Rice-Husk Conversion to Energy
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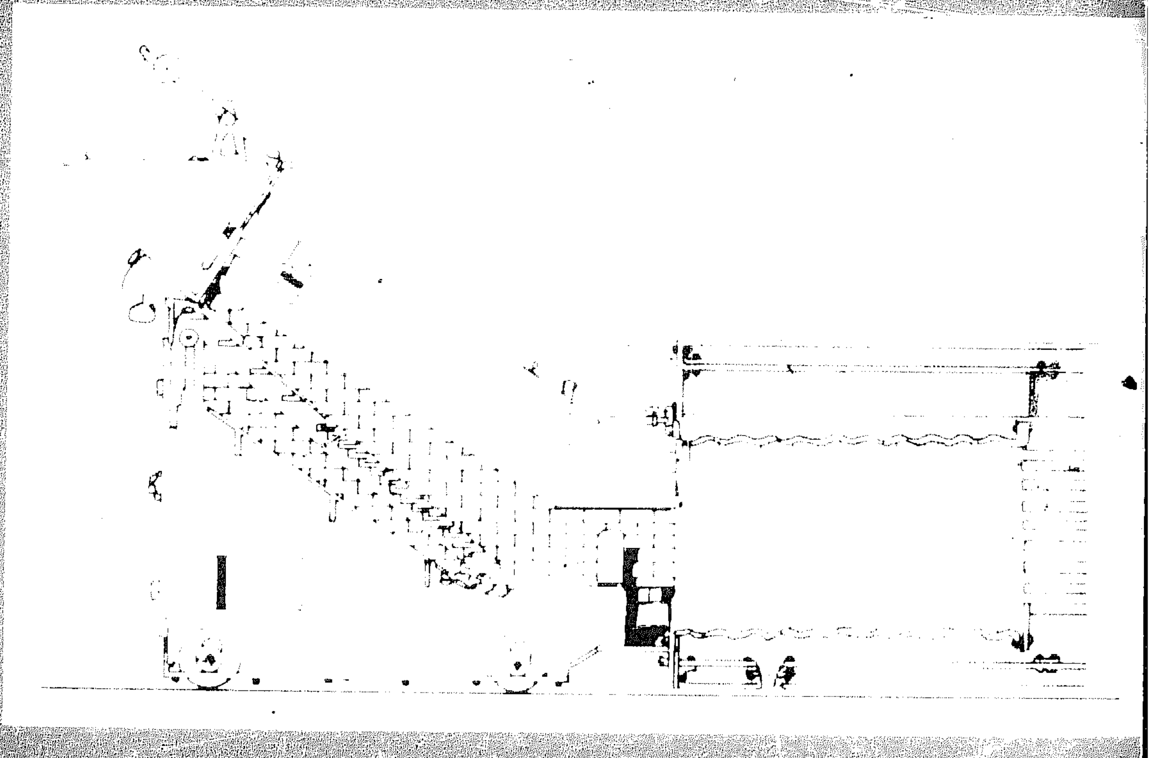

FOOD AND AGRICULTURE ORGANIZATION
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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FOREWORD

The focal point of this study is the pressing need to utilize rice husk as an energy source, especially in the developing countries. It surveys the available processes and equipment for burning rice husk for energy production, mainly inside rice mills, combined with high grade ash production and potential utilization. After reporting on studies and interviews at the principal research institutions, machinery suppliers, and companies that make use of ash, it puts forward suggestions for further research and development activities, with special emphasis on the requirements of the developing countries.

The information contained in this paper includes the views of the author and knowledge obtained from organizations and individuals. Reference to a company and/or product name by the author does not imply approval or recommendation of the process or product to the exclusion of others which may also be applicable or suitable.

The author wishes to express his sincerest appreciation for the interest, data, advice and assistance he received from the many persons who contributed to the accomplishment of this study.

Comments and requests concerning this paper should be directed to the Chief, Food and Agricultural Industries Service, Agricultural Services Division, FAO of the United Nations, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Chapter 1: INTRODUCTION -- DISCUSSION

1.0 INTRODUCTION

In view of the crucial need to introduce modernized processes that will permit the utilization of rice husks as an energy source, especially in the developing countries, FAO commissioned Mr. Eldon Beagle to survey the available processes and equipment for burning rice husk to produce energy, mainly inside rice mills, leading to high-grade ash production as well as potentials for ash utilization.

This survey includes a desk study based upon Mr. Beagle's extensive experience with rice husks and their utilization as well as visits to major research institutions, machinery suppliers and companies concerned with the conversion to energy and the utilization of the residue.

The author visited some 30 countries and talked with millers, researchers, teachers, government officials, and industrial leaders. He also engaged in extensive correspondence with interested and knowledgeable persons in those world-wide areas he was unable to visit. The results of the survey are reported herein, along with suggestions for further research and development activities. Special emphasis is placed upon the requirements of the developing countries.

1.1 GENERAL DISCUSSION

1.1.1 BASIC CONSIDERATIONS

Husks are the largest milling by-products of rice, constituting one-fifth of the paddy by weight. With current annual world paddy rice production at 300 million tons, some 60 million tons of rice husks are produced each year. Proper utilization of this vast quantity, either through commercial application or other useful consumption, could have a major impact on the economies of both the rice milling industry and the country concerned.

1.1.2 RICE HUSK UTILIZATIONS

A broad variety of actual and potential industrial rice-husk utilizations exists, but the consensus has been that only a small percentage of the available husks are being utilized in any manner whatsoever. Traditionally, one of the major uses of rice husks was as fuel to provide energy for rice-mill operation, but the ever-increasing number of diesel and electrically-driven rice mills has largely eliminated such use except in certain areas. Consequently, it is believed that most rice husks remain as unused waste material and create a significant disposal problem. Common practice has been to dump the rice husks onto open fields or into nearby waterways. At times the husks are burned first and the residual ashes dumped. However, both char and ash can be utilized in a beneficial manner. Appendix A discusses some typical further utilizations of rice-husk chars and ash.

Recent field investigations, however, have provided increased data as well as accuracy and it was found that the utilization of rice husks is greater than has been originally estimated, particularly in the production of energy and its residual by-products. It now appears that about half of the available 60 million tons of rice husks are actually utilized in some manner. Since some of these usages are to expedite husk disposal, they may not represent the most beneficial utilization, and therefore in total offer the largest opportunity for improvement. Of the remaining half, it appears that some 30% do not currently and cannot in the foreseeable future lend itself to any economically feasible scheme, largely because the quantities available at any one site are inadequate. However, the last 20% offer full opportunity for beneficial development.

One of the best examples of beneficial use exists in India, where 40% of the rice husks available nationally are used as the energy source for parboiling 45 to 47% of the total rice crop. However, most of these steam-producing installations do not operate at high efficiency, so that in no known case does the available husk provide both motive power and necessary process steam. In a very few cases a small amount of electricity is generated for ancillary purposes.

Considerable confusion arises from the fact that many discussions of husk utilization really involve huller bran and not husk. 30% of the husk in the world comes off as huller bran. This is not a problem of husk utilization but rather one of utilizing the usable rice by-products.

Huller bran is not husk and not a waste. The first operation is to separate the mixture--recover the husk, utilize the bran for feed and utilize the husk for energy. However, in some cases the huller bran could be used in total as an animal feed--in the manner of the use of rice-mill by-product.

The utilization of rice husks as a source of energy production very possibly represents an entirely new dimension in utilization thinking, offering the possibility that this disposal nuisance can now be thought of as a basic raw material, "a national treasure" as it is considered in Japan.

There is repeated emphasis in this report upon the local opportunity concept of feasible rice-husk utilization. It must be remembered that solutions satisfactory for any specific set of conditions are most likely to be completely unsatisfactory when applied to another set of conditions, because of such vital considerations as husk availability, technological capability, and actual market potential. Therefore, in every instance, particularly where energy is a prime consideration, both the entrepreneur and any interested government must fully evaluate all the pertinent factors before the validity of any utilization concept can be established.

1.1.3 WORLD-WIDE ENERGY CONSIDERATIONS

Although some countries are better endowed than others with the natural resources (viz., fossil fuels) commonly used to produce energy, there is a real and increasing worldwide concern about what was thought to be an almost limitless abundance rapidly being transformed into short supply, leading to upward spiralling costs, and non-recoverable depletion. There is widespread realization that no energy source can be wasted, either now or in the future.

As oil, coal, and natural gas availability decreases and prices increase, substitute means for maintaining existing levels of energy consumption must be developed and applied. The alternative is reduced consumption, which has broad negative implications, especially in the developing countries where the need for energy is on the increase.

While this situation will spur the development of hydro- and nuclear-produced electric power, the latter are certain to become more expensive and their use more discriminating. This means that a reappraisal of the most beneficial usages of all energy and resources is necessary. Additionally, the influence of cost factors must be reassessed and probably relegated to a less significant role. This has special significance for the developing countries, because it means that existing, proved technology should be applied to produce energy through the utilization of indigenous renewable fuels, freeing the more precious resources for applications where they can be most efficiently utilized domestically or exported in order to generate foreign exchange.

Need now exists for an alternative type of small prime mover which can be operated using such fuels as low-grade coal, lignite, wood, and agricultural and industrial wastes. The need for such a small engine is most acute in countries with few or no indigenous resources of liquid fuel and where mechanization of agriculture as well as village industries is one way of raising standards of living.

When a rice mill is operated from a power grid, it must be considered that either foreign exchange or a national resource is being utilized. In Indonesia, for example, it might be more advantageous to utilize indigenous fuel even at a higher energy economic cost and then sell the freed petroleum in foreign trade. Governments should loan, offer credits, or otherwise extend incentives to the individual miller to induce as well as enable him to build his own power plant using indigenous fuels and thus to reduce the load on the national or public generation facilities and the national or public distribution grids.

1.1.4 RICE HUSKS AS AN ENERGY SOURCE

Today, in considering any utilizations of rice husks, the significant changes in needs and economic conditions throughout the world exert an overriding influence upon the definitions and practicality of any plan for beneficial use. The rapid emergence of a universal need for energy resources has reshaped the feasibility potentials for by-products that can be utilized in the production of energy. This need also results in a broadening of perspectives regarding such usage: utilizations must now be viewed for their potential contribution to energy saving as a whole as well as in relation to specific local and national considerations.

The declining energy supplies, rapidly increasing consumption, and increasingly severe environmental constraints sharply focus attention on the need for additional amounts of clean energy sources. Conversion of the plentiful supply of organic solid wastes into clean energy forms provides an opportunity to expand the energy resource base while reducing the pollution now associated with waste disposal. Successful development of such conversion methods thus broadens the beneficial usage not only of rice husks, but also of other crops, some of which are grown specifically to provide additional energy from the sun because both sources consist essentially of cellulose. Possibly, this could be considered the first major practical application of solar energy to alleviate the energy shortage. The concept appears all the more attractive because the proposed energy resources are renewable, while the current utilization of fossil fuels is a non-recoverable depletion of energy resources.

Considerations of this nature prompted FAO to consider in early 1974 that the most practical use of rice husk in the foreseeable future was as fuel to provide energy, first of all for the rice processing industry, including parboiling, rice bran extraction and industries directly related to the rice industry.

Thus, rice husks now appear very attractive as a raw material, particularly in a "vertically integrated" energy system, wherein the raw material is used to produce energy while the resultant residue is marketable at higher prices than the raw material. This concept is especially applicable to rice husks because of the high residue levels obtainable. However, in order to receive full benefits it will be necessary to develop new methods of burning to produce higher grade and more uniform residues than are now obtainable with existing methods. Therefore, a basic need exists for developing more efficient methods to extract maximum heat from rice husks in a salable fashion consistent with feasible utilization of the residue.

There is a continuing challenge to develop heat-conversion processing units (furnaces, boilers and reactors) for the efficient conversion of rice husk into salable heat and residue. Most existing furnace designs convert about half of the available energy in the husk, which represents the volatizable level of the husk, the remaining heat potential existing in the fixed carbon portion. At least two methods have been developed for converting the fixed carbon heat potential; one uses high oxygen levels in the combustion cycle and the other features infra-red penetration in the transparent frequency range. Either method results in the release of all the heat potential and a carbon-free residue as well as a controlled carbon-silica product.

Also of considerable importance are other methods of conversion such as pyrolysis (for the production of char and oil) and gasification (for the production of producer gas). Several on-going research and development projects are concerned with the individual processes and equipment necessary. A detailed discussion of each possibility is presented in later sections of this paper.

Improved conversion methods should not only be geared toward obtaining maximum energy, but should be equally concerned with producing an improved, consistent grade of residue. Utilization of rice-husk derivatives has been limited because of the lack of uniformity. Higher quality derivatives are needed in a number of applications, including chemical usages, rubber reinforcement, and as a ceramic additive.

The urgency of carrying out heat-related research becomes obvious not only from current energy considerations but also from a consideration of the energy contained in a ton of husk. 6,000 BTU are available in a pound of husk, and a ton of husk replaces 84 gallons of heating oil of 140,000/BTU/gal at a price of 20¢/gal: the monetary equivalent is therefore US$16.80/ton of husk.

The beneficial use of rice husks as a fuel probably dates back well over a thousand years. For centuries, the Chinese burned a mixture of rice straw and husks in an open-top burner for cooking. The resultant black ash (char) was then used as an absorbent for human waste and this mixture spread on the fields as fertilizer. More recently, a furnace designed to utilize rice husks as fuel was developed in 1880 by C.R. Cowie of the English firm bearing his name (3)1/; in a few years every Burmese rice mill was powered with a husk-fired boiler. A portable husk furnace, along with supporting power plant equipment and even a suction gas producer, is illustrated in a 1910 publication which showed the advanced state of the market at that time.

In 1913, P. Poli (181A) suggested research on the utilization of rice husk as fuel. It has been reported that such utilization was practiced extensively in Brazil in 1915, and by 1925 most commercial rice mills in the world were operated by steam engines--generally of British, French or German manufacture, and usually of improved superheat design. Continuing development and use of steam equipment and processes appeared to lag shortly thereafter, primarily as a result of the advent of electrical power. New mills utilized this source of energy or diesel power and many of the existing mills were converted to electricity, which appeared to be inexhaustible, cheaper and a readily available source of power for milling purposes.

Casual interest in rice husks as a fuel began to reappear in the 1950s, but largely as a means to facilitate disposal of the nuisance waste. Some mills were using husks as fuel in their steam boiler furnaces to facilitate their disposal and in several countries many continue to use them. By 1970, the realization that the increasing consumption of energy derived from fossil fuels represented a serious energy problem became firmly established, and interest in renewable energy sources was rekindled. In the United States, there was talk of rejuvenating old technologies and turning to the beneficial use of non-fossil energy resources. In France, interest was aroused by publicity on a German-built automobile that had completed 15,000 miles of tests running on a fuel produced from straw.

It is obvious that the utilization of rice husks for energy purposes is not necessarily confined to rice mills. Husks should be considered as an available raw material in the same manner as any other raw fuel source. The practicality of its use is influenced by the following factors:

1/ Numbers in brackets refer to the Bibliography; numbers preceded by the letter W refer to the list of Workers, Suppliers and Institutions.

- quantity available in each location
- area available
- seasonal considerations
- transportation costs
- low density
- competitive fuels or power sources available.

According to one opinion, a change in point of view would accelerate acceptance of steam-raising equipment throughout the world. Such plants should be viewed first from the steam- and power-generating perspective and secondly as incinerators-furnaces. These plants should be operated only by the most efficient method which is, of course, the heat-coupled or back-pressure method of operation.

An Italian expert insists that any system which will assure full utilization of rice husks for energy purposes requires strict government regulation. Licensing and price control are essential elements, as is mill operation on a regular full-time basis throughout the year, with husk being pro-rated for the most efficient operations.

