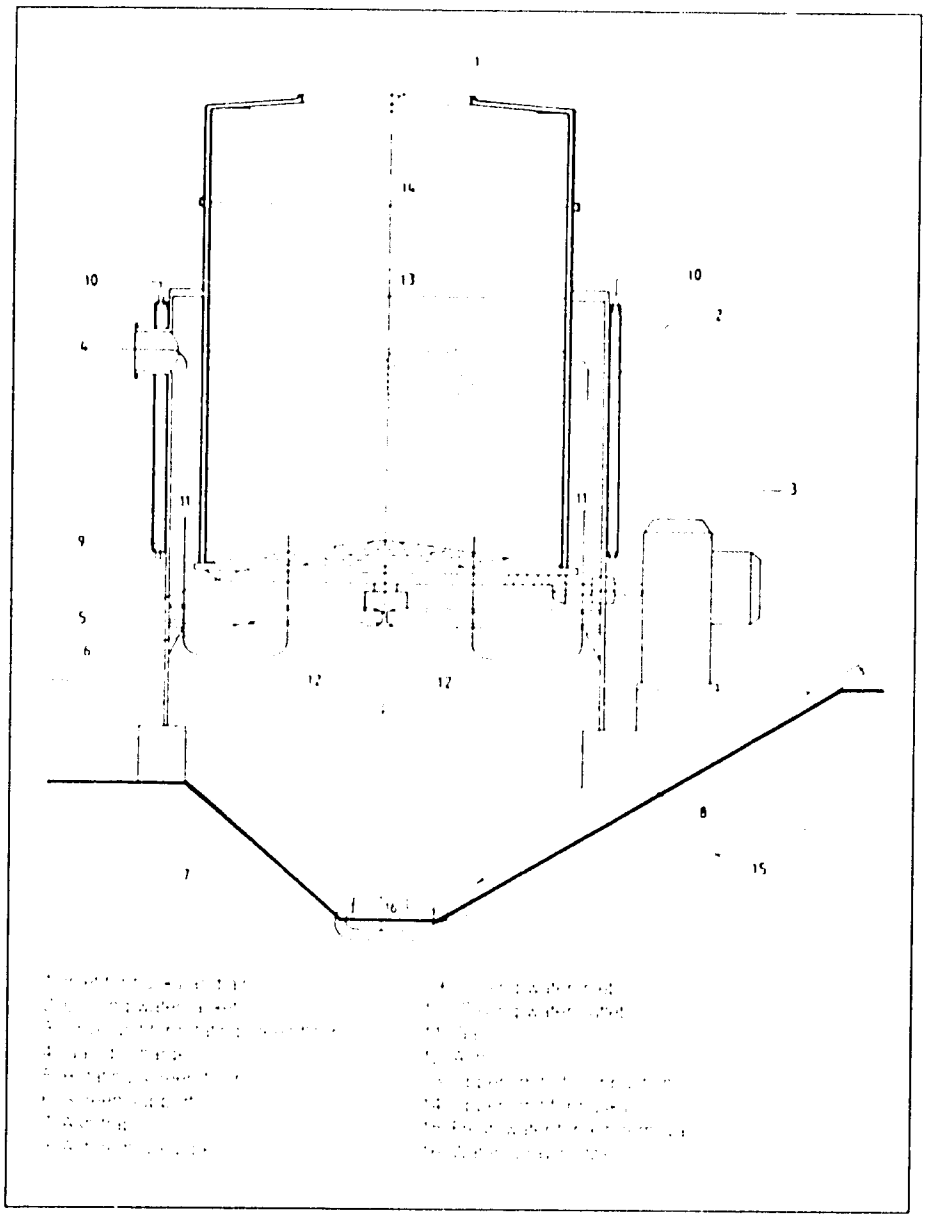

Fig. 5. Rice husk gasifier, 140 kW gasifier power system, Mali. (Source: German Agency Technical Cooperation (GTZ), Eschborn)

The IDEA study recommended a project for the pilot scale production and field testing of small husk gasifier systems in India, in order to provide more reliable data on manufacturing costs and operating performance of the gasifiers.

A major experiment with a larger husk gasifier system will begin soon at a 4-ton/hour rice mill at Sonepat, 50 km from New Delhi. The project has been developed by the Indian Institute of Technology at New Delhi with funding from the Indian Government's Department of Non-Conventional Sources of Energy. An indirectly heated rotary gasifier will use 250 kg of rice husks per hour. Tars will be cracked with superheated steam at 300°C in a ceramic packed bed inside the furnace. Ash will be removed in a train of cyclones. The gas will be used in a diesel generating set originally rated at 150 KVA (120kW); expected output with producer gas is around 100kW.

Chinese husk gasifier systems

A large husk gasifier-engine/generator system producing from 100 to 140 kW of electric power was developed in China in the early 1970s, although information on these systems was not widely available outside of China until 1982. The gasifier is a throatless cylinder surrounded by a jacket of cooling water; it has a powered rotating grate and a water-cooled ash pit. In the original models the gas was cleaned in two wet scrubbers packed with plastic balls, although some modifications in the gas cleaning train have apparently been made.

The gas is used in a very large low-speed six-cylinder diesel engine which has been converted to spark ignition by adding spark plugs and reducing the compression ratio to 8.5; the shaft power rating of the engine with diesel fuel was 214 hp. The use of this engine seems to be the key to the success of the Chinese gasifier systems. Its tolerance for tar is rather high. The uncovered valves are easily accessible. Each Sunday, when the mill is not in operation, one set of valves is removed for cleaning and is replaced with a clean set for use until the following Sunday.

Approximately 100 of these gasifier power systems are reported to be in use in rice mills in China. Two of the systems were installed at mills in Mali in the 1970s and a third unit was added in Mali in the early 1980s under a project of the German Agency for Technical Cooperation (GTZ). In 1987 another Chinese gasifier was installed in Burma.

In 1986 F.H. Schule Gmbh in Hamburg announced an agreement with Chinese authorities under which Schule would undertake the marketing and installation of the Chinese husk gasifier systems in other countries. The gasifiers, gas cleaning trains, and engines would be built in China; Schule would design fuel feeding equipment and ash removal systems to fit the situation at each site. As of September 1989, there had been no installations of Chinese gasifiers by Schule under this agreement.

The husk gasifier power systems are described in Chinese papers as suitable for use in mills producing 25 to 75 tons of polished rice per day. Assuming that they operate 24 hours a day, such mills process approximately 1 to 3 tons of paddy per hour. While a 1-ton/hour mill might produce enough husks to fuel the standard Chinese gasifier, the power output of the system is closer to the power requirements of a 3-ton/hour mill and it is probable that most of the systems have been installed in larger mills.

An international group organized by FAO visited a gasifier installation at the Bachai rice mill near Suzhou in 1982. The mill was processing 3.5 tons of paddy per hour, 24 hours per day, and producing 75 tons of polished rice per day. The power requirements of the mill were about 80 kW (about 20 kWh per ton of paddy).

Prior to the installation of the gasifier system in 1980, about 6 liters of diesel oil were used at Bachai to generate power for the milling of each ton of paddy. A Chinese paper indicates that the use of the gasifier system in a mill processing about 2.5 tons of paddy per hour, 24 hours a day, would save from 3300 to 4180 barrels of diesel fuel per year.

The maximum power output of the original Model 6250 gasifier system developed in the 1970s was stated as 140 kW for periods up to 12 hours, although the maximum output in continuous operation for longer periods was about 125 kW. An improved Model 6250M1 was developed in the early 1980s, and the maximum output of this model has been described as 150 kW or 160 kW. There have been reports of one or more 200 kW husk gasifier systems at large mills in China; these may consist of two of the original models, each producing 100 kW, since there is no other

indication that larger gasifiers have been built in China.

The Chinese papers on the systems usually list the husk consumption as between 2.0 and 2.5 kg/kWh. However, the fuel consumption rate is considerably higher in a Chinese husk gasifier installed in 1967 at a 3.0 tonne/hr mill near Niono, Mali. The plant was studied in 1986 by Twente University of the Netherlands under a gasifier monitoring project funded by the World Bank and the United Nations Development Programme. The unit consumed 300 to 320 kg of husks per hour to meet the average net load of 80 kW. The fuel consumption rate was 3.75 to 4.0 kg per net kilowatt-hour. Net power output was 250 to 266 kWh per tonne of husks (226 to 241 kWh/ton).

The high fuel consumption rate at the Niono mill was due to incomplete combustion of the carbon in the husks; 0.42 kg of solid residue was generated from the burning of each kg of husk, and 43% of the residue was unburned carbon. The low efficiency of this gasifier (32%) is apparently due to the rather low load, which is about half of the gasifier system's rated output of 160 kW.

The fuel consumption rate is lower at the Chinese gasifier plant installed in the mid-1980s at the rice mill at Molodo, Mali, under a project funded by the German Agency for Technical Cooperation (GTZ). This unit burns 250 to 350 kg of husks per hour to provide up to 122 kW of net power. The fuel consumption at maximum output is about 2.9 kg of husks per kilowatt-hour, and the net output is about 348 kWh per tonne of husk (315 kWh/ton).

Although they are apparently well sized for typical Chinese rice mills, the standard Chinese gasifier systems are too large for most mills in other Asian countries in terms of both husk consumption and power output. A system requiring 350 kg of husks per hour needs the equivalent of the entire husk supply generated by a 1.75 ton/hour mill. Mills of this size or larger represent only a small fraction of the total mills in most developing countries.

In 1987 FAO funded the development in China of a scaled-down version of the Chinese gasifier system which was designed to produce about 60 kW. A prototype was designed and built by a technical team of the Provincial Food Bureau of Jiangsu Province and has been operated without major problems for over 300 hours at an oil mill, apparently providing power for the extraction of oil from rice bran. Details of the unit were provided in 1989 in *Rural Energy*, a publication of the FAO Regional Office in Bangkok.

Experiments with 100, 110, and 120 cm diameter gasifiers showed that a 110 cm diameter model provided a combustion temperature which was high enough to minimize tar in the gas but low enough to prevent slagging of the ash.

The gas cleaning train (Fig. 6) consists of (a) an "ash flushing tube" (cascade-type wet scrubber) which is 320 cm high and 20 cm in diameter, (b) two "turbulent flow towers" (packed bed wet scrubbers) which are 232 cm high and 24 cm in diameter and are packed with coke, and (c) a 1 m^3 capacity gas storage tank with a cyclonic interior design, which also serves as a centrifugal tar separator. Water flows through each of the three scrubbers at the rate of 2.3 to 2.5 m^3/hr; the water pressure is 1.8 to 2.0 kg/cm^2.

The gas flows from the storage tank into a gas/air mixer linked to a mechanical governor which controls the flow of gas to the engine but maintains a stable gas/air ratio. The gas is used in a 6-cylinder, 750 rpm diesel engine which has been converted to spark ignition. It drives a 3-phase, 1500 rpm synchronous generator. Maximum output for periods up to 12 hours is 60 kW.

At maximum output the gasifier system consumes about 125 kg of husks per hour (2.08 kg/kWh), or about two thirds of the husk output of a mill processing one tonne of paddy per hour. The power output is equal to 480 kWh per tonne of husks (435 kWh/ton), which is about twice the output of low-pressure steam systems burning husks.

A program for the further demonstration and dissemination of this husk gasifier technology is being developed within the FAO-sponsored Asian regional network on rice husk gasification.

Charung Engineering Company Ltd.

Charung Engineering of Thailand is the only commercial firm identified during research for this report that has substantial experience with the production and marketing of rice husk gasifier/engine systems.

The firm offers three systems producing 90 kVA (72 kW), 180 kVA (144 kW), and 270 kVA (216 kW). The larger systems use larger gasifiers and two or more engines. Thirty-four units have been sold in Thailand,

and in late 1989 Charung was filling orders for five units in India and another unit in Cambodia.

The gasifier design is similar to that of the Chinese systems. The units have a water jacket around the gasifier (to control internal temperatures and avoid slagging problems), a slow-moving rotating grate, and a water-sealed ash pit.

The gas cleaning train consists of the following six components: (a) A cascade-type wet scrubber cools the gas and removes large particulates and some of the tars; the water is filtered and recycled. (b) A blower avoids a pressure drop through the gas cleaning train. (c) Additional particulates are removed in a cyclone. (d) A packed-bed dry filter filled with charred rice husks removes more particulates and tars; the char is changed at intervals of 100 hours. (e) A final char filter traps any remaining tars. (f) Remaining moisture is removed in a condenser.

All of the Charung systems use diesel engines, originally rated at 280 hp, which have been converted to spark ignition in the Charung shops to permit them to operate only on husk gas. The compression ratio is lowered from 21 to 11. The recommended engine maintenance program includes oil change every 160 hours, replacement of the rings every 2000 hours, periodic replacement of spark plugs, and an annual engine overhaul.

Charung's smallest (90 kVA) system includes a gasifier which is 1.97m in diameter and 3.0m tall. It uses 200 kg of rice husks per hour, which is about the husk output of a 1-ton/hour mill although most or all of the Charung systems has been installed in larger mills. The single engine/generator set produces about 72 kW or about 360 kWh per tonne of husks (326 kWh/ton).

A typical installation of the 90 kVA system is in a rice mill processing 50 tonnes of paddy per day or about 3 tons/hour during 16 hours of daily operation. The gasifier system provides about 80% of the power needed by the mill, with the remaining power purchased from the grid.

The gasifier for the 180 kVA (144 kW) system is 2.33m (7.6 ft) in diameter and 3.6m (11.8 ft) tall and consumes 400 kg of husks per hour. Gas is fed to two engine/generator sets. In the 270 kVA (216 kW) system the gasifier is 3.0m (9.8 ft) in diameter and 4.5m (14.7 ft) tall and fuel consumption is 600 kg/hour; this system

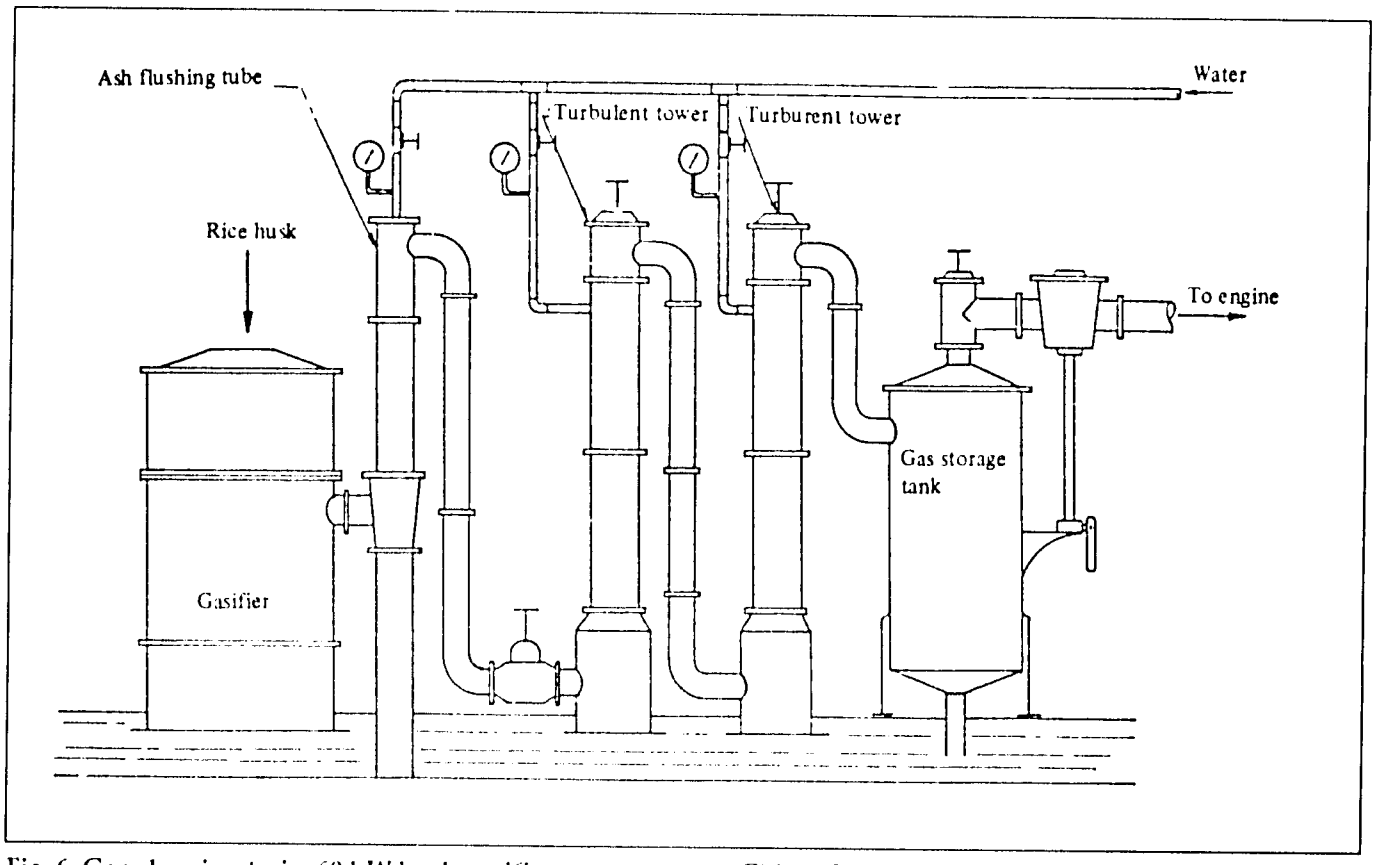

Fig. 6. Gas cleaning train, 60 kW husk gasifier power system, China (Source: *Rural Energy*, FAO Bangkok)

has three engine/generator sets.

The largest Charung installation is at the 400 ton/day Rien Tong rice mill in Chachoengsao province. A traditional husk combustion system was replaced by two of the largest gasifiers operating six engine/generator sets. Total net output is 288 kW.

The capital cost of the complete 72 kW system including gasifier, gas cleaning train, engine, and inexpensive induction generator is about $30,000 or about $416 per kW.

An induction generator can only be used in a system which is connected to the grid, and substantial power from the grid is required for a brief period to initiate the operation of the gasifier power system.

Until about 1987 the rate structure in Thailand allowed rice mills to achieve substantial savings in power costs with the Charung gasifiers. The miller could choose either a low rate per kilowatt-hour plus a moderate demand charge or a somewhat higher flat rate per kilowatt-hour. Under this structure, a Charung gasifier system could save enough in energy costs to pay for itself within about 1 year. For example, the 80 ton/day (3.3 ton/hour) Ruang Tong Tanyahart rice mill in Chachoengsao province paid 80,000 bahts ($3200) per month for electricity prior to installing a 72 kW Charung system in 1983. In 1986 the mill's monthly power bill was only 10,000 to 12,000 bahts ($400 to $480).

Under the current rate structure in Thailand, however, any factory using over 25 kW must pay a much higher demand charge. Due to the initial power demand, the potential savings from the Charung gasifier systems with induction generators have been greatly reduced. Charung is now seeking financing for the development of a new gasifier system with a synchronous generator which would not require power from the grid, and meanwhile is exporting present systems to countries with rate structures which allow more substantial savings in power costs.