1.2 GENERAL PROBLEMS

1.2.1 LACK OF VALID DATA BASE

There is a classic approach to good planning. Simply stated, it is to identify the problem, examine the alternative solutions, select the most feasible approach, and implement it. When addressing the problem of rice-husk utilization, whether for energy or other purposes, the underlying problem which thwarts any valid application of the planning process is the almost universal lack of reliable data. Even within a single country, only broad generalizations are possible without adequate and accurate basic information. In most countries (Australia is a notable exception) no entity exists that can provide accurate and timely information regarding the national production and disposition of rice husks. There is usually no inventory of producers, nor, in most countries, of the rice mills themselves, let alone data on husk production, disposal, and utilization. Such utilization information as exists generally comes from individuals on a personal basis and results from limited personal observations. As a consequence, much of the information is incomplete or inaccurate. Usually, the situation in one mill or group of mills is generalized to include all of the mills in the observer's vicinity or experience. Actually, there can be a wide variance between two mills in the same town.

1.2.2 INEFFICIENT MILLS

The lack of data and formal planning, and outside-industry interference of the rice industry throughout large parts of the world, have resulted in many countries in a proliferation of inefficient mills. This inefficiency is a reflection of mill size in relationship to the paddy available as well as the potential utilization of the offal.

In many developing countries, there is a tendency to favour the low head-yield huller mill with its bran-husk mix, which creates a significant problem in most beneficial use, especially if parboiling is a consideration. Steam plants supplying the process steam are feasible only in larger mills.

Conversely, large, highly sophisticated rice mills have been built at great expense in situations that do not reflect the actual needs of the country. Consequently, when they do operate it is only for short periods or at reduced capacity, and they offer little or no overall potential for beneficial usage in energy conservation.

When considering the efficient utilization of rice husk for energy purposes, it should be remembered that this efficiency is a function of the actual amount and rate of paddy processed. In most existing systems for converting husk to steam in white rice milling, the milling units are too small to provide enough efficiency to warrant the capital outlay.

1.2.3 FINANCING

A financial capability is needed to plan, install, and operate viable sized rice mills that can efficiently process the paddy available within a reasonable area surrounding it and make most beneficial usage of the offal, particularly as regards husk utilization for fuel. This calls for new thinking and special consideration by the governments involved to provide the initial capital loans and other incentives to make such an approach feasible as well as attractive. While initial capital outlays are greater in this approach, the benefits to the country justify this higher investment over the long run.

Some countries (Indonesia and Italy for example) currently have a tax based on the basic energy unit. Any use of indigenous fuel under these circumstances will of necessity be taxed to produce the same income. This exerts a tremendous restraint on the utilization of indigenous energy sources--a sort of negative incentive. The government on the one hand is very desirous of encouraging the development of indigenous energy sources, but on the other hand is completely discouraging them. A ready solution to this complex problem is not easily formulated.

1.2.4 THE RICE HUSK ITSELF

There are four distinct problem areas associated with any consideration of rice husk utilization. Firstly, there is the husk itself, which must be disposed of in some manner. Secondly, the quantity of husks varies considerably from one place to another, and this significantly influences opportunities for utilization. Thirdly, there are large variations in local opportunities as well as marketing potentials for the utilization of rice husks and its residue. Finally, the physical and chemical properties of the rice husk themselves are of special significance because they affect handling, storage and utilization.

1.2.4.1 <u>The existence of paddy husks</u>: The morphological development of the rice plant has resulted in the evolution of a protective envelope which must be removed to gain access to the edible rice grain. This envelope is commonly known as the husk or the hull and constitutes about 14 to 26% of the harvested paddy weight. Common milling practice is to remove the husk at the correct time in the cycle to produce the best possible milling yield.

An understanding of what is obvious to all rice growers and rice millers is essential in any consideration of husk utilization. Rice husks are the inevitable by-product of rice milling, but rice is <u>not</u> milled to provide a supply of husks for any utilization scheme. Consequently, the <u>first</u> consideration for any husk utilization scheme is that it be compatible with local milling practices to assure a reasonably consistent source of supply. Next, such schemes must be measured against technical feasibility, the proposed beneficial use, and the realistic distribution potential. The latter aspect is of special significance because to manufacture a product that has no market within the possible distribution range merely replaces one disposal problem by another.

1.2.4.2 <u>Production irregularity</u>: The single most important factor in the so-called "rice-husk problem" is an obvious, albeit unappreciated, one. It is simply the amount of husk available for any projected utilization or to be disposed of. In each instance, significant variations stem from purely local considerations. Additionally, no apparent correlation has been found between the seriousness of the problem and the quantity of rice grown, the rice milled, or the husks available for processing. Thus, the existence of twice as much husk does not double either the disposal problem or the utilization opportunity. Each situation remains unique.

This becomes most apparent by comparing the situations existing in the United States and Bangladesh. In the state of California, the annual rice crop is 2 million tons of rough rice, with a peak production of 1,900 tons of husks per day from the eight mills in the state. This maximum output continues on a seven-day-a-week basis for several months, after which the output is drastically curtailed over another indeterminable period. The peak production periods show no seasonal correlation or predictable occurrence. As a result, any planned utilization of rice husks calling for quantities exceeding the minimal amounts available necessitates that the cash return be sufficient to offset the cost of storing large quantities of husks. Bangladesh is at the opposite end of the production scale. It has an annual rice crop of approximately 19 million tons of rough rice, but 80% of this is milled in the villages by hand pounding, and the commercial portion of the operation is spread among a large number of small mills, the largest of which have production capacities of six tons of husks per day, while most mills produce only one or two tons of husks per day, and in many cases this is huller bran (about 29% of the paddy weight) as produced in huller mills. Thus, it becomes immediately evident that there is little in common between the California and Bangladesh utilization problems. Similarly, the circumstances affecting every other rice-producing area of the world are unique and the most feasible approach to overall utilization concepts is one based upon local opportunity, with all the local conditions becoming weighted factors.

As an obvious result of this situation, most proposals and discussions that appear reasonable to a miller in the United States, with a production capacity of 450 tons of husks per day, are almost unintelligible, if not outright ridiculous, to the Bengali miller whose production is limited to one or two tons per day. Also, the interests of the millers in the other rice producing regions of the world lie somewhere between those of the United States and Bangladesh. Therefore, it is impossible to attempt a single discourse on the problem of husk utilization that will satisfy the needs of the two widely divergent millers while addressing the broad spectrum of problems that lie between the two.

1.2.4.3 Variations in local opportunities and the marketing potential for products: Just as there are broad differences in the rates of rice husk production throughout the world, there are significant variations in the local opportunities for utilizing these rice husk residues. Some of these differences can be attributed to the geographical isolation of the miller from commercial markets and his lack of an aggressive sales orientation. In other instances, no understanding of the distribution potential, in actual distances, exists. Similarly, failure to grasp the concept of beneficial use acts as a deterrent to any improvements in residue utilization.

The desire to develop a technological capability for turning residues into salable commercial products must be tempered with a realistic consideration of the actual marketing potential for these products, including adequate evaluations of the economic feasibility of transportation and of the user market. Conversely, when local opportunity does exist, along with a valid marketing potential, there must be an active willingness on the part of the entrepreneur to project imagination and to participate in a feasible rice husk utilization scheme. In Pakistan, for example, the husks are used as the fuel in the rudimentary "chatti" process of parboiling, yielding a net economic benefit for the miller, who would otherwise have to invest in costly fuel and still dispose of the husks.

A more sophisticated and commercial utilization of rice husks is found in Europe, where Italian husks are sold to a converter, who turns them into ash which is then shipped to Germany and England for refractory use. All of this is possible because a technological market exists along with an adequate transportation system. Small amounts of ash also have been shipped from India to Europe, the miller obtaining a significant economic benefit from the sale of his husks. Additionally, the activities of the converter contribute to the gross national product. However, in this case no utilization is currently made of the husks' heat value, which is all lost through open burning.

Very often, the entrepreneur does not pursue a utilization scheme because he is unaware of how to ascertain the validity of the concept. However, the approach to making such determinations is relatively straightforward; it can generally be considered to be made up of the following basic elements:

- complete familiarity with the properties of rice husks;
- an inventory of locally available sources of supply, skills and facilities;
- maximum utilization of existing literature to permit the valid selection of applicable technologies;
- evaluation of the available market potential in the context of actual market needs. Here, marketing horizons must be limited by practicality rather than provincialism;
- the need for overcoming traditional product use and regulatory barriers by educating potential customers;
- a continuing, aggressive sales campaign.

1.2.4.4 Physical and chemical peculiarities: Rice husks are difficult to handle because of their silica-cellulose structural arrangement, which imparts peculiarities different from those of any other plant offal. No other plant offal even approaches the amount of silica found in rice husks. The peculiar silica-cellulose "drinking-straw bundle" structural arrangement of the husks results in an object that does not burn or even liberate heat in a manner resembling that of any other organic substance. These minute silica-crested tubular structures offer an inherent resistance to burning. Often, they seal off and prevent the thorough, uniform burning essential to obtaining a desired end-product.

In its normally available shape, the protective envelope has an apparent density that is quite low, usually, 7 to 9 lb/ft^3 1/. After grinding, its concavo-convex form remains evident and the apparent density is in the range of 17 to 25 lb/ft^3, well below that normally expected, since rice husks have a true density of approximately 45 lb/ft^3. Some of the properties of rice husks and their derivatives are shown in Chapter 3.

The physical peculiarities of rice husks makes them difficult to store in outdoor piles. They are easily drifted by the wind, and when rainsoaked and decomposing, the piles can be set afire by spontaneous combustion. Dry storage in a warehouse is expensive because of the low density of the husks, and its cost is usually excessive when compared to the value to be derived from beneficial use. However, the size and shape of the husks also permit fluidity and ease of bulk handling using normal conveying equipment. At the same time, their lightness imposes problems in volume handling. For example, conveying equipment that can accommodate 50 tons of paddy can handle only ten tons of husks in the same time period. Additionally, husks have a low inertia and a high air resistance, so that any handling that involves throwing them through the air is rendered relatively difficult. They also cause excessive wear on handling machinery because of their high silica content. However, the adaptability of husk to pneumatic conveying is an important feature utilized in most husk handling systems.

1/ For conversion factors, see Appendix

Chapter 2: GENERAL ENERGY CONVERSION CONSIDERATIONS

2.0 INTRODUCTION

Rice husk can be converted to energy through the use of a number of different technologies. In many cases it cannot be said that a single technology is being used in a given process, a number of different situations being involved in the transition of the raw husk to an energy form and the resulting residue, because of overlapping reactions and split reactions. The difficulty is compounded by contradictions in definitions, since there seems to be no definition that is agreed upon by all workers in almost any phase of energy conversion. Appendix contains a list of definitions and terms as they are used in this report.

Processes and technologies exist today for extracting energy from rice husk at quite high efficiency levels. Methods have been developed for converting fired carbon heat potential; one features infra-red penetration in the transparent frequency range, which results in the release of all the heat potential and the production of a carbon-free residue. This process also offers the advantage of producing a product of any desired carbon/silica ratio, to enable further by-product utilization. (See also Section 5.3.1.4.)

Characteristics of rice husk combustion have been discussed for many years--formally since about 1880 (Cowie). One of the best and most descriptive was written by Burrows (109A):

> "Rice husks are flame retarding and, at ordinary temperatures, self-extinguishing. A lighted match, tossed onto a pile of rice husks will generally burn out without producing a self-sustaining flame in the husks. Heated in a crucible over an open bunsen flame, the husks produce a flammable gas and smoke, which ignites, leaving a black cinder of almost the same size as the original husk. Distillation of the husk decomposes the cellulose to carbon and steam, driving off volatile residues and tars with the steam. Neither ignition nor distillation removes the carbon residue from the cinder, nor does any silica, as such, become apparent in the cinder at this stage. Heated to a red heat, in a stream of air or oxygen, the carbon is partially or completely burned off as carbon dioxide, leaving residues of carbon-silica or silica.
> In attempting to maintain a red heat within a column of husk cinders, without external heating, for sufficient time to completely remove the carbon, one is faced with very delicate requirements of draft control, cinder size distribution, column wall insulation, oxygen level in draft air, etc. In preliminary experiments, we have produced a product, utilizing controlled forced draft, but no heat other than the heat of combustion of the cinder, and no supplemental oxygen in the draft air. With additional heating and an increase in the oxygen level, the carbon is completely burned off, the residue consists of microparticulate silica."

In the following sections, each of the various methods or technologies available to effect the conversion of rice husk to energy is discussed.

2.1 BURNING IN AN EXCESS OF AIR

Although the energy in the husk could be released directly by burning, there are several reasons why this is not always the answer. Raw husks cannot be easily stored and do not burn cleanly or easily. Energy recovery efficiency is low or non-existent.

In a simple form, the energy released cannot be stored, but must be used as it is produced. The combustion products may be corrosive or pollutants. Finally, the supply of husks may be irregular, seasonal, or otherwise erratic, out of tune with energy demand. Therefore, excess-air burning or use of a field-burning disposal system is possible only in special circumstances.

In situations where the amount of gas transferred is more than the amount of air necessary for efficient, clean combustion, an external combustion chamber may be called for. When combustion is completed in the separate combustion chamber at low excess-air rates, process efficiency (in terms of net heat production at minimum flue-gas volume) is maximized, and reduction in the size of the air pollution equipment required is obtained.

2.1.1 BURNING IN AN ATMOSPHERIC PILE

If the pile is very thin and there is some air blanket turbulence, as on an open field, true burning will occur. It will also occur in an air-suspended burner or furnace. However, as soon as the unburned mass is brought up to a temperature of about 350°C, decomposition sets in, and the volatile component of the husk distills off and will flare upon ignition if given the chance in the configuration of the action.

Except in a driven-wind situation, a thin outside pile without other fuel generally acts as if in a controlled atmosphere, which it is, because it does have a CO_2 blanket control system.

Very seldom will thermal convection be sufficient to create excess-air burning conditions unless there is sufficient externally induced turbulence.

2.1.2 BURNING IN A CLOSED AREA (INCINERATION)

Incineration is a combustion process designed to reduce the weight and volume of a waste on a controlled basis. The term is used only for burning materials for disposal, and in this respect differs specifically from the term "pyrolysis".

An incinerator for husk would be a closed area or vessel built specifically in which to burn husk for disposal. Some of the burning buildings in France could be called incinerators, and there are probably other areas in which a formal burning-disposal enclosure is used.

A properly designed incinerator with an adequate stack for draft and a simple step grate could automatically solve many of the problems of husk disposal in various parts of the world, Malaysia being one. The only requirement would be an ash removal system that operated simply and efficiently and was of adequate capacity.

2.1.3 BURNING IN A FURNACE

2.1.3.1 Traditional style: In furnace burning, the resultant product and type of burning depend on the grate system employed and the depth of material on the grate; also relevant are the radiation derived from the interior surfaces of the furnace, and the flow of air through the grate.

In general, the more benign the furnace, the greater the percentage of heat conversion, and the lower the carbon in the ash available. However, this is not compatible with high-ratio output, so most furnaces are somewhat of a compromise in design. In some boilers, design parameters allow husk burning in the tubes; in others, attempts are made to allow no unburned material or residue to enter the tubes. If this is the desire, the design of the furnace must be such as to ensure that the gas flow is settled out in the furnace section, so that the residue can be removed in the furnace section, with no particulate matter entrained at the entrance to the boiler tube sections. If natural draft is employed with no scrubbing or filtration, the tubes must have an adequate section, so as not to create an excessive pressure differential. In this case, attention must be given to the furnace design to ensure that no particulate enters the tube section, as the velocity of gas in the tubes may not be sufficient to convey the particulate matter through. In some cases it is advisable to use a steam soot-cleaning system, which will also scour the husk residue that would otherwise insulate the tubes, lowering the operating efficiency of the boiler.