Grain Processing Industries (India) Private Ltd.

Grain Processing Industries, an Indian manufacturer of rice milling machinery, has developed a large updraft husk gasifier system which is currently producing mechanical power for a rice mill and could be used in cogeneration systems in "zero energy" rice mills.

The updraft design is similar to husk gasifiers built by British and Italian firms earlier in this century. Husk is fed from a small surge bin by a screw conveyor and elevator to the air-sealed top of the gasifier. The present unit is fed at the rate of 420 kg of husk per hour, which is the husk output of a mill processing 2 tons of paddy per hour. Air enters below the grate of the conical gasifier; the gas exits near the top. Ash falls into a large water bed below the gasifier and is removed annually.

The gas is cleaned initially in a wet scrubber with a flow rate of 15,000 liters (3963 gal) per hour; the water passes through a cooling and cleaning tower and is recycled to the scrubber. A water-jacketed condenser circulating 300 liters of cooling water per hour condenses 30 to 35 kg of tars from the gas per hour. Most of the remaining particulates and moisture are removed in a dry filter.

The initial model of the GPI gasifier is installed at the Bijoy Lakshmi rice mill at Balichak, Midnapore District, West Bengal. The parboiling mill processes about 2 tons of paddy per hour. All of the mill's husk output (about 420 kg/hour) is used in the gasifier. The gas is used in two single-cylinder diesel engines to produce mechanical power for the mill; a 350 rpm horizontal engine produces 50 hp, while a 720 rpm vertical engine produces 20 hp. Exhaust gas from the engine is diluted with ambient air and used directly in a mechanical paddy dryer.

Grain Processing Industries foresees two types of "zero energy" rice mills using the husk gasifier. In a mill which does not parboil rice, all of the gas could be used in a large engine/generator set to generate about 220 kW of net power. A 2-ton/hour mill would need only about 60 kW, so around 150 kW of power could be sold to the grid or to another industry if such sales were permitted by modified Indian regulations. Exhaust gas from the large engine at 500°C would be used for paddy drying.

In a parboiling mill, the 840 m^3/hour of gas from the husk gasifier could be divided into three streams: (a) 260 m^3/hour could be used in an engine producing 122 hp of shaftpower or 82 kW of electrical power for the mill; (b) 340 m^3/hour of gas would be burned as a boiler fuel to produce 800 kg/hour of steam for parboiling, (c) 140 m^3/hour of gas would be burned to provide 500 m^3/hour of air at 110°C for a mechanical rice dryer,

supplemented by exhaust heat from the engine and stack gas from the boiler.

Gariboldi Engineering Company

A husk gasifier system which could be used to produce about 80 kW of electric power was built in 1987 by Gariboldi Engineering of Milan under a collaborative project with ENEA, the Italian government's energy research agency. The gasifier was designed to consume 165 kg of husks per hour, which is less than the husk output of a 1-ton/hour mill.

In contrast to the open-top models built in China and Thailand, the Gariboldi downdraft gasifier has a sealed top. Air is admitted through a central air tube leading into the center of the bed and through nozzles around the circumference of the gasifier. The most unusual feature is the use of a husk fuel hopper above the gasifier as a dry filter for the final cleaning of the gas after it passes through a cyclone and wet scrubbers; the husks then pass down into the gasifier, eliminating problems of disposal of contaminated husks used for filtering.

In initial tests in 1987/88, the tar level in the gas was too high to permit the use of the gas in an engine. Several modifications have been recommended including the addition of a tar condenser or centrifugal tar separator, a water-sealed ash removal system, an agitator in the fuel bed, and an improved control device for grate rotation.

Economic Evaluation of Husk Power Systems For Rice Mills

An economic evaluation of a proposed husk power plant in a rice mill requires careful consideration of capital costs, husk supply, husk costs (if any), annual period of operation, potential savings in power costs, savings (if any) from the use of exhaust steam for process heat, and income from ash sales. (See Section 5 for a detailed treatment of such considerations in Indonesia)

Husk supply and costs

A low pressure steam power plant at a rice mill uses about all of the husks generated by the mill each day to provide about the amount of electric power needed to operate the mill. Since the annual husk consumption of the power plant increases or decreases as the annual rice output of the mill increases or decreases, the fuel supply roughly matches fuel consumption. However, a reduction in the anticipated annual output of the mill (due to reduced rice production or economic factors) increases the cost of power per kilowatt-hour and can threaten or eliminate the economic viability of the power plant investment.

If there is no significant market in the area for the husks generated by the mill, it is not necessary to consider fuel costs in evaluating a husk power project at a rice mill. The use of the husks in the power plant may even result in savings in husk disposal costs.

In areas in which the husks have a market value, the economic analysis should include the "opportunity cost" of husks (i.e., the income that would have been received from the sale of husks if they were not used in the husk power plant). As noted earlier, IDEA's analysis showed that the net present value of an investment in a husk gasifier system decreased by over 3% with each 1% increase in the opportunity cost of husks. PRM Energy Systems calculated that the unit cost of power from a 4-MW husk power plant would be twice as high with husk costs at $20/ton ($0.06/kWh) than with no opportunity cost of husks ($0.028/kWh).

Annual period of operation

Husk power projects in rice mills with rather long milling seasons and high annual outputs tend to be more financially attractive than projects in mills with shorter seasons and/or lower annual outputs. The cost of power per kilowatt-hour from a husk power plant operating for only 6 months a year is considerably higher than from a comparable plant operating nearly all year, since the annual capital cost cannot be spread over as large a total annual power output.

The possibility that husk-fired plants at rice mills could provide year-round power by burning rice straw or other residues during the non-milling season was raised in the report of a convocation in Baton Rouge sponsored by A.I.D. in January 1988 for the U.S. rice residue utilization industry. The use of straw would require a substantial investment in equipment for the collection, baling, storage, and preparation of the fuel.

Net savings in power costs

The primary reason for the installation of husk power plant in a rice mill is to reduce the energy costs of rice milling. The extent of the net savings in power

costs depends on the level of present power costs and on the cost per kilowatt-hour (including capital costs) of power from the new system.

Although some new husk power systems may replace obsolete steam engine systems or diesel-driven line drive systems, most new power plants will be installed in electrified mills which use power from the grid or from diesel-driven generators.

A 5-ton/hour mill operating 12 hours a day, 6 days a week, and requiring 40 kWh per ton of paddy uses about 62,400 kWh per month. If power from the grid costs the equivalent of $0.06/kWh (as in Indonesia in 1987), the monthly power bill is $3744.

A 6-ton/hour mill in Thailand paid about 80,000 bahts ($2932) per month for grid power before installing a husk gasifier power system. IDEA Inc. surveyed a 5-ton/hour mill in India in 1986/87 which used about 21,600 kWh per month of grid power to provide about half of the needed energy; even with India's subsidized power rate (about 1 rupee or $0.06 per kWh), the grid power cost Rs. 22,000 ($1333) per month. The other half of the mill's power was provided by a diesel generating set at a cost of about Rs. 29,100 ($1737) per month. The total monthly power cost at this mill was thus about $3,000. The bill would have been much higher had the mill operated at a rate nearer to its maximum capacity.

Energy costs are even higher at mills that rely only on diesel fuel to provide mechanical or electrical power. The German Agency for Technical Cooperation (GTZ) estimated that a 3.5-ton/hour mill in Mali would require 198,000 liters of diesel fuel to operate a diesel power plant for 9 months a year. Diesel fuel cost the equivalent of $0.62 per liter in 1986 in landlocked Mali, and the monthly fuel bill for the diesel plant was estimated at about $14,000 per month.

Husk power systems tend to be especially attractive if they replace diesel systems in areas with high diesel fuel prices. IDEA's cost-benefit analysis indicated that the difference between the price of husks and the price of diesel fuel critically affected the financial and economic viability of a gasifier system added to a diesel system. The sensitivity analysis showed that the net present value of the investment in the gasifier rose (or dropped) by nearly 7% with each 1% increase (or decrease) in the cost per liter of diesel fuel.

The cost of power from the proposed husk power system must also be carefully estimated. The unit cost of power depends primarily on the annualized capital cost of the system (which is determined by the level of the initial investment, interest rates, and the payoff period) and by the annual period of operation, although labor costs and husk costs must also be considered.

Savings or income from the use of exhaust steam

A steam power plant burning husks tends to be more economically attractive if there is a demand for process heat in the rice mill or in an associated processing facility. This permits the use of exhaust steam from the turbine (or steam engine) and eliminates the need for a cooling tower or condenser. In effect, the generating plant becomes a cogeneration plant.

In parboiling mills, exhaust steam from the turbine can be used for parboiling and/or drying of the rice. Other mills often use steam for paddy drying. Another possible use of steam in rice mills is for the stabilization of rice bran, an essential step before the extraction of edible oil from the bran (see section 7). Some rice mills are located in large agroindustrial facilities which include other operations that require process heat.

Income from ash sales

Husk power plants in the United States derive substantial income from the sale of ash. Actual and potential markets for rice husk ash are reviewed in section 5.

Ash from the 2.8-MW husk-fired power plant at Mah Boon Krong in Thailand is sold to steel industries in Europe. PRM Energy Systems estimated that ash from 2 planned 2.5-MW straw-fired plant in India would be sold to the Indian steel industry or other buyers for more than $60 per ton and would generate profits from ash sales in excess of $650,000 per year.

5
POWER FOR THE GRID FROM RICE RESIDUES

Grid Power from Husks in the United States

In the past few years several large power plants have been built in the United States which use rice residues for the generation of power for the grid.