There is a great range of efficiencies in the various designs of grating systems, as in furnace design as a whole. No results are available to indicate the value of one system as compared with another. As a standing rule, it is felt, as was recommended by B.R. Wolf, that for natural draft systems or furnace discharge, induced-draft systems must not create over 1.0 m/sec air flow through the grate in order to ensure the retention on the grate of the particulate residue. Of course, this limit dictates the size of the grate, as the necessary combustion air for any given quantity of husk can be calculated.

A furnace carrying the residue through the tubes requires a velocity of not less than 3.5 m/sec. The furnace tubes should not be less than 70 mm (2.8 in) in internal diameter; too small a tube will aggravate the tendency for tubes in certain areas to plug. The head areas must be adequate in section so as not to create air-flow channels which will deprive certain tubes of equal pressure drop. Well designed and adequately sized fire-tube boilers conveying all of the husk residue through the tubes have operated for many years without any maintenance whatsoever other than the required annual cleaning and inspection. Following direct questioning and inspection, the author has never found a single case of wear of inlet radii and thinning of tubes.

2.1.3.2 Air-suspended: Air-suspended turbulent cyclonic furnaces can be described as

- direct fired
- tangentially fired
- top extraction
- bottom extraction

Several modern facilities using suspension-burning principles may be divided into two categories: those which suspend the burning fuel in the gas stream in the combustion enclosure, and those which suspend it both in the gas stream and in another medium: the fluidized bed. Although the principles are not new to the power or process industries, the application of suspension burning to husk-fueled power systems is innovative at this time. Advantages of flue-gas stream suspension burning include a more rapid response to automatic control, an initial cost saving due to the lack of grate surface and mechanical stoking devices, and the ability to achieve complete combustion with a much smaller percentage of excess air in the furnace (which represents a significant economy where the husk is a useful fuel and every BTU has a value).

A good example of the direct-fired type is the Gariboldi smoke-tube boiler system, in which a portion of the heat is released in the furnace, and burning continues while in the boiler tubes. A tangentially fired power system external furnace is typified by the Pitts combustion chamber.

2.1.3.3 Fluid-bed furnaces: Fluidized-bed suspension burning systems have all of the advantages of the flue-gas stream suspension, plus one which is important where a system must operate intermittently (e.g. one shift per day). Fluidized beds, usually sand, comprise a "thermal flywheel" of large capacity. When the operating temperature is reached, they retain heat over a long period, losing only about 110°C during an overnight shutdown. The savings on auxiliary fuel for preheat on the next start-up are appreciable and tend to offset fuel preparation costs.

A unique use of the fluid-bed furnace principle is typified by that described in UNIDO-ID/WG 89/20, Use of inert media (sand and paddy husk powder) in simultaneous parboiling and drying of paddy, by N.G.C. Iengar and R. Bhasker. However, no commercially installed fluid-bed furnace working on raw rice husk is known to the author, though the "Copeland" furnace has at various times been suggested for that use. One objection to fluid-bed furnaces is their high power requirement and capital outlay, and except in very special circumstances it may be difficult to justify their installation. (See also Section 6.3.2.5.)

2.1.3.4 Allowable heat release: It would, however, be interesting and educative to determine the allowable and possible heat release in an air-suspended combustion system using a cyclonic furnace, in practice similar either to the Pitt or Finch designs. The author has no knowledge of any proprietary investigation to determine its advantages or disadvantages.

2.1.3.5 Spot heating: In an air-suspended burning system, each particle of husk volatilizes and burns individually. Usually in this type of furnace the resultant char product is partly crystalline or has very low carbon content when the uncontrollable temperatures and varying air/fuel ratios create individual hot spots. This can be seen in practice: in general there is a black char residue, but upon examination small silver flecks or grey blacks seem to be visible. These are the grain or portions of the grain that either were exposed to a different temperature/air fuel ratio or differed in some way in residence time from other particles or pieces of particles.

In an air-suspended excess-air furnace, it would appear to be difficult to obtain a constant and homogeneous level of product.

2.1.4 FINE-PARTICLE FUELS

For many years, occasional interest has been expressed concerning the practicality, effects and efficiency of burning finely divided fuels. In the literature available, only one reference--Ramzin (182)--shows any effort to learn about the effects of use of rice husk as a fuel of fine granulation. It would appear that only under the most special conditions would the cost of grinding husk to a fine powder be justified. Rice husk is a very abrasive material and is possibly the most expensive agricultural by-product to reduce in size. It would appear, however, that transport considerations would make it feasible to crack (grind coarsely) the husk. A very low cost grind through 1/4" to 3/8" hammer-mill screens will raise the density from 8 to 17-18 lb/ft^3, making the transport or collection of the husk profitable.

2.2 BURNING IN A CONTROLLED ATMOSPHERE (BCA)

This situation is very close to all of the other methods of conversion, but in a simplistic view of things.

BCA is very close to distillation, gasification and pyrolysis, and assuredly some readers will differ with the following classification and definitions used.

In order of completeness of coverage, the list of means of heat conversion includes:

- burning in a controlled oxygen situation
- gasification
- distillation
- pyrolysis
- carbonization
- thermal decomposition

each lower classification being a little less comprehensive than the preceding one.

In this paper, "distillation" is used when discussing a process in which the gaseous portion is fractioned out to a range of products similar to those investigated comprehensively in the years before 1940; "gasification" normally refers to generation for gas use purposes, such as producer gas generators. "Pyrolysis" and "pyrolytic conversion" are generally used to express the current ideas of conversion to synthetic fuel oils, chars, gases, etc. For all these terms, the process is the same: heat decomposition under controlled-atmosphere conditions.

According to Lewis (120A), "A number of process variables determine the ultimate yield and final composition of the solid, liquid, and gaseous products from pyrolysis and gasification. For pyrolysis processes, the major variables are chemical composition of raw material, heating rate, and ultimate material temperature. One conclusion that may be drawn, based on several investigations of these and other process parameters, is that the complexity of these interactions makes it impossible to predict the final product characteristics."

2.2.1 Burning in an atmospheric pile: While it is normally thought that open pile or atmospheric burning is essentially an excess oxygen situation, in reality it is not, in ideal conditions. This is because the process is self-limiting by the CO_2 blanket and controls itself to regulate automatically the gas formation and generation-distillation by blanket control and oxygen access. Practically, however, this does not happen, as the air currents around such a pile disturb the blanket. By mass configuration there is some control on the resultant analysis and phase result. In other words, if a purely amorphous product is desired, the pile configuration must be such that internal temperatures do not rise above about 900°C, a temperature at which amorphous products crystallize. The radiation and convection from the mass must balance the rate of heat release from the decomposition to hold the temperature in balance. In the ideal pile, atmospheric process is closer to pyrolysis than to burning.

2.2.2 Burning in a closed area or volume: This is more fully covered in a later section on burning buildings (see Section 5.3.2.6.). In this type of burning it is usually possible to maintain control of the oxygen input and, the whole activity taking place within the walls, there is no disturbance of the inert blanket covering the pile. A natural thermal convection creates a slight draft through the pile, but the lower air control keeps the temperature at any desired level. One of the problems of burning raw husk in a building involves the gasification of the mass and subsequent flaring, which is less controllable than the carbon burning sequence. In a US patent, Hughes (169) considered that by first volatilizing in a distillation-type converter and then burning the char under controlled conditions in the enclosure, a marketable product might be produced. The problem here was to retain sufficient heat in the mass to ensure continuation of the conversion. Otherwise, when the proper amount of oxygen was introduced, the cooling effect would eliminate any possibility of further burning.

A similar problem has been considered by Burrows (109A): "It has been demonstrated that the charred hulls produced may be oxidized by air to a form in which silica is predominant, most of the carbon being burned off. This requires special equipment to confine the heat of combustion and to control the air feed rate. For some applications, it might be desirable to retain more of the carbon, utilizing the combination process to increase the silica-to-carbon ratio and achieving some activation by opening additional channels for absorption. This could be accomplished in the same equipment by simply increasing the air flow rate."

Brick firing (in "burnout brick") is another example of burning in a closed area. The energy contained in the husk mixed in the body of the brick is liberated when the brick is baked in the kiln, and the energy value of the entrapped husk is added to the value of fuel used in calculating the total energy supplied. The burning of the husk in the brick is under very controlled conditions, and gasification develops because of the porosity of the brick.

2.2.3 Infra-red burning: The controlled processing of rice husk using infra-red penetration has been developed in recent years. The infra-red radiation from the incandescent overbody heats the husk to burning temperature, while the counter-current air coming through the belt cools the belt and furnishes sufficient and controllable combustion air. No other type of burner can do this.

The total heat used for kindling and radiant energy in the second stage and the total heat release of the husk in the machine can be captured in the conversion sections of the system with ducting above the afterburner to boiler section. It is the only way a large-particle, low-density, amorphous ash can be produced commercially.

2.2.4 Enriched-air combustion: For some applications of microparticulate silica in industry, it is necessary to have a silica essentially free of coloured matter (predominantly black); for such applications, it is necessary to carry the combustion to completion, burning off all the carbon. This can be accomplished by adding just enough oxygen to the air stream to maintain the conditions of complete combustion. A very moderate increase in the oxygen level of air suffices.

However, one drawback to such a use is the fact that the carbon is not the only impurity present in the ash. There is also a residue of about 5% of other compounds and fluxing agents intimately mixed in the silica matrix, composition varying with both the variety and geographical planting location. The commercial practicality of rice husk as a silica source has never been demonstrated.

2.2.5 Other controlled burning: Several similar methods and apparatus developments are in existence though none have attained any commercial viability. Three of these are Kocee (170), Gravel (167) and Finch (168).

In 1970 Thomas (155) studied the physical makeup, ashing and decomposition of husk. The results of this work were widely reported and have proved most helpful to many workers.

2.3 DESTRUCTIVE (DRY) DISTILLATION

This is a process in which substances are heated (600-1000°C) in the absence of air or oxygen so that thermal decomposition occurs and gases and vapours of the decomposition products are passed to a collecting and condensing system. A solid non-volatile residue remains when the process comes to an end. The term carbonization is often used for such a process.

Bituminous coal is subjected to destructive distillation in large quantities to produce coke, coal tar, and coal gas.

Large quantities of wood were formerly subjected to destructive distillation to produce methanol, acetone and other chemicals. Such destructive distillation processes could not compete economically with synthetic methods, but charcoal is still produced by destructive distillation (W19).

The recovery of oils and chemicals from oil shale or tar sands requires that these be subjected to heating in the absence of air, and this process is therefore at least partially an example of destructive distillation.

The terms cracking, pyrolysis, and thermal decomposition have the same general meaning and are roughly synonymous with destructive distillation. The latter, however, is applied particularly to coal, while cracking refers most often to petroleum. Pyrolysis and thermal decomposition are used more generally.

Depending on operating conditions, husk will yield char, tar and pitch, light oil, organic acids and alcohols, ammonium sulfate, and gases. These products (Table 1) can be separated and sold or used as fuel.

TABLE 1

Products of destructive distillation of rice husk

(Source: 118)

Product	Percent by Weight	
	Min.	Max.
Liquor	40.90	43.20
Charcoal	37.10	39.80
Acetic acid	2.99	3.58
Methanol	1.30	2.07
Acetone	0.41	0.81
Loss (by diff.)	17.30	10.50

Most so-called distillation units are either controlled-burning or pyrolysis units. Distillation is used in this paper to describe a process in which the fractions are utilized in an identifiable production. It is usually used to describe older (1910-1950) work. Most recent work can more correctly be called pyrolysis.

When rice husk is heated in the absence of air to about 320°C, spontaneous decomposition takes place, with a generation of heat. The residue is charcoal and the vapours on condensation result in a gas of low calorific value and a water solution which, on distillation, can be separated into methanol, acetic acid and tar. The charcoal formed is finely divided and difficult to remove from the process. The methanol and acetone are commercially produced today in synthesis plants at a lower cost. This competition apparently renders the use of rice husk uneconomical.

There are a number of good background papers on rice husk distillation. Vigino Francesco (142A) obtained at 700°C from 100 kg of husk: gas 26 m^3; distillate 20 kg containing 4% acetic acid; tar 5 kg; and 40 kg of carbon containing 38% ash. Marcusson (125) at a lower temperature (200-300°C) obtained: gas 20 m^3 of about 2700 calories; distillate 33 kg; tar 6 kg; and carbon 41 kg.

According to data received from Iyengar (W129), further distillation of the tar portion produces a gas containing 21% CH_4, 18% H_2, 27% CO and 31% CO_2.

TABLE 2

Analysis of rice-husk distillate

(Source: 142A)

Acetic acid	7.32%
Acetone	.91%
Ketone	.05%
Methyl alcohol	trace
Alcohol	.01%
Tar distillate 100-125	2.80%
Tar distillate over 125	2.70%
Tar mineral	.04%

Possenti (129; 130) and Borasio (108) also did considerable analysis and presentation of distillation products. Fieger reviewed progress in his report (219) as did Tucker (229) in his thesis, on which Fieger's paper is based. A good overall study and presentation on a modern level was made by Staäckman (228). The general feeling has been fairly negative, and this has been borne out by the lack of commercial use of this method.

The only commercial rice-husk distillation units known to the author to be operating are usually used only as char producers or disposal units, and the excess flue gas is flared off.

2.4 PYROLYSIS

Pyrolysis is the name given to the transformation of a compound into another substance or substances by heat alone. Although the term frequently carries the implication of decomposition into smaller fragments, there are many examples of pyrolytic change which involve either isomerization with no change in molecular weight, or building-up reactions (polymerization) giving rise to compounds of higher molecular weight. Hence, the term "pyrolysis" is broader in its scope than "thermal decomposition".

Like incineration, pyrolysis is a controlled-combustion process. Unlike incineration, however, pyrolysis does not imply that a waste is being burned; in fact, the pyrolysis process has been used for years by industry (e.g. production of charcoal and methanol from wood, and coal gasification). The process requires raising the fuel to a temperature at which the volatile matter will distill (boil off), leaving carbon and inert material behind. The carbon and volatiles do not burn in the process, owing to an intentional deficiency of air in the primary reactor. Volatile matter may be burned off as waste in a secondary chamber to which air is added, or may be cooled and condensed to selectively recover oils and tars. Alternatively, the gases may be cleaned and used as a gaseous fuel.

By contrast, however, solid residues from processes may be marketed as charcoal or as a filtre-absorbent for use in waste-water treatment. Since the process involves combustion in an air-deficient atmosphere, the volume of off-gas is lower than with incineration--a large benefit for air-pollution control. The combustible gas is seldom emitted, however, and is usually burned as a fuel or processed for recovery of hydrocarbons.

The potential of agricultural residue pyrolysis as an effective method of capturing renewable solar energy is well documented. Traditionally, agriculture has been considered a source of essential calorific energy to drive the biochemical engine of man. There is no reason to prevent the industry from providing calorific energy for other applications-heating, electric power generation, etc. Unfortunately, the latent heat energy of agricultural residues is not in a suitable form for utilization in these applications. However, pyrolysis represents an excellent method for converting this latent heat energy into a useful form of energy: high-temperature producer gases. The problem has been to find an efficient, low-cost pyrolyzer with large-scale throughput. Several such systems are described below.

As compared with hydrogenation and hydrogasification, pyrolysis has the advantage of operating at normal atmospheric pressures, reducing construction and operating costs.

The oxygen-free atmosphere is obtained by recycling a portion of the product gas. Heat requirements for the process are in the range of 500° to 900°C. The importance of this process lies in the fact that it yields multiple products, all of which are combustible without polluting the environment. Depending upon the feed, 90% or more of the energy in the feed can be recovered as low-sulphur fuels that can be burned by conventional methods. This results in the production of an easily convertible, transportable or storable high-grade fuel from low-grade fuel. The process of making charcoal by pyrolysis dates back to 2000 B.C. Pyrolysis is used in the manufacture of coke, coal being heated in the absence of oxygen to drive off the major fraction of the volatile organics. The fuel gas produced by this process is known as coke-oven gas.

Pyrolysis reactor designs include the fluidized bed and vertical and rotary reactors. The main reactor criteria are the method of heating (indirect or direct), feed condition, temperature of reactions, and air pollution considerations.

An allied development which, although it has never directly used rice husk as the input, nevertheless shows promise of development along that line is the pyrolytic converter of the Georgia Institute of Technology (W178). The output is in the form of sterile char. No use is currently made of stack heat but any form of waste heat utilization would be possible.

The Wallace Atkins Oil Corp (W223) has offered, on a proprietary basis, a pyrolytic process for conversion of rice straw and husk to usable oil, gas and char. No definite information is available.

Garrett (W179) has operated for several years a federally funded research project designed to demonstrate the economic and technical effectiveness of the flash-pyrolysis process to convert agricultural wastes, including rice husk, activated carbon and heating oil being produced as by-products. A modified 4-ton/day pilot plant has been operated utilizing rice husks to provide process engineering data for the design of commercial-scale demonstration plants. Results on the laboratory pyrolysis reactor show a recovery of 40% synthetic oil; 33% char; and 8% gas.

Detailed descriptions of several similar processes are set out in other sections of this report (see Sections 5.3 and 6.5).

Pyrolytic processing of husk is involved in the production of silicon tetrachloride ($SiCl_4$) (233, 234), as the first step in the manufacture of $SiCl_4$ from rice hulls must be the pyrolysis of the hulls. In this step, drying occurs, followed by decomposition of cellulose and saccharides to carbon and water vapour, and cracking of other organic compounds to carbon and volatile substances. The pyrolysis gas thus contains a variety of organic compounds, some of which are condensable, but it is essentially free of inorganic particulates. Residual hydrogen content must be very low to prevent excessive consumption of chlorine, and residual water must be negligible to prevent hydrolysis.

A new system has also been developed for resource recovery from solid wastes by pyrolysis using high-power plasma arc torches. The commercial applications of this process applied to rice husk are not known.

The US Bureau of Mines has done considerable work on pyrolytic conversion of agricultural products, some of which is applicable to rice hulls. Crentz (174) produced a scrubbed pyrolysis gas with a 74% energy recovery. However, no direct rice-husk work appears to have been done by the Bureau of Mines.

2.5 GASIFICATION - PRODUCER GAS

When rice husk is burned in the presence of only a limited supply of air, it gives rise to a mixture of gases, known collectively as producer gas, consisting principally of carbon monoxide and hydrogen, which are inflammable, and the non-inflammable gases carbon dioxide and nitrogen. If water vapour is introduced into the generator the proportion of hydrogen in the mixture is increased.

The use of this gas mixture in internal-combustion engines has been practiced for many years, but has been confined chiefly to the stationary engine, in which the weight and size of the necessary generator and cleaners are unimportant. Its successful utilization as a fuel for motor-powered vehicles presents difficulties, but from time to time efforts have been made to adapt it to them. During World War II, producer-gas-fueled vehicles were extensively used in many countries.

Countries most interested, for both economic and political reasons, in the utilization of producer gas as a source of power are those dependent on foreign supplies of oil.

Producer gas can be utilized for drying purposes, for steam generation, for partial substitution of SNG in internal-combustion engines, for the generation of electricity or for other commercial heating usage. It can also be used to replace or supplement liquid fuels if the burner or engine is equipped with the proper mixing and control mechanisms.

During World War II, rice-husk-derived producer gas was used to supplement the town gas system in Vercelli, Italy. The mixture used (59% fossil gas of 4350 cal and 40.5% rice-husk gas of 1500 cal) resulted in a net 3200 cal gas, yielding an overall saving of 23% of the coke requirements of the town's system.

Also, a few rice mills utilized rice-husk gas derived from fueled producer-gas units for fuel for paddy trucks, bottled at about 200 atm.

In Italy during and immediately after World War II there were 57 rice-husk-powered rice mills. Only one remained with the installation intact in 1975. It has recently been reported that a rice mill at Kouroma, Mali, is powered with a Chinese producer gas/ic engine system.

The principle involved in a gas producer is the combustion of carbon in the presence of some oxygen to produce, first, carbon dioxide and then, with further reduction, carbon monoxide. The burning conversion of one pound of carbon directly to carbon monoxide produces 4,451 BTU. If the carbon monoxide is caused to combine with fresh oxygen any time after it leaves the gas generator, this second combustion process produces 10,093 BTU. The producer-gas heat value per pound of carbon is then 14,544 BTU (123).

Producer gas can be used to operate internal-combustion engines, to fire boilers, as a fuel for gas dryers to dry any commodity-air (fluid or direct-contact), for kilns (either tunnel or rotary) or for heat-treatment furnaces.

From 100 kg of husk, Possenti (129) produced 100-130 m^3 gas, 2-4 kg tar, 20-25 kg carbon, 1.22-1.24 kg/m^3 density of gas with a heating value of 1300-1600 $kcal/m^3$.

TABLE 3

Producer-gas analyses under varying operation conditions (Balestra distillation unit)

Gas	Content
CO_2	4.2 - 7.7 %
O	2.4 - 2.8 %
H	4.8 - 7.8 %
CH_4	7.2 - 4.5 %
CO	25.0 -22.7 %
N	56.4 -54.5 %
Heat	1586 -1350 $kcal/m^3$

1 hp/hr requires 1.8-2.4 kg of husk, assuming 20-22% efficiency.

It is possible to produce a generator gas of 2500 kcal/m^3, as compared with the 8000 kcal/m^3 of natural gas.

In experimental work by Maheshwari et al. in 1974 (178; 179) a gas was produced with an approximate analysis of CO_2: 8% CO: 16% N_2 + other: 76% with a heat value of approximately 150 BTU/ft^3.

Another comparison of gas composition and comparative caloric values of wood blocks, sawdust and rice husks is shown in Table 4.

TABLE 4

Gas composition and caloric values of rice husk and other fuels

	For Reference		
FUEL DATA	Wood Blocks	Sawdust	**Rice Husk**
Net. Cal. Value per lb (dry)	7,750 B.Th.U.	6,350 B.Th.U.	6,340 B.Th.U.
Fixed Carbon	18.7 %	20.67 %	17.4 %
Moisture	0.0	0.0	0.0
Volatiles	77.0	78.4	60.9
Ash	4.3	0.93	21.7
Lbs./B.H.P. (Dry)	1.75	2.2	2.2
Lbs./B.H.P. (29% Moisture)	2.2	2.8	2.8
CO_2	6.9 %	12.2 %	3.0 %
O_2	0.2	0.8	0.4
CO	28.1	18.2	32.2
H_2	13.9	10.2	6.4
CH_4	3.7	3.2	0.6
N_2	47.2	55.4	57.1
Cal. Value per cu. ft. gross at 60° and 30"	170 B.Th.U.	123 B.Th.U.	135 B.Th.U.
Cu. Ft./Lb. of Fuel (Dry)	32	33	30
Cu. Ft./Lb. of Fuel (20% Moisture)	25	26	24

excerpt courtesy Power Gas Corp.

The calorific value and the percentage of combustible gas varies according to furnace design as well as the presence of wet or dry gas. Table 5 shows the results obtained with different types of producers.

TABLE 5

Combustible gas produced under varying conditions

Type	Production of combustible gas
1. Up-draft dry-gas producer	37.5%
2. Up-draft wet-gas producer	44 %
3. Cross-draft dry-gas producer	37.5%
4. Cross-draft wet-gas producer	38.5%

The calorific value of the gases gives the advantage to No. 2 which is about 13% higher than the other types, owing to the presence of water gas. The development of wet-gas-type producers with the necessary filtres and scrubbing can increase the thermal energy of the gas by approximately 11%, with a 14% increase in combustible gas.

A primary advantage of gas-producer systems is that minimum attendance is required. The system is relatively simple in design and thus maintenance is nil. One of the most critical design requirements is the removal of ash from the producer. It is important to note that depending on the ultimate usage, the producer gas may or may not require a filtring and scrubbing system to remove entrained particulates.

In summary, rice husks can be economically gasified to produce a combustible gas with a calorific value of approximately 130 to 150 BTU/ft^3. This producer gas can be utilized to drive a gas engine or turbine-generator or to provide steam to drive a rice mill or electric generator in the range of 5 to 220 HP or even higher. Coupled with generating units, these gas engines would prove a valuable source of power for general industrial and lighting purposes, and particularly for developing the rice industry. They can provide an ample and cheap power supply for irrigation pumps, farming equipment, milling plants and by-products processing installations.

As a practical circumstance, the local- or farm-level unit must be able to use any indigenous fuel, not only rice husk.

Working on current projects involving the construction of experimental gas producer generators and test systems are Paras (W135) and Cruz (W136). Horsefield (W219) is currently involved in design and application work. There are undoubtedly many more workers in different institutions and laboratories all over the world studying, designing and constructing such equipment. It is difficult to identify them except by chance or when their results enter the publications and reference systems. Equipment for gas producer systems is discussed in Section 6.5.

2.6 OTHER CHEMICAL, THERMO-CHEMICAL AND BIOCHEMICAL PROCESSES

2.6.1 BIOCHEMICAL FUEL CELLS

Some popular interest was generated several years ago by a popular article by Halacy (177A), describing biochemical fuel cells, their development, history, and operation. The background information cites the various scientists and government and private agencies engaged in the development of such devices. In one type of biochemical fuel cells, rice husks (hulls) are employed as an activator or electrolyte "carrier".

"In a more specific sense, the properties which characterize biochemical fuel cells may be summarized as follows:

(i) Biochemical fuel cells require mild conditions of electrolyte concentration and temperature.

(ii) Unusual and complex reactants may be used such as natural products, vegetable or animal matter (either freshly produced or waste) and as oxidant oxygen, or air or oxygen containing anions which occur naturally and in sea water.

(iii) Catalyst regeneration may be continuous, therefore the cell has a very long life.

(iv) The operating power density is likely to be very low. Typical fuels can be prepared from carbohydrates, fats, or proteins. Examples of the carbohydrates are waste cellulose starch or sugar solutions. These are regarded as primary fuels which have to be degraded into simpler substances such as glucose before they can be thought of as electro fuels." (Hart)

2.6.2 COMPOSTING - MULCHING

Rice husk serves as a compost or mulching agent in several manners: as a moisture retention helper or as a weed growth inhibitor, the heating effect of the pile of husk while decomposing assisting in the sterilization of the soil. When rice husks are mixed with sewage sludge and allowed to heat properly, a sterilized, odourless mulch results. This process, "Tillo" (W207) utilizes the energy of decomposition only to cure its own matrix.

2.6.3 WASTE HEAT

The recovery or utilization of the waste or stack heat from any rice-husk conversion process represents a special form of conversion: that from an unusable reservoir of heat to a captive convertible source. Any process which generates heat can be utilized as the source of waste heat; only economic factors can determine its inclusion or rejection as part of the overall energy system.

2.6.4 FERMENTATION

"A process has been developed by the USDA-NRRL, using the organism clostridium acetobutylicum, for fermenting xylose or pentose sugars obtained from agricultural residues including rice husk to liquid fuels or solvents. H.M. Tsuchiya, J.M. Van Lanen, and A.F. Langlykke, U.S. Patent 2,481,263, September 6, 1949." Lathrop (223).

No other reference to a fermentation approach to rice-husk energy conversion has been found in the literature.

2.6.5 HYDROGENATION

Hydrogenation, also called deoxygenation, is a chemical reduction reaction in which oxygen is abstracted from cellulose by carbon monoxide and steam, under 100 to 250 atmospheres pressure, at temperatures between 240° and 380°C in the presence of as much as a 5% alkaline catalyst. Using appropriate combinations of these conditions, dependent upon the type of catalyst and reacting waste materials, 99% of the carbon in the waste material can be converted to oil. Quantitatively, this gives a product yield close to 2 barrels oil/ton dry husk, ash-free basis.

A release from India reports as follows: "Hydrogenation of Agricultural Waste: bench scale experiment on the conversion of paddy husk to fuel oil by reaction with CO and water gas in presence of catalyst and water has been carried out in 500 ml autoclave.

Under optimum conditions more than 99 percent of organic matter in the husk was converted into liquid and gaseous products. Out of this 40-50 percent is benzene, soluble liquid product and the rest is gaseous products." (Annual Report, 1973/74: CFRI Jealgora, Dist. Dhanbad, Bihan (W59)).

It has been indicated that the principal cost factors are the high capital investment for high-pressure equipment and the cost of the carbon monoxide. With the uncertainty of these costs and some unresolved technical problems, no one is willing or perhaps able to estimate the economic feasibility of a full-scale plant.

There appears to be no indication of commercial activity regarding the hydrogenation of rice husk.

2.6.6 ACID HYDROLYSIS

Acid hydrolysis converts cellulose waste into fermentable sugars (glucose) by heating the material with an acid at an elevated temperature. The sugars can then be fermented to produce ethyl alcohol, citric acid, animal fodder, and other useful substances.

Iyengar (W78) has mentioned acid-hydrolysis conversion of rice husk to sugar and to methane as a distinct and attractive possibility. Other than indirectly (furfural), no utilizable hydrolysis processes for energy conversion utilization are known.

2.6.7 SINGLE CELL PROTEIN (SCP)

Research efforts to produce SCP by direct fermentation are centred on two approaches --one by W193 and the other by W180. The processes are initially similar, but use different cultures and conditions. Interest concerning rice husk as a cellulosic source is, however, essentially academic.

2.6.8 ENZYMATIC HYDROLYSIS

Processes operating under mild chemical and physical conditions have been developed (U.S. Army NATICK Laboratories, Natick, MA, USA) utilizing a cellulase-producing microorganism to break down the cellulose, glucose being the final product. Yields of up to 80%, glucose basis, have been achieved. The glucose, in solid or syrup form, can be utilized either for nutrition or fuel. Current association with rice husk has been limited to composition references in published literature.

2.6.9 WET OXIDATION

Wet oxidation converts cellulose waste into carbon monoxide, carbon dioxide, a mixture of organic acids, and a solid fibrous sludge by heating the material under pressure with water and oxygen.

No references have been found to the use of this process in the conversion of rice husk to energy.

2.6.10 HYDROGASIFICATION AND HYDROCARBONIZATION

Another process (developed by the Bureau of Mines' Pittsburgh Energy Research Center) which converts waste to a usable fuel is hydrogasification. The process reacts any carbonaceous feed material with hydrogen at pressures around 1,000 psig, and temperatures near 650°C. In contrast to hydrogenation, hydrogasification yields a pipeline-quality gas as a product consisting primarily of methane and ethane.

There appears to have been no work of this type concerning rice husk.

2.6.11 CATALYTIC CONVERSION OF SYNTHESIS GAS

A little-considered substitute or auxiliary fuel is methanol. If small amounts of other alcohols, such as ethanol, propanol and isobutanol, are mixed with methanol, a new product with a higher energy value results: methyl fuel.

There are several processes available for producing methyl fuel, but only two of them are on a commercial scale. The developers and manufacturers of these processes are Imperial Chemical Industries (Davy-Powergas) (W157) and Vulcan-Cincinnati Inc. Both produce methyl fuel by a catalytic conversion of synthesis gas. Synthesis gas (carbon monoxide and hydrogen) has been in production for many years. Traditionally, it has been produced from methane or coal, but it can be produced by the partial oxidation of any carbonaceous fuel. Synthesis gas itself has been in use by Europeans without further conversion.