These include an 11 MW plant which has operated with rice husks in Louisiana since 1984, a new 29 MW plant starting up in California which will burn husks and straw, and another new plant of the same size in California which will burn up to 60% husks and straw mixed with chipped wood wastes. Descriptions of these plants are provided below.

All three of these plants use high pressure steam systems which enable them to produce three to four times the quantity of power per ton of husks that is generated by low pressure plants. The Louisiana plant operates at 650 psig (44 bar) and generates about 960 to 1000 kWh per ton of husks (1050 to 1100 kWh/tonne). The first of the California plants will operate at 1525 psig (103 bar) and is expected to produce between 1150 and 1400 kWh per ton (1265 to 1540 kWh/tonne).

Agrilectric Power Partners Ltd. (Louisiana)

Agrilectric is the builder and operator of the first husk-fired power plant in the U.S. producing power for the grid. The 11.5 MW plant began operation in 1984 at a site adjacent to the Farmers Rice Mill of Lake Charles, Louisiana, one of the ten largest rice mills in the world.

The plant burns 288 to 300 tons of husks per day. They are ground at the rice mill and pneumatically conveyed to the power plant. The plant's cyclonic suspension burners were developed by Agrilectric and the McBurney Corporation (Atlanta, Georgia) which had previously built two 44,000 lb/hour husk-fired boilers for Uncle Ben's Inc. (Houston, Texas).

The watertube boiler was manufactured by Deltak Corporation (Minneapolis, Minnesota). Erosion from entrained ash in the combustion gases is minimized by the straight-through design of the tubes, superheater, evaporator, and economizer. The boiler produces about 112,000 lb/hour (50,400 kg/hour) of steam at 650 psig (44 bar) and 750°F (398°C).

The steam is used in a General Electric turbogenerator rated at 12.5 MVA. Exhaust steam from the turbine is condensed in a 22,000 gallon/minute (83,600 liter/minute) condenser. Cooling water is obtained from an artificial lake supplied by deep wells.

About 16% of the gross power output is consumed in the operation of the power plant and the rice mill. All of the net power is sold to the regional electric utility, Gulf States Power. The gross output is from 960 to 1000 kWh/ton of husks; the net output is 806 to 840 kWh/ton (886 to 924 kWh/tonne).

Ash is removed from hoppers under the furnace, the boiler, and two large flue gas bag filters and is conveyed to a bagging station. The bagged ash is sold to the steel industry for use as an insulating material, to manufacturers of refractory materials, and to firms using the ash to absorb toxic wastes.

The plant's reliability exceeded 93% in the first 3 years of operation and the exceptional level of 97% reliability was achieved in 1986.

Oxford Energy Company

Oxford Energy has built the world's largest power plant fueled entirely with rice residues. The 28.7 MW facility at Williams, California, was in the startup phase in the fall of 1989; some modifications are anticipated before the plant goes into full operation in 1990.

The power plant is not located at a rice mill; husks will be purchased from rice mills under long-term contracts. The Sacramento Valley produces over 1.45 million tons of rice per year and the Valley's mills generate about 290,000 tons of husks annually. Although some husks are used for poultry bedding, most of the husks have been landfilled. Each day the plant at Williams will burn between 500 and 600 tons of rice husks mixed with some rice straw; the total consumption of rice residues will be around 185,000 tons per year. Trucks delivering husks will unload directly at the power plant or at an outdoor plastic-covered fuel pile. A 4-month fuel inventory will be stored at the site.

The husks are ground before combustion using four 10-ton/hour hammermill-type grinders from Crescent Industries. Grinding doubles the density of the husks to around 20 lb/ft^3 (320 kg/m^3). The grinders will operate at night to utilize surplus power during off-peak periods. A 4-day supply of ground hulls will be maintained in a silo with a capacity of 240,000 ft^3 (6796 m^3).

The ground husks are burned in eight suspension burners which utilize proprietary technology purchased from Agrilectric Power Partners. The single drum boiler by Zurn/NEPCO (Redmond, Washington) is rated at 193,000 lb/hour (87,544 kg/hour), 1525 psig (103 bar), and 955°F (512°C). The two-pass, welded-wall boiler has a relatively large volume. Tube erosion problems are reduced by minimizing gas velocities.

Temperatures are carefully controlled to prevent slagging problems.

The high pressure steam feeds a 12,000 rpm Asea Brown Boverie turbine. Shaftpower from the turbine is geared down to drive a 3600 rpm synchronous-type generator at rated 29 MW, supplied by Brush Electrical Machines Ltd. (England). Exhaust steam from the turbine at 160 psig (11 bar) goes to the boiler reheater; reheated steam drives a 3600 rpm low pressure turbine.

The plant uses 365 gal/minute (1.38 m^3/minute) of water from on-site wells; 99.5% of the incoming water is recycled and reused in a complex three-stage condensing system.

Screw conveyors remove the ash from hoppers under the furnace and superheaters. Ash is also removed from hoppers under the fabric filter baghouse, the air heaters, economizer, and reheater.

Specific husk consumption and power output data on the plant are not yet available. If the plant produced 29 MW with 500 tons of husks per day (21 tons/hr), the gross output would be about 1400 kWh per ton of husks (1540 kWh/tonne). If 600 tons of husks per day (25 tons/hr) were needed, the gross output would be about 1150 kWh per ton of husks (1265 kWh/tonne). Either way, the plant at Williams will be the world's most productive husk-fired power plant in terms of both total output and output per ton of husks. The output per ton of husks will be about four times that with low pressure steam systems.

The total cost of the project is approximately $54 million or about $1880 per kW. Power will be sold to the area utility company, Pacific Gas and Electric, under a 15-year contract. Income from power sales in initial years will be about $10 million per year. Additional income will be provided by ash sales.

Thermo Electron Corporation

A new 28 MW power plant at Woodland, California, will burn a fuel mixture consisting of 30% to 50% unground rice husks, up to 10% to 30% ground rice straw, and 40% to 60% chipped wood wastes. The plant is located in the rice-growing Sacramento Valley will purchase husks from local rice mills. The plant was in the startup phase in the fall of 1989.

The power plant was built by Thermo Electron Corporation of Waltham, Massachusetts, which will also operate the plant. The circulating fluidized bed (CFB) boiler was provided by Gotaverken Energy Systems (Charlotte, North Carolina). CFB boiler technology was developed in Sweden to burn solid fuels with large variations in moisture content and heating value. Although extensive tests with rice husks have been carried out in a CFB unit in Sweden, the Woodland plant will be the first commercial power plant to use rice husks on a continuing basis in a fluidized bed boiler.

Combustion gases rise through the water wall of the boiler at the top of the combustor and pass into two refractory-lined cyclones. Particles of unburned fuel and ash fall to the bottom of the cyclones, and are recycled into the bottom of the combustor where combustion of the unburned fuel is completed. Some ash is removed from the bottom of the combustor. Flue gases pass through convective bundles which include a steam generating bank as well as superheater and economizer. Additional ash is removed from a bag house dust separator.

The CFB units operate in a narrow temperature range of about 1450 to 1650°F (787 to 898°C) which is well below the ash melting temperature for rice husks (2624°F, 1440°C). Although no slagging problems are expected with the husks, the use of rice straw is considered experimental. The ash from the straw begins to melt at about 1513°F (823°C), which is not far above the minimum temperature of the CFB boilers.

The CFB units are designed to withstand the passage of some sand from the fluidized bed which becomes entrained in the flue gas, so serious erosion of boiler surfaces by the rice husk ash is not anticipated.

When using 50% rice husks in the fuel mixture, the plant at Woodland will burn about 14 tons of husks per hour. The boiler will produce up to 250,000 lb/hour (113,000 kg/hour) of steam at 900 psig (61 bar) and 900°F (482°C). The turbine will produce up to 28 MW of gross power and 23 MW of net power.

Cogeneration and Grid Power from Husks in Italy

A "stand-alone" cogeneration plant has produced 600 to 700 kW of electric power and process steam from rice husks since 1983 at the Seda distillery at Saluzzo in northern Italy. The plant was built by two Milan firms, Gariboldi Engineering and S. Stefano Ticino. The layout of the plant is shown in Figure 7.

Husks are purchased from nearby rice mills in the upper Po Valley and brought to the power plant by trailer truck. In 1985 the husks cost about $40 per tonne. The maximum load is 10 tonnes of husks in a 100 m^3 (3531 ft^3) trailer. A large truck dumper raises the trailer and dumps the husks into a 100 m^3 hopper. The husks are carried by a chain conveyor to a 2000 m^3 (70,620 ft^3) storage silo. A screw conveyor and elevator bring the unground husks to the furnace.

In the Gariboldi suspension-type furnace, a rotary wheel distributes the husks over a stationary grate at the rate of 1700 to 2000 kg of husks per hour.

The boiler produces 10 tonnes/hour (22,000 lb/hour) of medium-pressure steam at 48 bar (705 psi) and 430°C (806°F). The steam is used in a Siemens turbo-alternator which is rated at 1050 kVA (850 kW). Exhaust steam at 3 bar (44 psi) is used for process heat in the distillery.

There is no ash extraction in the furnace; all of the ash is entrained in the gas stream and removed in the cyclone after it has passed through the boiler. The ash is transported by a screw conveyor to a storage silo. After cooling, the ash is bagged for sale to the steel industry for use as an insulating material.

In a typical period in 1985/86, the plant burned 1700 kg of husks per hour; net output was about 600 kW. In twelve months in 1985/86, the plant burned 10,665 tonnes of husks. Net output was 3,828 MWh or 312 kWh per tonne of husk (282 kWh/ton); 83% of the power was used in the distillery, and surplus power was sold to the grid.

Grid Power From Rice Residues in Developing Countries

At present no power plant fueled with rice residues is providing power for the grid in any developing country. The potential for private investment in such plants in Indonesia was examined in 1987/88 by a team sponsored by the A.I.D. Bioenergy Systems and Technology Project (BST). Issues related to the development of rice power projects in developing countries were discussed in a convocation at Louisiana State University in 1988 on market prospects for U.S.

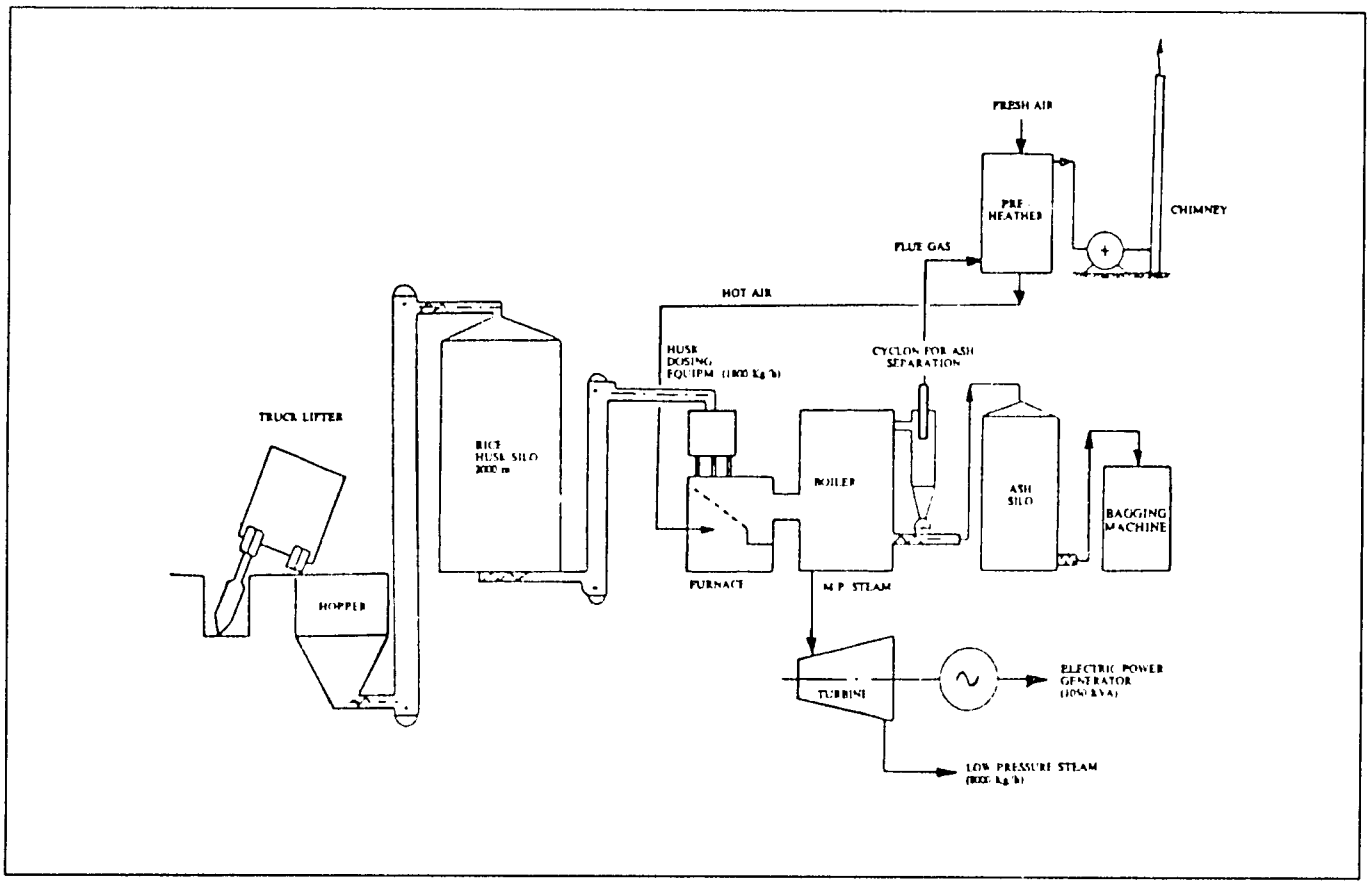

Fig. 7. Seven hundred kilowatt husk-fired steam turbine power plant, Italy. (Source: National Committee for Energy Research (ENEA), Rome)

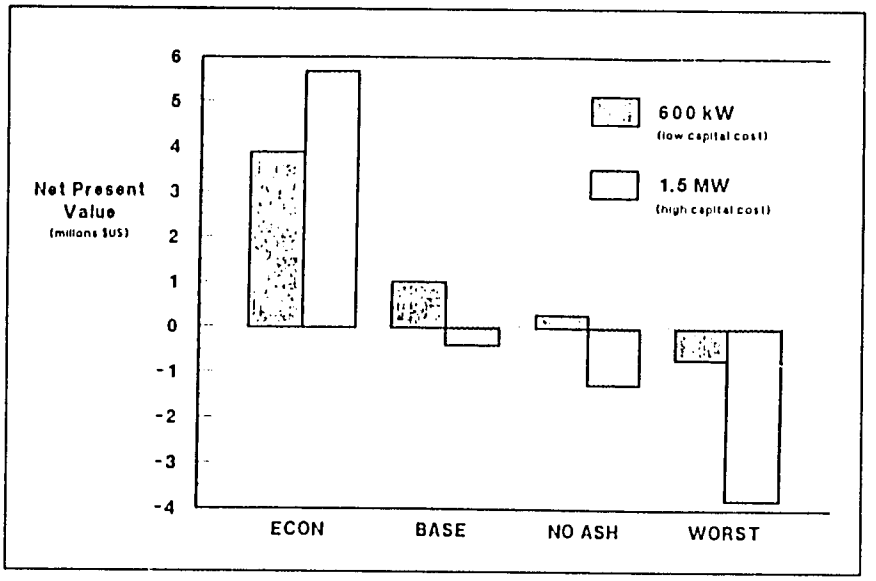

Fig. 8. Net present values, 600 kW low pressure system and 1.5 MW high-pressure system, Indonesia. (Source: Report of BST Team, Indonesia, 1987)

rice residue utilization technology.

The reports on these two BST activities examined a number of interrelated variables in a grid power project with rice residues including the choice of low pressure or high pressure steam systems, capital costs, annual operating period, husk consumption, husk availability, and income from the sale of power, ash, and (in some cases) steam. Conclusions and generalizations from these reports and some other sources are summarized in the following sections.

Low or high pressure system

The most basic choice facing the planners of a grid power project using rice residues is between a relatively small low pressure system or a much larger high pressure system. With a low pressure system, the power output per ton of husks or straw is relatively low but capital costs and fuel demands are also relatively modest. High pressure systems are much more efficient and produce two or three times as much power for each ton of fuel as the low pressure systems. However, these high pressure systems are very expensive and appear to be cost effective only in rather large units which require a very large supply of rice residues.

Using current or expected market prices in Indonesia for the costs and benefits of the rice power systems in a "base case" analysis, the BST team in Indonesia concluded that a 600 kW low pressure system would be financially attractive but that a 1.5 MW high pressure system would not produce positive returns. This difference, illustrated in Figure 8, was due to the substantially lower capital cost of the low pressure system.

In the base case the capital cost of the 1.5 MW high pressure plant was assumed to be $4.2 million ($2800/kW), while the estimated cost of the 600 kW system was only $800,000 ($1333/kW). However, in an "economic case" which assumed higher future values for husk and ash as well as power prices equal to the full generating costs avoided by the utility, both the 600 kW and 1.5 MW plants would produce substantial returns.

Agrilectric Power Partners and Arkel International have developed plans for a "modular" 2 MW husk power plant which reduces capital costs by minimizing on-site construction costs in the developing country. Thirteen completed modules would be shipped from the port of New Orleans and fitted together in a short time at the site in the developing country. Agrilectric and Arkel estimated in 1987 that the modules would cost about $3.5 million; transportation and erection would cost up to $750,000, depending on the country and site, bringing the total cost to about $4.25 million or about $2125/kW.

Annual operating period

As in all power plant investments, high load factors and long annual operating periods are critically important to the financial and economic viability of any investment in a husk-fired power plant.

The base case used by the BST team in Indonesia assumed that the husk power plants would operate for 290 days a year. A sensitivity analysis indicated that the unit cost of power from plants operating only 140 days a year would be two to three times that from plants operating 290 days. The cost of power from the 600 kW low pressure plant operating for 290 days ranged from $0.02 to $0.05 per kilowatt-hour, depending on capital costs and discount rates; if the plant operated for only 140 days per year, the range would be from $0.05 to

$0.12. The unit cost range for the 1.5 MW high pressure plant was $0.075 to $0.11 per kilowatt-hour when operating for 290 days and $0.09 to $0.23 when operating only 140 days per year.

These figures clearly indicate that a high pressure power plant cannot be economically viable unless it operates for the entire year minus the necessary annual maintenance and repair period. Moreover, power available throughout the year can be sold to the utility at a more favorable price than power available for only a part of the year, since the purchase of year-round power may reduce the utility's need for additional generating capacity.

The principal disadvantage of a plant operating all year is that it requires a much larger annual fuel supply, much of which must be stockpiled during the milling season for use in the non-milling season.

Availability and cost of husks

The fuel requirements of a proposed rice power plant should not exceed the quantity which can be economically and reliably obtained in the area around the proposed plant site.