In addition to automobiles, methanol has been suggested for use in home heating and as fuel for burning at steam electric-generating stations and for fuel cells.

2.6.12 ANAEROBIC DIGESTION (BIOGAS PRODUCTION)

Anaerobic digestion employs anaerobic bacteria to convert cellulose waste, at high temperatures and in an oxygen-free atmosphere, into methane, carbon dioxide, hydrogen sulfide, and a solid residue.

No practical instance of either mesophilic or thermophilic digestion of rice husk is known to the author. Rice husk is not sufficiently biodegradable to be of significance for such production.

Chapter 3: PHYSICAL AND CHEMICAL CHARACTERISTICS OF RICE HUSK

3.1 PERCENTAGE OF HUSK

Percentages of husk in paddy vary widely, but 20% can be taken as a fair average. Some varieties in Italy show as low as 14%, while varieties in other countries reach as high as 26 and 27%. In Alor Setar, Malaysia, the analysis of two local paddy varieties showed 18.1 and 22.59% respectively, and these could be milled, in subsequent lots, in the same mill. Fraps (87) reported Japanese 17.9% husk, Honduras 20.98% husk, Blue Rose 17.9% husk. It is easier to visualize wide differences in widely separated countries with different varieties and climatology than to accept wide variations in adjacent fields.

In some countries, particularly those that harvest a form of stalk rice, the term "husk" is sometimes thought of to include all dockage that is brought to the mill from the paddy field. In this case there is a disproportionate amount of straw. To illustrate, an analysis in Sri Lanka showed 26% husk, which was really 22% husk, the balance being straw and other dockage. The accuracy of testing depends on techniques of collection, pre-cleaning and milling; the other variable is the consequence of local terminology.

Attempts are currently being made to increase the weight of paddy without increasing the weight of husk. Plant breeders expect that in the future husk proportions will be less than 15%.

3.2 ANALYSIS OF HUSK

Analyses of husks are variable by type and variety. There are many characteristics in which the paddy was shelled. Rubber-roll shellers yield about 1% more rice. The epidermis (silver skin), when shelled with a disc (stone), stays with the husk percentage; when shelled in a rubber roll, the analysis shows a higher rice outturn and thence a higher bran outturn. An analysis shows less silica and more cellulose for a disc-shelled sample, and more silica and less cellulose for a rubber-roll-shelled sample. Similarly, in disc shelling the rice germ is trapped inside the grain, and this affects fat and protein analyses, as well as fuel values.

In milling parboiled paddy, husk is obtained, free of broken grains and of germ. This is because of the better milling yields of parboiled paddy, the tougher grains. The germ is melted into the caryopsis. The epidermis is always included in the husk percentage, the water separating the bond holding it to the grain.

Table 6 shows a tabulation by Houston (8) of analyses of hull over a hundred-year period. A tabulation of husk analyses, partially overlapping Houston's but containing more easily comparable data, appears at Table 7.

Analyses of rice husk have also been made from the standpoint of its characteristics for use as fuel. A tabulation of these analyses appears in Table 8.

TABLE 6

Composition of rice hull
(% by weight)
Source: 8

H_2O	Crude Protein	Crude Fat	Nitrogen-Free Extract	Crude Fiber	Ash	Pentosans	Cellulose	Other	Year
9.7	3.4	1.4	27.0	42.8	15.7	...	...		1871
8.27	2.87	0.85	34.99	38.15	13.85	...	...		1889
8.97	3.50	0.49	37.86	41.89	18.29	17.24	...		1904
10.0	3.7	1.4	32.3	...	...	...	38.1		1907
8.5	3.6	0.9	29.4	39.1	18.6	18.14	...		1916
6.62, 6.12	2.56, 2.69	0.50, 0.86	...	35.99, 36.08	18.70, 20.10	18.17, 18.14	...		1916
...	4.4	1.6	35.5	4.15	17.1	...	...		1919
11.04	1.7	0.4	28.95	...	...	...	43.12		1920
...	5.95	2.22	38.97	31.71	21.13	...	...	1.76 starch	1924
9.2	7.26	0.90	...	...	18.0	...	65.00[b]		1926
8.80	...	0.89	...	...	17.80	...	34.34	46.97 lignin	1926
9.3	3.3	1.1	34.0	35.4	16.9	...	...		1927
11.35	3.90	1.27	25.83	40.22	17.43	...	...		1928
9.8-11.00	2.94-3.62	0.8-1.20	24.70-27.90	...	15.68-18.24	...	41.10-42.90		1928
7.7, 6.8	1.8, 2.0	0.6, 0.6	32.7, 30.0	35.0, 38.9	22.3, 21.7	...	...		1933
9.03	1.79	0.44	25.79	40.67	22.29	...	...		1940
8.25	...	...	...	...	21.30	20.90	...		1943
3.74	6.06	1.33[a]	27.25	...	17.03	16.94	35.48		1943
8.1	3.0	0.9	...	...	18.5	18.1	39.1		1944
8.1	3.1	0.9	28.9	40.1	18.9	...	...		1946
...	...	...	...	...	13.6	...	43.7	39.2 lignin	1947
...	2.86	0.92	...	38.43	21.41	19.32	...		1949
8.49	3.56	0.93	29.36	...	18.59	...	...		
8.3	2.88	3.5[a]	...	...	22.6	26.0	42.2	19.2 lignin	1950
9.23	6.38	0.65	31.58	31.30	...	...	39.05		1952
0.0	...	...	...	...	19.03-29.04	...	...		1953
10.0	2.00	1.20[a]	...	...	17.60	21.95	41.22	32.88 lignin	1953
10.23	1.94	0.52	29.6	...	18.33	...	39.39		1954
8.0	3.0	0.8	28.4	40.7	...	...	...		1956
...	1.75	2.98	26.05	44.81	24.16	...	...		1962
8-11	2-3	0.5-1	25-30	36-45	22-24	...	...		1964
0.0	1.8-2.6	0.56, 0.81	29.9, 30.8	44.5, 46.3	21.2-24.0	...	...		1969
0.0	2.18-4.84	0.38-0.78	26.0-34.1	47.28-49.92	15.27-20.32	...	...		1970
2.4-11.35	1.7-7.26	0.38-2.98	24.7-38.79	31.71-49.92	13.16-29.04	16.94-21.95	34.34-43.8	21.4-46.97	Range

[a] Alcohol extract. [b] Cellulose plus pectin.

TABLE 7

Composition of rice husk
(% by weight)

Investigator	Description	year	Moisture	Ash	Protein	Fat	Fiber	N.F.E.	Insoluble
Auriol	50 S. variety Vietnam		10.23	18.32	1.94	0.52	39.39	29.60	17.64
Borasio	Neruvialong	1928	10.50	15.68	3.62	1.20	41.10	27.9	14.50
	Tolmino	1928	10.00	18.24	2.94	0.88	42.40	25.54	17.50
	Originario	1928	10.30	18.20	3.10	0.90	42.80	24.20	17.20
	Originario	1928	9.80	17.80	3.00	0.95	42.10	26.35	16.70
	Maratelli	1928	11.00	16.10	2.98	1.10	42.90	25.92	15.50
Browne	not known	1904	8.97	18.29	3.50	0.49	41.89	27.86	17.24
Fontillas	not known	1941		24.91	2.19	2.69	49.22	20.67	
Fraps	minimum	1916	6.11	14.83	1.78	0.54	31.43	24.56	13.69
	maximum	1916	10.95	22.00	5.00	1.98	46.37	36.83	20.84
	average	1916	8.49	18.59	3.56	0.93	39.05	29.38	17.52
Grist	not known	1959	9.02	17.14	3.27	1.18	35.68	33.71	
Joachim	Ceylon	1928	11.35	17.43	3.90	1.26	40.22	25.83	
Morrison	not known	1956		19.1	3.0	0.8	40.7	28.4	
Morse	California	1965	7.08	25.51	2.37	0.24	42.23		
Possenti	Italian	1941	10.3	18.2					
Reed	minimum	1917	5.00	16.4	1.75	0.51	36.57	15.27	
	maximum	1917	9.69	22.03	4.12	1.31	46.82	20.98	
	average	1917	7.91	19.54	2.66	0.80	41.29	18.58	
Ross	not known	1889	8.27	13.85	2.89	0.85	38.15	34.99	
Wise	Hondourus	1916	6.62	18.70	2.56	0.50	35.99		
	Japan	1916	6.12	20.10	2.69	0.86	36.08		

Fuel-related characteristics of rice husk

Investigator	basis	year	Heating Value		Ash	Moisture	Carbon	Silica	Hydrogen	Nitrogen	Sulfur	Oxygen	Volatile Matter	Fixed Carbon
			K cal/Kg	Btu/lb										
Agnew #1	dry	1972		6958	18.1								65.0	16.9
Agnew #2	dry	1972		6530										
Beagle		1968		6389	1913	5.72	39.71		5.01	0.46	0.07	29.90		
Beagle	dry	1968		6777	20.29	0	42.12		5.31	0.49	0.07	31.72		
Fontillas					24.91									
Greaves Cotton		1975		6165										
Grist		1959		6000	17.14	9.02								
Maheshwari — IR8	dry	1974	3090		17.4	3.56	39.26		4.99	1.99	0.10		68.6	14.0
Patnai	dry	1974	3560		15.8	3.56	38.92		5.10	2.17	0.12		69.3	14.9
Paoman	dry	1974	3065		18.6	3.56	38.19		4.67	1.52	0.11		68.7	12.7
Dular	dry	1974	3560		16.5	3.56	38.51		4.88	1.82	0.10		67.6	15.9
Basmati	dry	1974	2980		16.5	3.56	38.68		5.08	2.09	0.10		66.6	16.9
Nelson		1950			22.6	8.3		95.8						
Possenti		1941	3300											
Power Gas		1950		6340	21.7								60.9	17.4
Ricegrow. — Char		1970				2.8	55.8	37.05						
Rodgers #1		1936		6074										
Rodgers #2		1936		6152										
Spilling		1970	2900	5500	23.0									
Thai A863		1922	3619		18.7	9.1	40.0		5.0	0.30			56.4	15.8
Thai A864		1922				1.1	2.2		0.2					
Tucker		1952		6274					5.0	0.32				
Tulio		1972		6708		9.8								

A tabulation by Houston (8) of analyses of rice-hull ash appears at Table 9, while Table 10 tabulates rice-husk ash analyses.

TABLE 9

Composition of rice-hull ash
(% d.b.)
(Source: 8)

SiO_2	K_2O	Na_2O	CaO	MgO	Fe_2O_3	P_2O_5	SO_3	Cl	Year
93.21	1.53	0.30	0.51	0.07	0.45	2.69	0.42	0.15	1870
89.71	1.60	1.58	1.01	1.96	0.54	1.86	0.92	...	1871
96.97	0.58	...	0.57	0.12	...	0.57	...	...	1916
...	...	1.75	...	...	...	...	...	...	1917
97.3	...	...	0.43	...	0.38[a]	1.44	...	...	1925
...	...	...	1.38	...	...	2.78	...	...	1928
94.50	1.10	0.78	0.25	0.23	tr	0.53	1.13	tr	1928
...	0.75	...	1.3	...	...	0.23	...	...	1929
95.4	...	...	...	...	...	...	...	...	1930
95.49	1.88[b]		0.86	0.28	0.94[a]	0.36	...	...	1933
...	1.8–2.5	...	1.0–1.5	...	...	0.5–2.0	...	...	1941
96.5	1.00	0.4	0.25	0.25	tr	0.3	1.00	tr	1952
96.62[c]	1.59	0.0	0.32	0.76	...[c]	...	0.40	0.42	1953
...	...	...	0.52	...	...	0.32	...	...	1962
96.20	0.79	...	0.24	0.24	...	0.46	...	...	1966
92.47–95.04	1.70	...	0.25	0.23	...	0.67	...	...	1966
92.6	...	...	0.2	...	...	0.2	...	...	1966
86.9–96.2	...	...	...	...	...	...	...	...	1966
93.96	...	...	0.88	0.76	...	2.85	...	...	1968
91.16	4.75[b]		0.65	0.99	0.21	...	0.10	...	1970
86.9–97.3	0.58–2.5	0.0–1.75	0.2–1.5	0.12–1.96	tr–0.54	0.2–2.85	0.10–1.13	tr–0.42	Range

[a] Total of iron plus aluminum as oxides.

[b] Total of potassium plus sodium as oxides.

[c] Trace elements present include aluminum, copper, iron, and manganese as well as detectable amounts of barium, boron, and zinc. Tin was not found.

TABLE 10

Composition of rice-husk ash

INVESTIGATOR		YEAR	C	S_1O_2	H_2O	CaO	MgO	Na_2O	K_2O	Fe_2O_3	P_2O_5	Al2O3	MnO_2	SO_3	Cl
BEAGLE		1965		95.00		0.70	0.015			0.09		0.08	0.50		
BORASIO		1928		94.50		0.25	0.23	0.78	1.10	TR	0.53	TR	TR	1.13	TR
		1929		94.23		2.27	0.12	0.39	2.22	0.53	0.24	TR	TR		
		1930		93.95		2.28			3.15	1.01					
FRAPS		1916		96.97		0.57	0.12		0.58		0.57				
GARBARINO	IGN	1942	0	90.27	5.00	0.94	0.67	0.40	1.25	TR	0.51	TR	TR	0.33	TR
	CHAR	1942	25.50	65.00	6.50	0.65	0.49	0.34	0.95	TR	0.37	TR	TR	0.27	TR
JOACHIM		1928			11.35		0.27				0.50				
JONES		1954		96.50		0.25	0.25	0.40	1.00	TR	0.30		TR	1.00	TR
THAI-863	IGN	1922		95.7		2.70					0.30				TR

Chapter 4: USE OF RICE HUSK AS FUEL

4.1 GENERAL

The carbon in rice husk was fixed by solar conversion of carbon dioxide and water via photosynthesis. It is one of the most abundant renewable agriculture-based fuel materials in the world that can be feasibly collectible. The production of rice husk is today about 60 million tons per year, equivalent in energy to 130 million barrels of oil.

However, the husk supply must be realistically appraised as to its potential, not purely by multiplication. The widespread, very small, sources of husk production affect critically the potential for commercial or beneficial utilization.

Although rice husk has been utilized as a fuel, primarily in rice mills, for over a century, this utilization has never attained commercial status because of the bulk, erratic supply, transportation difficulties, lack of straightforward technological results and a paucity of coordinated efforts on the problem. The first recorded use of husk was in Burma in 1880 (Cowie 3); a furnace he designed and built was installed in a mill, and in less than five years almost every mill in Burma had a furnace of similar design. Apparently this was an external furnace utilizing a step grate of now-conventional design.

Some of the drawbacks to the use of husk as a fuel were its low density, its low calorific value and the amount of residue (as high as 50%) resulting from normal furnace burning.

In many countries, rice husk is used as a fuel for household use. Some use husk for fuel for operating rice mills, in brick kilns, in dryers. This is an easy and cheap source of energy, involves no foreign exchange cost and disposes of the husk. When fuels are used away from the mill, there is a small income to the miller; when the energy is used in the mill, there is a real cash saving.

Where there is a need for process steam, the utilization of husk for fuel is most advantageous, and most utilizations today stem around a process-steam or process-heat use. Only in large installations is husk used for independent power: two excellent power plants (one in the Philippines, one in Surinam), of 1200 kw and 1900 kw, utilize husk-produced steam for electrical generation without use of process steam. This point will be touched upon several times below.

The use for drying heat or kiln heat is of long standing; it is becoming more popular where conditions warrant such use.

Ramzin (182) was one of the first to investigate the combustion of fuels of fine granulation without pulverization. His work included rice husk. (See section 2.1.4.)

The calorific value of husk derived from a rubber-roll sheller is always less than that derived from a disc sheller.

Briquetting (compression, or extrusion of raw husk) has been advanced as a solution to the density and transportation cost problem. There have been efforts in several countries, Japan, India and Switzerland, to develop a machine capable of producing a marketable product. Rice husk briquetted on the Swiss machine operated by an Oregon concern (W162) shows the characteristics set out in Table 11.

TABLE 11

Rice-husk briquettes
Source: W162

Bulk wt. of loose material (10% H_2O	5.93 lb/ft^3
Bulk wt. of briquetted material	43.7 lb/ft^3
Specific wt. of briquette	81.15 lb/ft^3
Upper calorific value of briquette (0% H_2O)	6958 BTU/lb
Lower calorific value of briquette (0% H_2O)	6473 BTU/lb
Ash content at charring	18.1 %
Fixed carbon at charring	15.9 %
Volatiles at charring	65 %

Several incidences of briquetting the char from specific carbonization plants or furnace residue have been documented, some in conjunction with petroleum by-products and some straight char briquettes (Mifugi) from large-scale carbonization plants. Another approach is that of Park (48A), who mixes 5 to 9% carbonized rice husk with low-grade anthracite before briquetting, with good results. However, no lasting commercial utilization of such efforts is known, primarily because of the cost and maintenance of the equipment; in addition the burning of such compressed units made with rice husk creates certain problems.

Not everyone is enthusiastic about the utilization of husk for fuel: "We are convinced that it is irrational to use husk as fuel, and in our rice mills the furnaces for burning husk have been dismantled." (Pvt. communication, I. Leonov (USSR) to E. Beagle 1-3-74).

4.2 RICE HUSK AS A BOILER FUEL

Bhatia (214) gives a comparison of several fuels, as shown in Table 12.

TABLE 12

Economics of boilers
Source: 214

Fuel	Calorific Value	Cost of Fuel	Boiler Efficiency	Steam Output	Cost of Steam Production at 100 ps @ 30000 lb/hr
Coal	10.000	Rs. 50/ton	50%	6 lb/lb of fuel	Rs. 256 ($35.84)
Oil	18,000	Rs. 1.75/gallon	75%	16 lb/lb of fuel	Rs. 356 ($49.84)
Husk	2.500	Rs 7/ton	40%	1.2 lb/lb of fuel	Rs. 235 ($32.90)

The comparative studies of boiler utilizing different fuels show that husk fired boilers are cheapest because of low cost of the raw-material

Utilizing Bhatia's parameters, the author arrived at a slightly different result, using 1 lb of steam = 1025 BTU as shown in Table 13.

TABLE 13

Economics of boilers
(Beagle)

Fuel	Cost of Fuel	Lb of steam per lb of fuel	Cost of Steam ¢ per lb	Cost of 30,000 lb per hour
Coal 10,000 BTU/lb 50% efficiency	Rs 50/ton $ 7.00/ton ¢ .318/lb	4.87	.0652	$19.56
Oil 18,000 BTU/lb 75% efficiency	Rs 1.75/gal $ .21875/gal ¢ 2.28/lb	13.17	.1725	$51.75
Husk 5,500 BTU/lb 40% efficiency	Rs 7.0/ton $ .98/ton ¢ .044/lb	2.14	.021	$ 6.33

A good utilization and analysis of husk for fuel has been done in India by Scopa Chemicals (W83). They provide the following costs and comments:

Coal	$2.83 per 1000 lb of steam (approx) generated (at 100 psi)
Husk	$0.91 per 1000 lb of steam (approx) generated (at 100 psi) incl. transport

"With alterations, and not very costly ones, we feel all the existing Small Scale Industries which require steam up to 1 ton per hour having conventional vertical cross tube or fire tube boilers and which use coal as a fuel could change over. Provided, of course, that they plan effectively. With the use of husk the steam generation capacities drop to about 60 percent as compared to coal. A judicious balance of husk and coal in existing industries and boilers of larger capacities for new ones would offset this.

"The use of husk in fire tube boilers requires cleaning of the fire tubes after every forty-eight hours. Therefore, the husk is not suited for continuous operation of plants. In water cross tube boilers this difficulty does not arise." (Note: This caution applies when using a grating system designed for coal.) (See section

4.3 RICE HUSK AS A DRYER FUEL (See Section 6.2)

"Experimental evidence shows that 20 kg of husk which can generate 220,000 to 264,000 BTU when burnt would be enough to dry a ton of paddy from 20 percent to 14 percent moistur content." (Pingale) (227).

The tabulated results of an excellent study (179) of drying needs and costs are presented in Table 14.

TABLE 14

Comparative costs of fuels for various operations
Source: 179

Fuel	Cost $/Kg	Mechanical drying of raw paddy			Mech. drying of parb. paddy			Parboiling of paddy	
		Fuel reqd per tonne of paddy, Kg	Cost of fuel, per tonne of paddy .$	Remark	Fuel reqd. per tonne of paddy Kg	Cost of fuel .$	Remark	Fuel reqd. per tonne of paddy Kg.	Cost of fuel .$
Diesel	.175 47¢/gal	5.16	.90	without heat exchanger	15.6	2.73	without heat exchanger	16.4	2.67
Kerosene	.17 46¢/gal	5.12	.86	-do-	15.5	2.60	-do-	16.3	2.74
Furnace oil	.07 19¢/gal	11.50	1.02	with heat exchanger	34.4	3.02	with heat exchanger	17.1	1.51
Coal	.02 20.00 /tonne	54.00	.51	-do-	163.0	2.74	-do-	45.5	0.77
Electricity	.022/Kwh	52.50 Kwh	.96	-	158.0 Kwh	3.18	-	147.0 Kwh	2.94
Rice husk	.0015 1.50 /tonne	50.00	.08	without heat exchanger	152.0	0.22	without heat exchanger	140.0	0.20

Adapted from chart by T.P. Ojha , R.C. Maheshwari and B.D. Shukla ITT, Kharagpur 1974.

Another comparison of fuel costs, this time for a commercial kiln dryer, shows the dramatic savings possible with husk as an opportunity fuel. (Table 15).

TABLE 15

Kiln fuel comparison (14-million BTU/hr kiln)

Natural gas 100,000 BTU/therm		
14,000,000 BTU/hr divided by 100,000 = 140 therms/hr at .1125/therm		$15.75/hr
Propane 92,000 BTU/gallon		
14,000,000 BTU/hr divided by 92,000 = 152.17 gal at .27 gal		$41.09/hr
Actual fuel mix		
Natural gas use 2/3 of year; propane use 1/3 of year		$24.20/hr
Rice husk 5,800 BTU/lb		
14,000,000 BTU/hr divided by 5,800 = 2,414 lbs		
2,414 @ 2.13/ton		$ 2.57/hr
Savings/year (24-hour day)		
6336 x 24.20 propane/gas	$153,300	
6336 x 2.57 rice husk	16,284	
Fuel savings/year with rice husk	$137,046	

4.4 HEAT COUPLING

The largest utilization of husk in the world today is for energy. This is usually developed in traditional-type boilers and is used for process steam or for powering a prime mover. These systems are generally of quite low efficiency. There are, however, several outstanding examples of highly sophisticated power generation systems using rice husk as a raw fuel. As highly efficient as these target systems are, they are not utilizing to the fullest degree the modern concept of "heat power coupling", which can bring a process/power system using steam to an overall efficiency of at least 62% using reasonably obtainable pressures and temperatures. Here the prime mover (engine, motor, turbine) can satisfy all demands, as it fulfils the role of the always uneconomical reducing valve which, however, supplies heating processes with steam of a fixed pressure and temperature. The reducing valve actually destroys the available steam pressure gradient without utilizing it.

This sort of system for process (parboiling, bran-oil extraction) steam and power generation for mill operation would revolutionize the external energy requirements of the rice mill. It is not necessarily limited to installation in large (6 TPH and over) mills but can be successfully designed and built for 1, 2 or 4 TPH mills.

The largest single opportunity for the use of rice husk is for increasing efficiency where process steam is used; for example, Wimberly (W142) said, "The goal of Asian parboiling (and of course all parboiling) is to generate heat for all needs (cleaning, heating, processing, drying, milling) from husk fuel." Here the efficiency obtained from a heat power coupling (back pressure or extraction) system would give the necessary power and also the necessary process steam. Efficiency in a combined system (steam side) reaches about 65%. However, the boiler efficiency must also be improved over the traditional systems, primarily by the use of sophisticated grating units.

From the practical point of view, the objective is to produce the required quantity and quality of steam as and when required at the lowest cost. In assessing this cost, all the contributory factors must be taken into account, including fuel, labour, water and water treatment, parts, maintenance, repairs and capital charges. Of these costs, that of fuel is almost invariably by far the most important. It generally exceeds 70%; neglecting capital charges, the cost of the fuel is generally over 80% of the total cost of producing steam.

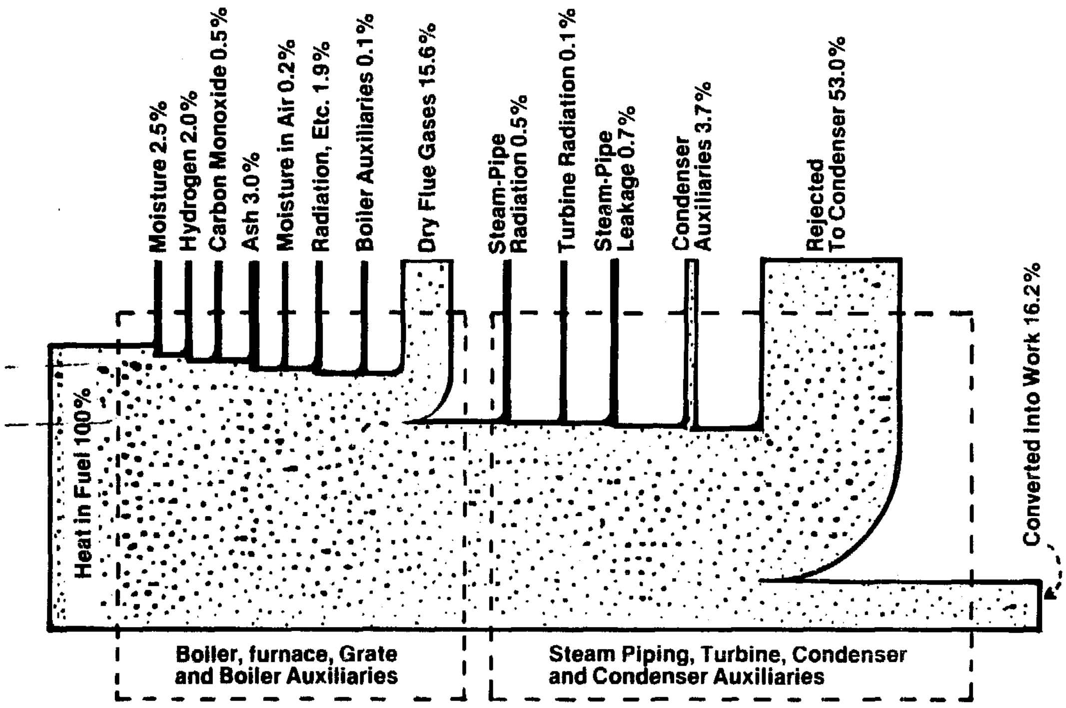
It is important to recognize that in industry, the attainment of maximum thermal efficiency is not the only object in steam-raising, although increased efficiency is important in decreasing costs. Increases in efficiency and economy go together so long as the improved efficiency results from better methods of working. But when maximum efficiency is obtained with the existing plant, an increase can be obtained only by modifying the plant; in other words, by incurring greater capital charges. It then becomes a question of striking a balance to determine the point at which charges due to improvements in the plant will offset the value of the heat saved.

Even in the most efficient stations, however, no more than about 30% of the potential heat in the fuel is converted into electrical energy, although the efficiency of the boiler plant may approach 90%. The principal loss is due to the fact that the exhaust from the prime mover consists of steam and water, and in the condenser the latent heat of the steam is transferred to the circulating water as low-grade heat, which is useless.

A graphic and tabular representation of the losses and gains from a boiler-turbine system appears in Figure 1.

Figure 1

Power Plant - Graphic Balance



As we have seen, the production of power from steam is always inefficient, for it is never possible to employ usefully more than a fraction of the latent heat of condensation of the steam. Whatever the initial state of the steam supplied to a prime mover, the exhaust can never be water, but must always consist preponderantly of steam. Steam which is used for process work, on the other hand, can be used efficiently, since its function is to carry heat at a temperature which is sufficiently high to ensure a reasonable rate of transfer of heat to the material which is to be heated. If the temperature difference is sufficient, condensation is encouraged, since the coefficient of heat transfer is then higher than when condensation does not take place.

Usually, the steam is not employed expansively, but at constant pressure, and frequently under substantially isothermal conditions. There is no advantage to be gained from superheat, except to prevent condensation while the steam is in transit from the boiler to the mill. Superheated steam behaves as a permanent gas; the film resistance to transfer of heat is high, so that the quantity of heat that passes in a given time may be less if superheated steam is used than if saturated or wet steam at a lower temperature is employed. There is also a greater danger of overheating and possibly damaging the rice with superheated than with saturated steam, while if superheated steam is blown directly into a liquid there may be insufficient time of contact for de-superheating to take place, with the result that bubbles of superheated steam may be blown completely through the liquid and be wasted.

Steam should therefore be delivered at the mill without appreciable superheat at a temperature and pressure which will permit reasonable transfer of heat through the heating surfaces. Condensation is advantageous because the coefficient of film resistance is lowered, and transfer of heat for a given drop in temperature from the heating medium to the material being heated is facilitated. The steam may be taken direct from the boiler, which should be operated at the necessary pressure, or exhaust steam from engines may be used.

Considerable economy can often be realized where both power and process steam are required, by exhausting the steam from the prime movers at a pressure sufficiently high to allow the demands for process steam to be met from that source. The power is thus obtained as a by-production.