The BST team in Indonesia estimated that, operating for 290 days a year, a 600 kW low pressure plant would use 13,920 tons of husks per year and a 1.5 MW high pressure plant would require 16,356 tons annually. The relatively narrow gap between these two figures is due to the much higher output per ton of husks of the more efficient high pressure plant. The Agrilectric/Arkel 2 MW modular plant, operating for 345 days per year, would need about 26,000 tons of husks.

These plants would require either the entire husk output of a single very large mill or the output of two or more smaller mills. The 600 kW plant would require the equivalent of the entire husk output of a mill processing 15 tons of paddy per hour, 24 hours a day, 6 days a week, during a milling season of 32 weeks. The 1.5 MW plant would need the equivalent of the annual output of a mill operating at the 18 ton/hour level for the same period. The Agrilectric/Arkel 2.0 MW plant would require a supply equal to the output of three 10 ton/hour mills in a 32-week season.

Since only a few large mills in Indonesia could provide all of the husks required by power plants of this size, the BST team concluded that the first husk power plant built in that country would probably be a "stand-alone" plant which purchased husks from several mills.

In areas in which the husks have no market value, it may be possible to obtain husks with minimum cost other than the transport cost. It has even been suggested that in such areas the government could require millers to transport their husks to a designated disposal site (at which a power plant would be built) to prevent undesirable dumping of husks in other areas. On the other hand, the construction of a new husk-fired power plant tends to establish a price for husks even in areas where the husks previously had no market value.

There have not yet been major studies of the cost of transporting husks or of the maximum radius around the power plant from which husks could be economically transported. Both costs and maximum distances are very site specific, since they depend on topography, available types of vehicles, and the local road network.

Despite expectations that transporting husks for substantial distances would be prohibitively expensive, IDEA Inc.'s report on husk gasifier systems indicated that the transporting of husks for distances up to 100 miles is fairly common in northern India due to the severe energy crisis faced by Indian industries. Bogor Agricultural University in Indonesia estimated that hauling husks for a few miles on primary roads would cost about $0.20 per ton per mile, but much of the husk supply is at mills which are not located on primary roads.

Transport costs could be reduced by grinding the husks at the mills and doubling their bulk density. At the Saluzzo plant in Italy, only 10 tonnes of unground husks can be transported in a 100 m^3 trailer which usually carries loads of 27 tonnes. Grinding the husks is necessary for some combustion systems, notably the suspension-type burners used in two large plants in the United States. Another possibility for reducing transport costs is to use inexpensive light weight vehicles suitable for loads of unground husks with a large volume but low weight.

The "base case" assumptions of the BST team in Indonesia included a husk price of Rp. 4,000 ($2.40) per ton. The team concluded that although the price of husk was one of the five key factors in determining the economic and financial feasibility of a proposed husk power system, the husk price is somewhat less

important than the other four factors (ash sales, annual operating days, electricity sale price, and capital costs including interest rates).

The rice residue convocation in Baton Rouge identified inadequate or interrupted fuel supply as a major risk associated with investments in stand-alone husk power projects. Plants which must buy husks are vulnerable to weather and other external factors which can influence the pattern of rice milling and the availability of husks.

The Baton Rouge group suggested that large stand-alone power plants could minimize fuel supply problems by maintaining a minimum of 45-day supply of husks at the plant site and by sizing the plant to use only 10% to 15% of the husk output in the surrounding area from which husks could be obtained without excessive transport costs. Long-term contracts for the purchase of husks were also recommended.

Income from the sale of electricity

Aside from capital costs, the most important factor in determining the economic attractiveness of a plant producing power for the grid from rice residues is the price paid for the power by the electric utility or cooperative.

In most developing countries, this price cannot be estimated in advance with much confidence. In the typical country there is very little legislation, procedure, or experience relevant to the purchase of power from private firms by government-owned electric utilities.

At the minimum, the price paid for power should be equal to the fuel costs avoided by the utility as a result of the purchase of power. If the husk-fired plant can reliably produce baseload or peakload power, the utility may be able to avoid investments in additional generating capacity and the purchase price should reflect these avoided capacity costs. In the absence of a firm government program to encourage private power generation, the electric utility may tend to resist power purchases and/or keep the purchase price at a minimum level which reduces the financial attractiveness of the proposed rice power system.

The BST team in Indonesia found that a 600 kW low pressure system with a relatively low range of capital costs would provide positive returns with all expected levels of electricity purchase prices. However, a 1.5 MW high pressure system would not produce positive returns if electricity prices were low and capital costs and/or discount rates were high.

Income from the sale of ash

There are a number of present and potential industrial uses of rice husk ash, and income from the sale of ash is a significant contributor to the economic viability of husk-fired power plants.

At present the most important market for rice husk ash is in the steel industry, which uses the ash as an insulating material for ladles and other units containing molten steel. Both the Agrilectric plant in Louisiana and the Mah Boon Krong plant in Thailand export ash to the steel industry in Europe. The Producers Rice Mill in Arkansas has sold rice husk ash in the United States for abut $200 per ton, making about $100 profit on each ton after transportation costs.

PRM Energy Systems estimated in 1984 that its 1-ton/hour reactor operating 350 days a year would generate ash sales of 6 tons per day and an annual net income from these sales of $126,000. A 2-ton/hour PRM reactor would produce 9.6 tons of ash per day and the net income would be $201,600. These projections were based on apparently conservative estimates that the net profit from ash sales would be $60 per ton. PRM currently expects that net income of this level or higher will be obtained through the sale of ash from the planned 2.5 MW straw-fired plant in India.

The "base case" assumptions used by the BST team in Indonesia in evaluating rice power projects included the sale of ash at $45 per ton. Elimination of these sales in a "no ash case" substantially lowered the net present value of the investment in a 600 kW plant and substantially increased the negative return on the investment in a 1.5 MW plant (see Figure 8). The team concluded that an assured market for the ash was essential for an economically viable rice power project.

If the husks are burned at temperatures between 550°C and 700°C (1022 to 1292°F), the ash will be amorphous (uncrystallized). Amorphous husk ash is a possolanic material which reacts with lime and accelerates the hardening of cement. The ash is used in cement in India and in some other countries. In 1984 husk ash cement was reported to be selling in India for about 70% of the cost of a quantity of ordinary Portland cement with equivalent strength.

The Laterite Products Company in Bangkok uses rice husk ash from a 60-ton/day Universal Energy

International rotary kiln combustor as one of the ingredients in the manufacture of concrete blocks.

Other potential markets for the ash include its use as (a) a source of silica for the production of glass, fiberglass, and even silicon cells for solar photovoltaic power systems, (b) a filtering medium for the removal of algae, bacteria, and dissolved organic carbons from beverages and from community water supplies, and (c) an absorbent for hazardous liquid wastes (including small oil spills on land) which permits the wastes to be landfilled with minimal leaching into the groundwater.

Some uses of the ash require a minimal fraction of carbon. One manufacturer of a combustion system is currently conducting tests to determine if the firm's units can produce husk ash with less than 1% carbon and less than 1% crystallization to meet the special requirements of a potential buyer in the electronics industry. Too high a fraction of carbon reduces the value of the ash as an insulator, but does not impair its suitability for some other uses.

Income or savings from the use of steam

Some "stand-alone" rice residue power plants in developing countries may be able to derive important income from the sale of steam or important savings from the use of steam in associated processing industries. Obtaining this additional source of income will require innovative planning and siting of the plant.

Some of these power plants producing power for the grid may be located in or very near a large rice mill in order to utilize husks from that mill as well as husks purchased from other mills. In such cases, the power plant could sell exhaust steam to the rice mill for parboiling, rice drying, and/or bran stabilization. Alternatively, the power plant could be located in or adjacent to another type of agroindustrial or industrial facility which has a substantial requirement for process heat. The husk-fired power plant at a distillery in Saluzzo, Italy is an example of this type of plant.

6
ENERGY FROM RICE STRAW

The potential energy in the world's annual production of rice straw is about five times as large as in the annual output of rice husks, but the use of this potential fuel has been minimal due to the decentralized availability of the straw and problems in the collection and combustion of this fuel.

Availability and Present Utilization of Rice Straw

The quantity of rice straw produced in a given area is slightly larger than the quantity of rough rice (paddy) harvested from that area and is about five times larger than the quantity of rice husks generated in the milling of the rice.

In villages in India surveyed by Punjab Agricultural University in 1985/86, the straw/grain ratio ranged from 1.042 to 1.203, with a mean of 1.113. Straw production ranged from 3.1 to 4.6 tonnes per hectare. A task force on rice straw utilization at the University of California at Davis (UC Davis) reported that over 3 tons of straw per acre (7.4 tons per hectare) was being produced in 1981 in California, although the volume of straw could be reduced by 15% by the use of new short-statured rice varieties.

The percentage of the straw which is removed from the fields depends on the harvesting methods and the local uses for the straw. In the Punjab survey, 60% of the straw was harvested by hand. Most of the grain was carried to threshing sites near the fields, where it was manually threshed; most of the straw was left at these sites. If the rice is harvested by hand, it is easy to remove the entire stalk; if combines are used, up to 40% of the straw remains in the field as stubble.

In some countries with acute shortages of domestic fuel, notably China and India, rice straw has been widely used for cooking. For centuries Chinese villages burned a mixture of rice straw and husks in open-top burners. The black char from these burners was used to absorb human wastes and the resulting mixture was used as fertilizer in the fields. In Indonesia, Thailand, and other countries in which more convenient domestic fuels are available, rice residues are rarely used for cooking.