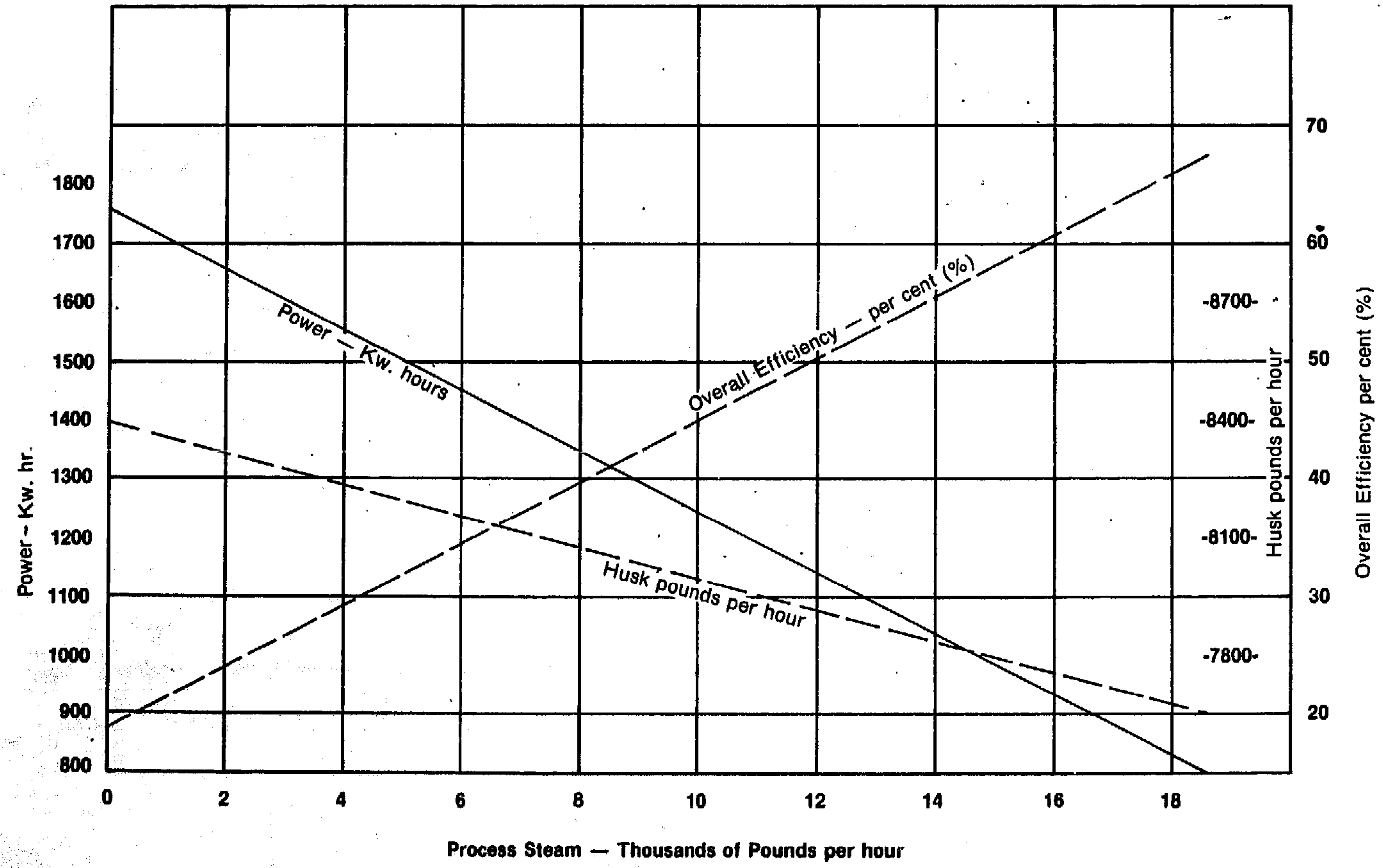
It has been felt that the use of steam engines is not possible where process steam is used for edible products, because of the small amount of oil that may leave the engine. However, the engine can be specified to operate with no cylinder lubrication (NCL) if such operation is needed. There would thus be no oil introduced, and the exhaust would be as clean as a turbine exhaust. The only requirement for NCL is that no superheat be used.

The use of low-efficiency systems designed only to provide process steam is an error. With a bit more sophistication and use of engine or turbine, the power can be had almost without cost, as shown by Figure 2.

It is instructive to observe the effect of varying the quantity of process steam withdrawn on: (i) the amount of power which could be generated; (ii) the overall efficiency of the plant; (iii) the pounds of husk required per hour; and (iv) the temperature of the feedwater. This has been done, and the results of the study are shown in Figure 2. It is found that, for every thousand pounds of process steam withdrawn, 51.4 kw less can be generated, 27 lb less husk will be required per hour, the efficiency rises by 2.62%, and the temperature of the feedwater to the boiler increases by 6.5°F. Even when the prime mover is employed primarily as a reducing valve and de-superheater, giving 18,620 lb process steam per hour at 50 lb/in^2, 800 kwh of electricity will also be produced. At the other extreme, when all the steam is being used to produce power, the output would be 1,758 kwh, but the efficiency would be only 19.4% compared with the 67.4% realized when the demand for process steam was 18,620 lb/hr.

Figure 2

Results of Heat Coupling



4.4.1 STEAM CONSUMPTION

Table 16 shows typical full-load steam consumption specifications, as compared with the observed performance of two representative engines (W154), operating with dry saturated steam at the engine stop valve.

TABLE 16

Steam Consumption

Inlet Pressure (psig)	Exhaust Pressure	Typical Specifications				Engine A 210kw-305 HP consumption: 10300 lb/hr (lb/kwh)	Engine B 350 kw-510 HP consumption: 17260 lb/hr (lb/kwh)
		Small (100 kw) Engines		Large (500 kw) Engines			
		(lb/kwh)	(kg/kwh)	(lb/kwh)	(kg/kwh)		
225	35 psig	47.2		44.9			
225	2.5 kg/cm^2		21.5		20.5		
225	40 psig	49.3		47.3			
225	3.0 kg/cm^2		23.2		22.1		
227	43 psig						49.3
225	45 psig	52.1		49.8			
235	45 psig					49.0	

4.4.2 MILL POWER REQUIREMENTS

4.4.2.1 Installed power: While the installed power of a rice mill can vary considerably according to the type of mill and many other factors, the general consensus is that 2.4 to 3.6 HP are needed per 100 kg/hr of paddy, the figure declining somewhat as mill size increases. Table 17 shows a good guide, subject to the complexity of the mill.

TABLE 17

Installed mill power requirements

Paddy Input (TPH)	Power Requirements (HP)	
	min.	max.
.5	10	30
1.0	25	65
2.0	70	100
4.0	140	200
6.0	200	300
15.0	530	800
25.0	900	1200

In sophisticated mills (return shellers, multiple break systems, more elevators, grading equipment), the HP requirement can be twice as high as in simple mills of the same size; where ancillary operations (drying, storage, threshing stalk-rice situations in Indonesia) are carried out, the power requirement can be tripled.

The total power requirement of a machine is roughly the same whether a lineshaft or an individual drive is used, but with electric motors the connected load may be higher. The power loss due to transmission lines in a lineshaft drive reaches about 9%, and in individual drives, the V-belt loss is 1 to 1.5%, but individual motor efficiencies, oversizing and conservative installation can bring the total connected load to 30-40% above the minimum requirement. Experience in specific cases shows an actual consumption of 62% of connected load. Lineshaft mills tend to minimize this problem, and the more sophisticated and modern a mill, the less is the tendency to oversize. However, every installation must have a reserve, the installed horsepower being about 20% greater than the actual load; for individual machines that can be adjusted and overloaded by the operators, the nominal load should be calculated at 40% over the actual load. Thus, if 11 HP are needed, or even 9 HP for a heavy-duty machine, a 15-HP drive will generally be used.

Table 18 shows the advertised horsepower requirements of specific mills. The variations among them are obvious, and the only possible conclusion that can be drawn is that each installation must be planned according to its own requirements.

TABLE 18

Advertised horsepower requirements

Paddy Input (TPH)	Manufacturer	Power Requirements (HP)
.25	Satake	10
.50	Satake	25
1.2	Satake	36
1.4	Schule	50
1.7	GDR	43
3 - 4.5	Satake	135
4	Satake	64.5
4	Satake	112
4	Dandekar	120
5	Schule	150

4.4.2.2. <u>Hydraulic drives</u>: Consideration should be given to the possibility of using hydraulic motors as individual drives. Powered either from a steam engine/turbine unit or from a producer-gas prime mover, they would offer advantages in simplicity, power balancing and safety.

4.4.2.3 <u>Steam-powered mill requirements</u>: One boiler HP is sufficient to supply 3 engine HP, while with poorer types of engines it will supply steam for about 1/2 engine HP. Compounding is advisable for large units with reasonably uniform loads; with fluctuating loads the simple engine governs better and is about as economical.

It is generally agreed that 1 kg of husk will produce 2.4-2.7 kg of steam, and that 1 HP will be produced by 7.5-11 kg of steam. B.R. Wolf engines ran 6.0 to 8.5 BHP/hr per kg steam maximum, with some degree of superheat. Wolf stated (Bianchi; private communication) that 300 kg/hr of husk would produce 38/44 HP plus about 260 kg of process steam. In this they calculated that about half of the available energy content of the husk would be liberated. This corresponds to other statements showing a 40% boiler efficiency on husk, as compared to 75-80% on gas or oil.

According to Schule, on the average about 15 kg of rice husk are required for generating necessary power for processing 100 kg of paddy into white rice, while about 20-24 kg of rice husk are produced in milling, leaving a substantial surplus. For driving rice mills, the multi-cylinder models of steam engines prevail. Steam consumption varies between 6.5 and 8.0 kg per BHP/hr, according to the number of cylinders per engine and the size and rating of the steam power plants.

The Philippine mill and power plant of Tulio consists of a 25 TPH mill and 1920 kw of engine-generator (Spilling) power generation using 5 TPH of husk, or about 400 kw/ton capacity. The Surinam power plant of SML, with a 15-TPH mill and 1200 kw turbine (Terry) generator, again shows a 400 kw/ton of capacity. It would appear that this is a conservative level of production when the power unit is over 1000 kw.

The older engine type (BR. Wolf) would produce 40 HP/300 kg husk, or 280 HP/ton or 210 kw/ton. The differences in efficiency are to be explained in two ways: the efficiency of size and the efficiency of the sophisticated grating systems on the modern furnace installations (Lambion). Using rice husk, these furnaces show efficiencies comparable with those of other fuels.

4.5 WASTE-HEAT RECOVERY

When recovered heat is put to some beneficial use, a corresponding quantity of fossil fuel is not burned, thus eliminating emissions from this source. The heat recovery thermal reduction method for solid-waste processing has been widely used in Western Europe for many years.

Heat recovery equipment can be incorporated into any incinerator system. Conventional systems may include this capability through a downstream waste-heat boiler associated with a refractory furnace, or by building the furnace with water-cooled walls as a boiler, which normally also includes a "convection section".

The two most common designs for waste-heat recovery installations involve steam generation by a boiler located immediately after a conventional refractory furnace, or by water-bearing pipes embedded in the furnace walls (water wall). The furnace/boiler combination is simpler and cheaper to construct, but requires 150-200% excess air to prevent refractory lining damage. The second design, with more efficient heat transfer, requires only 50-100% excess air and reduces the required air pollution control equipment. Both systems make unnecessary special cooling of effluent gases to protect this equipment. Heat recovery can offset a fraction of incineration costs, if the variable heat output can be matched to a customer's variable demand.

4.6 SMALL PRIME MOVER SYSTEMS

For mills that do not need process steam (white rice milling), the situation is totally different from that of a parboiling process mill. At the present time it is unrealistic to propose the use of steam-generating systems for motive power in this type of mill, particularly in mills of under 10 TPH paddy capacity. Since the number of larger mills (above 6 TPH) is insignificant in the world's total of rice mills, the development of some system other than the conventional steam process is indicated in order to bring the greatest benefit to the industry as a whole.

It appears that the best solution to the problem of the powering of small and medium mills* would be to use as a prime mover an engine fueled by a gas produced from the husk removed from the rice in the mill (gasogeno). This system of "producer gas" is of proven technology, having been in continuous use for over 75 years.

Advantages of a producer-gas unit prime mover over a furnace-type boiler unit prime mover include:

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* In this study, "small" mills are taken as having a capacity under 3 TPH in Europe, Thailand and Japan, and under 1 TPH in India; "medium" mills as having a capacity of 3-5 TPH in Europe, Thailand and Japan, and 1-3 TPH in India; and "large mills" as having a capacity in excess of those figures.

- on 1 shift operation - easy to turn off and on
- less maintenance
- no water purification (unless water scrubber used)
- good efficiency on shift basis
- boiler needs inspections - pressure vessel; gasogeno needs none
- boiler needs cleaning; gasogeno needs none
- seasonal shutdowns if boilers create problems
- gasogeno creates no air pollution problems (smoke or particulate)
- gasogeno requires no attendant
- maintenance of gas producer unsophisticated
- gas producer can be installed in outside areas

There are therefore two possibilities:

- Where there is a use for the steam produced for process purposes, the producer-gas boiler heat-coupled unit would give excellent efficiency.

- Where there is no use for steam, then use should be made of a dual-fuel or direct-fueled internal combustion engine system, either with a direct drive or with a combination of these, the large power consumption machinery being driven directly, and the smaller, more isolated, units driven electrically, together with the lighting, pumping, air conditioning, etc. This then would prove to be a very practical system.

Most in-house gas generator systems seem particularly suited to the 25-250 HP range.

A small rice mill handling 2 TPH of paddy requires about 100 HP. The 100-HP engine would consume about 180 to 240 kg/hr of husk. The 2 tons of paddy would yield 400 kg of husk, which would result in a surplus of husk of about 160 to 220 kg/hr, so that actually a 150-160 HP engine could be used, driving a generator and using modern individual drive practice as to the milling machinery, plus the necessary ancillary electrical requirements. More detailed treatment of the gas producer and equipment will be found in Section

4.7 CENTRAL LOCATION GAS PRODUCER

Another way to use boiler fueling is to produce gas with a "Balestra" unit* and burn it in a package boiler. In this way the husk-derived gas can be used as supplemental gas or stored for non-concurrent use (108) (129).

In white-milling areas where there are a number of small mills within a reasonable distance, a "Balestra" unit could be installed at each mill and the gas piped to a central gas holder and power plant. In the power plant, a dual-fuel pilot-fuel engine can be used for generation, giving complete flexibility as to fuel supply, while taking full advantage of the indigenous fuel source. Otherwise, if process steam is needed at a local mill or food processing or other plant, a heat-coupled steam system would give otherwise unattainable efficiency.

Composite systems such as envisaged here can only be designed when the engineer is fully cognizant of all the opportunities of the various systems and of the complete appreciation of all variables.

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* A "Balestra" unit is an updraft gasogeno of Italian design.

4.8 USE OF RICE HUSK IN MAKING PORTLAND CEMENT (See also Section A.3)

Portland cement is made by mixing and calcining calcareous and argillaceous materials in the proper ratios. The product consists primarily of lime, silica, alumina, and iron oxide, with gypsum added to regulate the setting time. Natural materials, such as limestone and shale, are combined in the basic process. Other materials (such as sand, sandstone, bauxite, and iron ore) are sometimes added to adjust the composition of the mix. The proportion of silica in various cements ranges from 18 to 20%. A Stanford Research Institute report (URS citings) indicates that the average new cement plant uses 0.9 to 1.0 million BTU per barrel (5.85 barrels = one metric ton).

Studies conducted by Staackman (228) suggest the economic feasibility of utilizing the energy generated from burning husks to ash, and of subsequently using the silica in the manufacture of Portland cement. Comparative cement plant operating costs are summarized in Table 19.

TABLE 19

Portland Cement Plant Operating Costs

	1970 Traditional Cement Plant	1976 Traditional Cement Plant	1976 Cement Plant Utilizing Rice Husk
Labour	$ 0.32	$ .32	$ 0.34
Fuel	0.50	1.50	0.44
Power	0.22	.22	0.23
Miscellaneous supplies	0.21	.21	0.21
Maintenance materials	0.12	.12	0.12
Supervision and overhead	0.12	.12	0.12
Depreciation	0.35	.35	0.36
Cost per barrel	$ 1.84	$ 2.84	$ 1.82
Cost per metric ton	$10.76	$16.61	$10.65

While there are variables in the amount of heat needed per ton of cement, the Staackman report puts forward a figure of 5.2 to 7.6 million BTU, while Pitman states that the requirement is between 300 and 700 lb of coal.

The general approximate feeling is that rice husk could furnish about one half of the energy needed for a traditional Portland cement producer. In 1970 Staackman suggested this as his first choice among husk utilization potentials. Since that time, the advantages of this use have increased sharply.

In Northern California, the cost of fuel in 1970-73 was $0.05 per therm ($10^5$ BTU), but during 1974 it had risen to $0.095, and by 1975 it reached over $0.15/therm. The economies delineated by Staackman now are much more considerable, so that when possible every cement plant should be using all available husk for fuel.