Compared to a good fodder for animals such as alfalfa, rice straw has low percentages of digestible energy and crude protein and high fractions of crude fiber and ash. The UC Davis study showed that untreated rice straw has limited value as an energy source for livestock. Nonetheless, the straw is widely

used for livestock feed in areas where other sources of fodder are limited. In some Indian states most of the rice straw is fed to cattle, and there is no substantial surplus of unused straw. In other states, notably Punjab and Haryana, better fodder is available and most of the rice straw is unused.

Relatively small quantities of rice straw are used for a number of other purposes including packing materials, roof thatching, fuel for brick kilns, growing medium for mushrooms, and feedstock for the production of fiberboard, paper, and chemicals.

In most rice-growing areas, only a small fraction of the rice straw is utilized for any purpose. Although the Indonesian agricultural extension service recommends that farmers return the straw to the soil to improve tilth and the level of organic matter, most of the straw is burned at threshing sites in Indonesia. Most of the straw is also burned in the Punjab.

In California the continuation of open burning of rice straw is defended by farmers as necessary for the control of stem rot (*Sclerotium oryzae*), a fungal disease affecting the rice plants. The UC Davis study indicated that, while open-field burning of the straw is the most effective means of minimizing loss due to stem rot disease, the complete removal of the straw from the fields would also minimize the stem rot. The study also noted that burning of rice straw contributes up to 9% of the pollutants in the air of the rice-growing areas in California.

Collection, Transportation, and Storage of Straw

The utilization of straw as a major source of fuel for a large power plant would require a complex logistical plan for the collection, transportation, and storage of the straw.

The technical and logistical aspects of the large scale use of rice straw are rather similar to those associated with the use of the residues left in the fields after the harvesting of sugarcane. Cane field residues are being utilized for power generation at present in several developing countries, and the BST project has funded a series of experiments with the harvesting, baling, and storage of these residues. A comprehensive review of the use of cane field residues for power generation is provided in "Power for the Grid From Sugarcane Residues" (Bioenergy Systems Report, August 1989).

At the time of harvest, rice straw contains 55% to 70% moisture. As with cane field residues, the fresh straw must be windrowed and left in the sun for a few days until it is dry enough to bale.

If the terrain and soil conditions permit, the sun-dried straw can be baled in the fields using commercially-available rectangular or round balers. The UC Davis study noted that the large round bales are less dense, more expensive to transport, and require more space for storage than the rectangular bales. On the other hand, experiments with cane field residues showed that the round bales were less subject than the rectangular bales to moisture absorption and deterioration during storage.

A team at Punjab Agricultural University in India made a comprehensive study in 1985-86 for the Punjab Electricity Board of options for the collection of straw as the exclusive fuel for a proposed 10 MW power plant. The study examined means of collecting approximately 187,000 tonnes of rice straw annually.

Under the plan proposed by the team, loose straw would be collected by farmers and transported by ox carts, trailers pulled by tractors, and trucks to five collection, baling, and storage centers. Each center would have three 12.5-ton/hour balers; they would operate 10 hours a day for 6 months a year in order to bale and store from 37,000 to 48,000 tonnes of baled straw at each center. Baled straw would be trucked to the power plant as needed in order to permit the operation of the plant for 300 days per year.

Around 50,000 tonnes of baled or unbaled straw will be brought directly to the 3.0 MW plant in the Punjab planned by PRM Energy Systems (section 4) from farms within a 7-mile radius. Both the methods and costs of transporting straw from farms to the power plant would depend on local conditions including the patterns of rice production, available vehicles, local road networks, seasonal weather variations, and other variables.

Industrial Combustion of Rice Straw

Experience with the industrial combustion of rice straw is very limited. Techniques for the preparation and/or feeding of the straw depend on the type of furnace.

At Louisiana State University baled rice straw was tested in a commercial furnace designed to burn bales

of agricultural residues to produce heat for grain drying. Ash tended to cling to unburned material in the bale and retarded combustion. Unless the bales were shaken periodically to remove ash, the air temperature declined steadily and the complete combustion of the large round bales required up to 24 hours.

Most combustion systems require pulverizing the straw. At the Oxford Energy plant in California, large bales of straw weighing 1,000 lb (453 kg) will be opened and chopped to 1 1/4 to 2 inch (3 to 5 cm) lengths in a tub grinder; the chopped straw will then be hammermilled before co-firing with ground rice husks in the plant's suspension burners.

The energy content of rice straw has been measured in California and in India at around 15 MJ/kg, which is about the same as that of rice husks. The Punjab Agricultural University study cited above used an estimate by Gariboldi Engineering that about 2.6 tonnes of straw would be needed to produce a Megawatthour of power in a low pressure power plant; this is equivalent to 384 kWh per tonne of straw (384 kWh/ton). Gariboldi stresses, however, that the potential power output is highly dependent on the moisture content of the straw.

The percentage of ash in the straw is also about the same as in the husk (15% to 20%), but the percentage of silica is not as high. Due to the presence of larger fractions of sodium and potassium in the ash from straw, the ash begins to melt when furnace temperature reach around 825°C (1517°F). Deformation of the ash from rice husks does not occur until around 1440°F (2624°F). Due to the lower ash melting temperature, very careful control of furnace temperature will be required when the straw is burned to avoid slagging problems.

7
ENERGY FROM HUSKS AND STRAW FOR RICE BRAN UTILIZATION

In the near future there may be important opportunities to use energy derived from rice husks (or possibly rice straw) in the commercial processing of the third underutilized rice residue in developing countries, rice bran.

Production and Use of Stabilized Bran

The white starch kernel of the grain of rice is surrounded by a tightly adhering brown layer of bran, which in turn is enclosed by the loose outer husk. The bran layer accounts for from 8 to 10% of the paddy by weight. Both the husks and the bran are removed to produce white milled rice.

The rice bran contains 12 to 16% protein and is rich in vitamins and minerals. From 15 to 20% of the bran is oil; if properly extracted, it can be used as salad or cooking oil as is oil from corn, peanuts, or cottonseeds. Although the world production of rice bran is about 35 million tons per year, only a small fraction of the bran is used as a foodstuff.

About 70% of the world's rice is milled in single-stage mills which remove the husks and bran in a single operation. The oil content of the resulting husk/bran mixture is too low (below 10%) for the economic extraction of the oil. The use of about 10 million tons of separate bran which is produced by multi-stage rice mills has been limited by powerful enzymes in the bran. After milling, they begin to breakdown the oil immediately into glycerol and free fatty acids; this process makes the bran unpalatable and prevents the economic recovery of the oil. However, the disintegrative enzymes in the bran can be destroyed by heat in a process known as bran stabilization.

About 15% to 20% of the stabilized bran can be extracted as oil using soivent extraction. The further refining of the crude bran oil requires dewaxing, neutralization, bleaching, and deodorization.

Japan produces over 100,000 tons of bran oil annually. Over 100 solvent extraction plants were operating in India by the mid-1970s, producing over 1.5 million tons of bran oil annually for use in the manufacture of soaps and other non-food products.

At present India is currently expanding production of bran oil in order to reduce its imports of edible oils. Two U.S. companies are participating in joint ventures with parastatal companies for the production of bran products in India.

California Rice Bran Inc., a subsidiary of Brady International, has a joint venture with Punjab State

Cooperative Supply and Marketing Federation Ltd. (MARKFED) of Changigarh, India. Stabilized bran is produced by 42 Brady extruders located in several large mills and in collection centers which receive freshly milled bran from smaller two-stage mills. Following stabilization, brain oil is extracted.

Helix International Corporation is developing a joint venture with Punjab Agroindustries Corporation (PAIC), also based in Chandigarh, to produce stabilized bran, bran oil, and defatted bran. The bran processing facility will be located at PAIC's new mill at Khanna. The facility will be built by Process Fabricators Inc. (Claremore, Oklahoma) and will utilize Helix International's new proprietary oil extraction process using isopropyl alcohol as the solvent rather than the hexane used in previous extraction plants.

At present the deoiled bran remaining after oil extraction is used as a high quality ingredient for livestock feed. However, the U.S. Agency for International Development, the U.S. Department of Agriculture, and several U.S. firms have been participating in efforts to promote the utilization of rice bran as a high-protein food for human consumption. Either whole stabilized bran or deoiled bran can be milled into rice bran flour which can be used in a variety of baked food products. Helix International is currently test-marketing a number of these products in the United States.

Interest in rice bran for human consumption has been heightened recently by research at the U.S. Department of Agriculture's Western Regional Research Center, Albany, California. Experiments with hamsters suggested that rice bran may be as effective as oat bran in reducing serum cholesterol levels in the blood stream. Further tests of rice bran with human volunteers at Louisiana State University and the University of Texas medical center in Houston are being funded by several major rice milling and food companies. If these test demonstrate the health benefits of rice bran, a rapid growth in the market for rice bran is anticipated.

Energy for Bran Stabilization

As indicated above, bran stabilization requires the application of heat to breakdown the enzymes in the bran. There are two major options for the use of energy from rice husks (or possibly rice straw) for bran stabilization.

One option is to use steam from a husk-fired furnace. In experiments in 1982 at the Tacurong rice mill in the Philippines, about 40 kg of husks per hour were burned in a kettle-type boiler to produce steam at 5 kg/cm^2 (71 psi). The steam was used in a 2-ton capacity stabilizer.

In 1982 an international group visited a rice bran stabilization and oil extraction operation at the 6-ton/hour Wuxian county rice mill in China. Steam from husk-fired boilers at 5 to 6 kg/cm^2 (71 to 85 psi) was used to cook the bran for 15 to 20 minutes in each of four stirred compartments. The bran was then formed into cakes and the oil was extracted in hydraulic presses operating at 35.5 kg/cm^2 (504 psi). Most of the bran oil produced in China is used in the manufacture of soap, with only a small fraction used for human consumption.

In larger mills with husk-fired power plants operating at medium pressures, it would be possible to use exhaust steam from the turbine for rice bran stabilization.

The most promising method of bran stabilization at present is with electrically driven extruder/cookers which are widely used for processing a wide range of food products. A screw forces the bran through a cylinder under pressure until it exits through a small extrusion die. The friction and pressure created in this extrusion process rapidly increases the temperature of the bran and destroys the enzymes. Research at the U.S. Department of Agriculture laboratory at Albany, California, indicated that the optimum temperature for extrusion of rice bran was about 130°C (266°F).

All such extrusion processes are relatively energy intensive. The Brady extruder used in the USDA research required an equivalent of 76 kWh per ton of bran to produce an extrusion temperature of 130°C; 14 to 16% more energy was needed to increase the temperature to 140°C. California Rice Bran's basic extruder model has a 75 hp motor. Insta-Pro International produces three models of extruders with motors rated at 50 hp, 75 hp, and 125 hp. A sensitivity analysis included in a USDA study in 1981 indicated the changes in the cost of electric power would have a significant impact on the return on investments in rice bran stabilization equipment.

The feasibility of providing additional electrical power for bran stabilization with a low-pressure husk-fired power plant would depend on the output of the plant per ton of husks and the power requirements of the mill. If net power output is relatively high (around 300 kWh per ton of husks) and the power demand of the mill is relatively modes (around 30 kWh per ton of paddy), there would be ample surplus power for bran stabilization with extruders. If the power output is only around 225 kWh per ton of husks and the power demand is around 40 kWh per ton of paddy, there would be little if any surplus power for bran stabilization.

This analysis suggests that providing electrical power from rice residues for bran stabilization would require (a) an efficient low pressure power plant using husks which is carefully designed to match the total power requirements for rice milling and bran stabilization, (b) a low pressure plant of greater capacity in which the power output is increased by using rice straw as a supplemental fuel in addition to husks, or (c) a husk power plant operating at higher pressures and producing more power per ton of husks.

8
NEW SYSTEMS FOR HUSK COMBUSTION

The three firms included in this section are currently conducting tests and/or developing modifications of combustion systems which were originally developed for use with other fuels, to permit their commercialization for use with rice husks.

AEON International Corporation

AEON International Corporation, an export trading company, is developing plans to export a power generation system for use with rice husks based on a "Biomaster" furnace developed by the Sukup Manufacturing Company, Sheffield, Iowa. The furnace which has been used for 15 years to burn corn cobs and stalks and other biomass to provide heat for grain drying, effectively burned rice husks during a recent 45-day test.

The core of the Biomaster is a vertical stainless steel cylinder with a refractory lining. A feed auger conveys the biomass from a fuel hopper to the bottom of the furnace. In the tests with rice husks, a stainless steel ash auger was installed in a trough in the floor of the furnace. A water cooling jacket will be added to prevent warping of the auger.

In grain drying applications a 15 hp fan circulates clean air through the space between the inner lining of the furnace and the outer steel shell. One option for steam generation is to replace this heat exchanger with boiler tubes. Another option is to use the flue gas from the furnace in a heat recovery boiler to generate steam.

Waste Conversion Systems

Waste Conversion Systems is testing rice husks in its Thermal Burner which was designed to permit the use of biomass fuels in boiler systems which were originally designed for oil or natural gas.

Fuel is conveyed from a fuel hopper to the burner in a variable-speed auger drive or through a surge bin. It is burned on a rotating stainless steel fire belt; ash drops off the belt and is removed by an ash auger. The hot gas passes through a nozzle into the retrofitted boiler.

Initial tests with rice husks in the WCS burner produced ash containing abuot 10 percent carbon. WCS plans further tests in 1990 with a burner modified to provide a longer residence time, somewhat lower temperatures, and ash with only about 1% crystallization. The firm feels the potential sale of such high-quality ash for use in the electronics industry would greatly increase the economic attractiveness of such a rice husk burner.

Energeo, Inc.

Tests now under way in California may demonstrate the feasibility of producing electric power from rice husks in a "Brayton cycle" system using a fluidized bed combustor and a gas turbine linked to a generator.

A new firm, Energeo, Inc., has been has been established to manufacture and market Brayton cycle systems through joint ventures in Asia and perhaps other areas.

A small prototype was operated satisfactorily with rice husks. A larger prototype unit has been operated with chipped wood residues at a lumber mill in Oregon to produce about 60 kW of net power. The

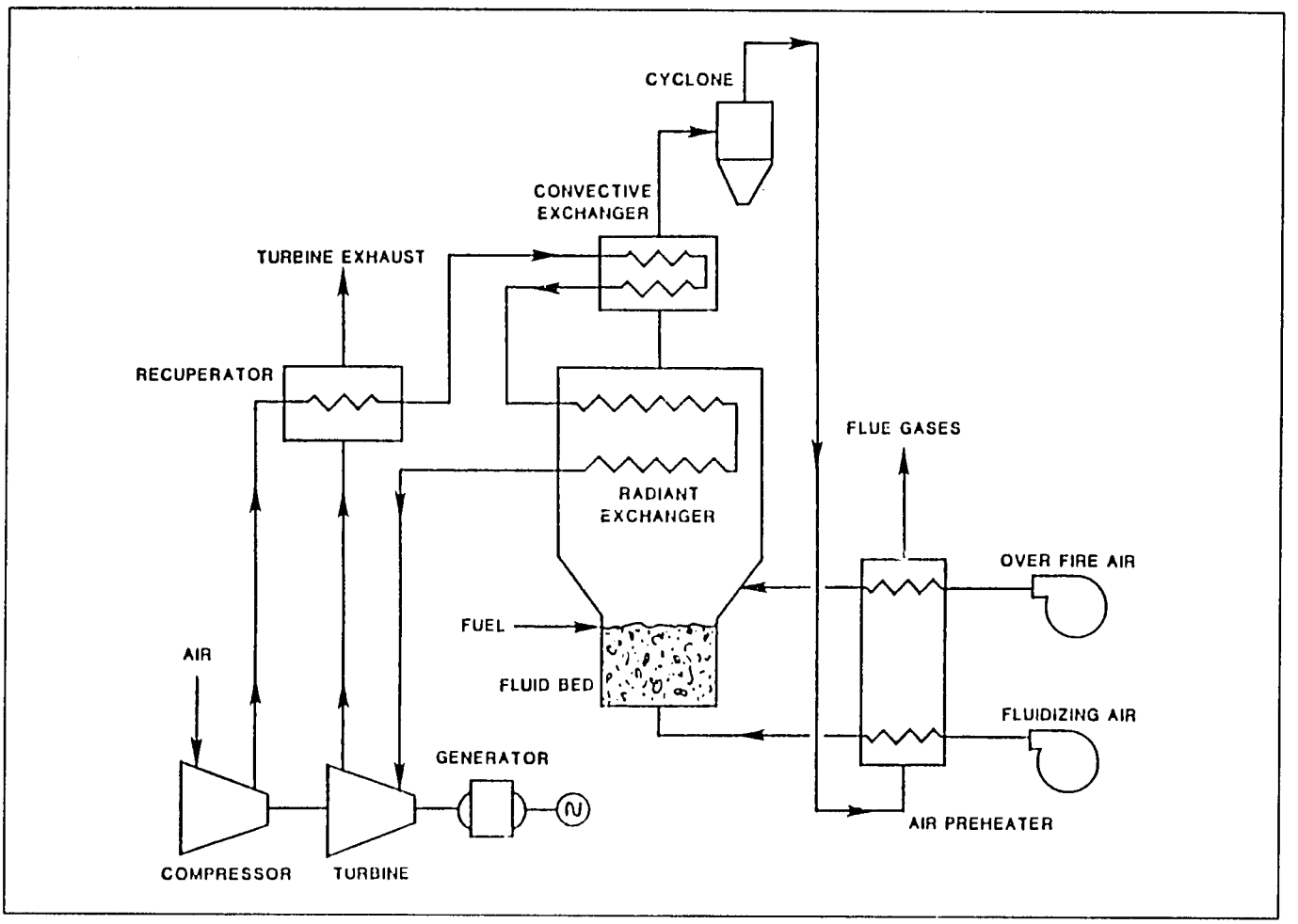

Fig. 9. Prototype Brayton-cycle power system. (Source: Energeo, Inc., San Francisco)

larger prototype is being tested with rice husks at the California test facility of a major manufacturer of gas turbine systems, Solar Turbines.

The Energeo design is shown in Figure 9. Fluidizing and overfire air are preheated by flue gases. Fuel is fed by a screw conveyor. All ash is entrained in the gas stream and is ultimately removed in a cyclone. Heat from the flue gas is radiated to the stainless steel tubes of a radiant heat exchanger at the top of the combustor. Since the gas does not pass through the exchanger tubes, erosion of the tubes by rice husk ash should be minimal.

The radiant heat exchanger transfers heat from the combustion gases to clean air which has been preheated in a recuperator by turbine exhaust air and in a convective exchanger by the flue gases from the combustor. In the prototype system the hot gas is fed to a somewhat modified gas turbine generator set originally designed for use in a system burning kerosene or diesel fuel. The planned Energeo units will utilize gas turbine generator sets which are already in use in Asian countries.

Energeo plans to design a commercial-scale system, producing between 100 and 200 kW of electric power. Preliminary figures indicate the system would burn about 560 lbs. (254 kg) of rice husks to produce 100 kWh; the expected output would be around 393 kWh per tonne of husks.

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