That this is happening and is practical is shown by the mid-1975 start-up of use, in a California cement plant (W176), of rice husk as a fuel and silica source, furnishing 1/2 of the energy and 15% of the silica needed to produce 35 TPH of cement. Considering that rice husk contains about 12 x 10^6 BTU/ton of energy and that cement manufacturing requires 6 x 10^6 BTU/ton, 10 tons of rice husk per hour can supply 57% of the energy requirement for 35 TPH. Again, considering that the silica content of rice husk ash is

17%, 10 tons of rice husk per hour can provide 18.6% of the silica needed for 35 TPH of production of a 26% silica cement.

At the current gas cost of $150 per 1000 therm, the rice-husk heat equivalent is 1200 therm per hour or a gas cost of $180. The laid-in cost of the husk is about $9 per ton, which allows $90/hr or $2,160/day for amortization of handling equipment and storage and the additional "confusion costs" of having to operate a dual-fuel operation. It appears that it would be very profitable to consider the use of husk on an "as provided" opportunity basis, particularly if the supplier would participate in the transportation costs. The only constraint would appear if the combustion conditions were such that a very poor heat release was obtained. Inspection of the husk residue particulate would indicate the combustion efficiency. An additional plus factor would be the ability of the plant to operate with allocation restrictions that otherwise would seriously hamper anything approaching a normal operation.

4.9 HUSK AS A "RAW" FUEL SOURCE

The thinking that husk energy must be used in the vicinity of the producing rice mill is misleading and erroneous.

A change in point of view would speed up acceptance of utilization techniques. These units should be seen as power plants first and disposal techniques second. Instead of rating plants according to the benefits derived for disposal purposes, they should be measured in terms of the power they could potentially generate. Indeed, the plants could be so efficient that it would be possible to include them among the national sources of energy.

Husk must be looked on as a raw-available fuel, in the same sense as any other raw fuel.

Considerations relevant to this view are the quantity available in each location; the area available; fluctuations in supply according to the season; transportation costs; the low density of husk; and the availability of competitive fuels (water power, gas, electricity, fuel oil).

In the light of these considerations, a study should be made of the amounts of energy needed, the market for husk energy, and the alternative disposal costs.

Capital considerations include the ease of capital acquisitions, interest costs, and labour cost and availability. After such a study it is possible to make an appropriate choice.

4.10 USES IN INDIVIDUAL COUNTRIES

In Argentina, Frugone & Preve (W1) operate seven rice mills, all having operation by steam engines and some being capable of alternative electrical operation. All were originally lineshaft-drive mills, but some have changed over to single-unit driven operation. The company can selectively use the cheapest method of operation. If the price of husk for commercial sale is such that it is better to operate on electricity and sell the husk, then this is done. If the price is low, so that it is cheaper to use the husk internally for fuel, then that is the mode used. At the time of writing, husk prices provide about a 30% benefit margin when the husk is sold and the mills that are capable of electrical operation are so run. However, the husk market has been dropping, so it could be that in the near future the mills will again be operating on steam. This arrangement has tremendous advantages. The mills operate on a purely economic basis, essentially always returning the full market value of husk, and never less than the equivalent value of the electricity. The flexibility available to the operator is clearly evident.

Brazil - Husk is presently used for steam power for mills.

Burma - Steam-powered mills are said still to exist.

France - Husk is used as fuel in one precook-parboil mill at Gimeaux.

India - A portion of the husk from white-milling in the South is sold for a good price. Some is used for fuel in the manufacturing of building brick (kiln firing). In 1974, the price was 40 Ks/Rs or 3.00/ton, and there was a good demand at that price. About 95% of the parboiling mills (approximately 50% of production) use husk-fired boiler units for their process-steam requirements. There are many installations of direct-fired dryers and of steam-powered white-milling units.

Iran - Has steam-powered mills, said not to be running because of a lack of supplies of paddy.

Italy - Husk is used as fuel in several parboiling rice mills, and as fuel in one producer-gas unit for white-milling. It is also used as domestic fuel for home and water heating.

Japan - Husk is used as domestic fuel for home heating, and as fuel in drying furnaces. None is known to be used for power. Many carbonization units exist, but very few utilize the heat from stacks.

Korea - Husk is used as domestic fuel; char is used as an additive in fuel briquettes.

Malaysia - Some mills (white) are powered by steam; all new ones, however, are powered by electricity. Husk is used for fuel for process steam for parboiling.

Mexico - Husk is not used as fuel as far as is known.

Pakistan - Only one formal utilization is known: a direct-fired dryer near Lahore. There may well be other installations, both for process and for power. The traditional methods use husk almost exclusively.

Philippines - Husk is used for fuel for steam for electric generation (Mindanao). It is also used for power to drive rice mills, mostly older ones.

Portugal - Husk is still used for mill power.

Spain - Husk is not used as fuel, but it is used in several char manufacturing facilities which do not make use of heat.

Sri Lanka - Husk is used for fuel for process steam for parboiling in boilers, and in "Goya" units. No mills, but only process units, are currently steam powered.

Surinam - Husk is used for fuel for electrical generation (W144).

Thailand - Husk is used for fuel for both parboiling and white-milling power, and for parboil process steam and drying steam. The standard Thai mill is steam driven from husk. No direct-fired drying appears to exist.

U.S.A. - Husk is used as process-steam fuel, and as fuel in cement manufacturing.

Vietnam - There was considerable use of steam powered mills. The current situation is unknown.

Chapter 5. PROCESSES USING HUSK AS AN ENERGY SOURCE

5.0 INTRODUCTION

Current practice is almost always to consider the conversion of husk to energy in parallel with its use as a source of raw material. In no case does the original concept ignore the possibility of a residue utilization, but in some the selected utilization is of doubtful value.

Grouping of the various processes in any logical pattern is difficult because most embrace several areas of technology, so that unavoidable duplications occur in descriptions. This chapter is designed so as best to embrace all the material available.

5.1 WET HEAT SOURCE

5.1.1 BOILERS FOR STEAM RAISING

For almost a century, the use of husk as a fuel for the production of steam has been common throughout the world. The design of the boilers and combustion systems varies widely, as does the efficiency of the systems.

Individual type and design of boilers are covered in Section 6.1, and furnaces are discussed in Section 6.3.

A great deal of confusion surrounds the use of rice husk as a fuel in boilers. In most peoples' minds, the low efficiency of such an installation is due to its use of husk fuel and it is not recognized that the efficiency depends upon the sophistication and workmanship of the furnace and boiler combination. There has however been considerable improvement in the traditional styles of furnaces and gratings, both in static-bed units and in turbulent-air suspended furnaces, used either as external furnaces or in conjunction with a waste-heat boiler.

Few water-tube boilers use husk, for several reasons, the most important being that usually the installation is not large enough to warrant the cost of water-wall furnaces and water-tube units, and that usually the heat release is not high enough to justify a water-wall furnace construction.

However, several designs of turbulent-air suspended systems have used water-tube boilers in a waste-heat boiler configuration to give high steam factors at reasonable cost. One of the classic husk-fired installations using a water-tube boiler is the Babcock & Wilcox unit at the Frugone & Preve mill in Robbio, Italy, a 750 kw generating plant installed in 1927 and operating until 1975, when a fire (not originating in the power system) necessitated changes in the mill configuration. Both of the newest large generating plants (Mindanao (W134) and Surinam (W144)) utilize fire-tube boilers with Lambion furnaces. This use of fire-tube boilers at pressures formerly attained only by water-tube boilers illustrates the advances in metal and construction capabilities in the last 50 years.

Integrated parboiling/milling operations often use husk-fired boilers (VCT, traditional or locomotive), particularly in operations of long standing. More sophisticated operations use multi-pass tube-type horizontal boilers. In Thailand, traditional design boilers are being newly constructed for steam-engine prime mover operation. Most mills in Thailand are husk-fired and steam powered.

5.1.2 HOT WATER HEATERS

Any boiler installation can be considered to be only a high-pressure hot-water heater, so that comments on boilers also are relevant to hot-water heaters.

However, in some instances, specific use of rice husk to heat water on a commercial basis has been noted. Development units have been noted in both India (W66 and Japan (W105) and some units featuring dual fuel (husk/oil) capability are installed.

In Japan the utilization of husk to furnish hot water is on a commercial basis; the manufacture of water heaters utilizing husk as a fuel or as an alternate fuel has been noted.

In India husk is used in commercial water-heating in motels and restaurants. Usually these are rudimentary units, obtaining husk from the local rice mill specifically for heating water. To illustrate the value of husk as a source of energy for water heating, a cooperative (Ryots) in Mandya (northeast of Mysore), India, sells about half of the husk produced by their two mills to local hotels for hot-water heating, both for space heating and domestic use of hot water. The price received during the demand season reaches 2 Rs/40 Kilo or $7.00 M.T. f.o.b. the mill.

It is certain that in many other instances husk is used as a fuel to heat water for a variety of uses.

In Italy, husk is used to fuel hot-water generators for domestic hot water and for heating purposes. The units are sophisticated and operate completely automatically. A small mill in Monticello (W82) uses husk for direct firing of a small water heater for use in radiant-heat systems in the mill, owners' homes and adjacent buildings.

5.2 DRY HEAT SOURCE

It is conceivable that rice husk would make a satisfactory dry-heat source for many uses not presently known. The slow, even heat release, the contained control that is inherent in the silica shell structure of the husk should be able to be used with distinct advantage. Very few, if any, of the competitive fuels have the controlled release capability found in burning rice husk. In a rudimentary fashion this feature is utilized when husk is used as a domestic fuel, but nowhere does it appear to be used commercially.

5.2.1 DRYERS FOR PADDY OR PARBOILED RICE AND OTHER DRYING TASKS

Rice husk makes a very successful fuel for all drying purposes. However, any projected use must be approached with a full appraisal of the supply (location - seasonality) in relation to fuel requirements. Many projected uses of rice husk as a fuel initially do not allow for the variability of supply, problems of storage and transportation, the resulting residue or the peculiarities of rice-husk combustion. Therefore, what seems to be a potential use becomes at times impossible.

It would seem that in many drying situations the best use of husk would be in the role of a supplementary fuel, even if the supplementary fuel would comprise 80 or 90% of the fuel requirement. It is best to make as much use of the available husk supply as possible in order to derive the maximum economic benefit.

At today's fuel price levels, rice husk often becomes an important raw fuel for drying purposes, both from the cash standpoint and from the standpoint of the utilization of national indigenous fuel resources.

In drying uses there are several obvious categories and these will be discussed separately; see also Section 6.2, where the equipment is discussed in more detail.

5.2.1.1 Farm or field-type drying (See also Section 6.2.1)

Considerable work has been done in recent years by both IRRI (W130) and UOP (W135) on the further development of box-type dryers, fired both by kerosene and by rice husk. A discussion of the various manufacturers, etc, appears in Section 6.2.

This type of dryer was in a highly developed state as early as 1914, as is evidenced by publication of details and photos of a modern box dryer in the 15 October 1914 issue of Il Giornale di Risicoltura (W98). This type of dryer had obviously been in use for a number of years, because by the time of publication a quite sophisticated unit was being produced.

A diagramatic view of a modern rice-husk fired box-dryer is shown in Figure 3. This is an indirect-heat exchanger type dryer.

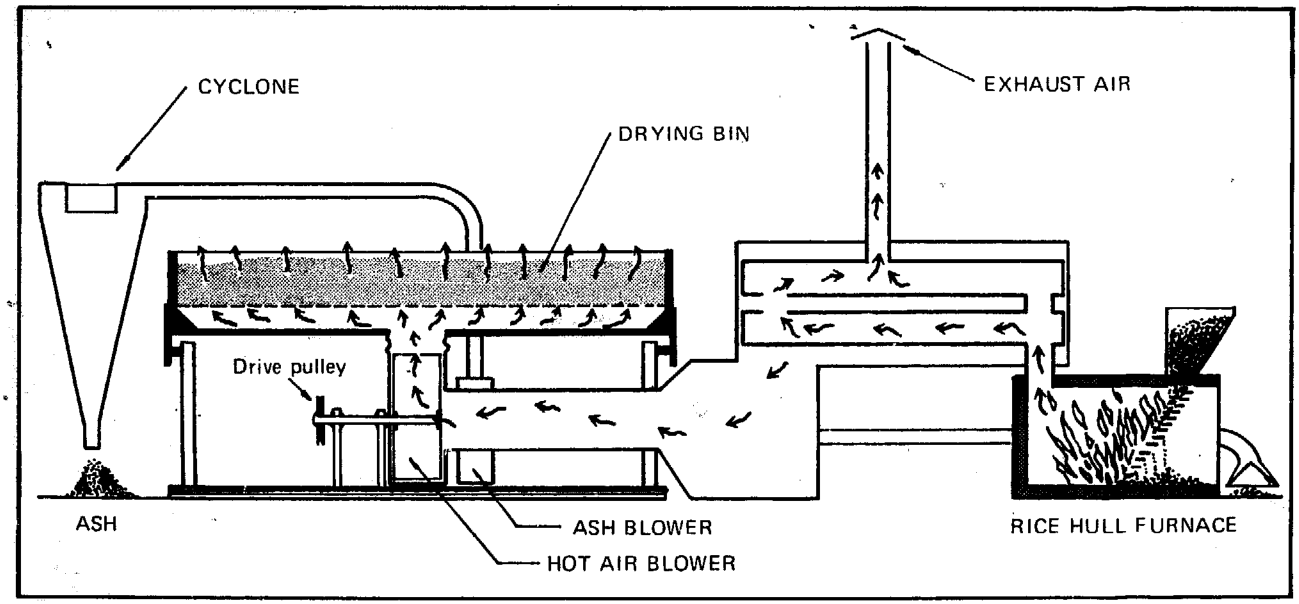


Figure 3 - Rice-husk fired box-dryer

A typical (W135) drying test of this type of unit showed that 1728 kg of paddy were reduced to 1603 kg of lower-moisture paddy in 4.5 hr, a 27.7 kg/hr moisture removal. The rice husk used totaled 55 kg, or 60,500 BTU/hr or 316,500 BTU total, indicating a burner efficiency of 33.5% and a heat utilization efficiency of 11.6%.

Losses can occur in heat transfer, stack losses, radiation, and the carbon remaining in ash/char residue.

The use of box-type dryers is limited to special situations where labour is available to fill and empty the drying chamber. In Italy box-type dryers have been developed with a continuous-flow system that charges and discharges mechanically.

Box-type dryers have the advantage of low initial cost. This feature was important in the adoption of this type of dryer for paddy-collection station use in Sri Lanka. The knockdown feature is also important, as it allows the dryer to be stored out of the way and out of the weather in the off season.

The economics of rice-husk fired vs. kerosene-fired box-dryers depends entirely on local usage, hours of use, and proximity of a source of rice husk to the dryer. In every case found, the cost of the rice-husk furnace was much higher than that of the kerosene burner. The higher cost can be amortized if the unit is used for extended periods of time. In many cases, raw-paddy rice drying is desired at a point considerably distant from the mill. In these situations it would be hard to justify the use of rice-husk fired box-dryers for field paddy-drying.

Each situation must be assessed according to local conditions. Any indigenous fuel furnace must be able to handle the complete range of locally-available agricultural and forest products. The typical furnace designed specifically for husk is usually not suitable for other material, particularly wood and wood trash. The furnace should be able to be constructed locally by farm labour from locally-available material, accept any fuel, and offer good efficiency.

5.2.1.2 Commercial or industrial - direct- and indirect-fired (See also Section 6.2.3.)

It can be expected that more use will be made of dryers in Asian countries, particularl because of the effect of higher labour costs in the economics of yard (sun) drying, primarily of the intermediate step in parboiling. As labour and yard drying become more costly, there is a trend to mechanical drying, and nothing is more obvious than the use of a direct husk-fired dryer. Parboiling is normally done at the point of husking, and in some concurrent fashion with the husking, so that sufficient husk is available without transportation costs. In many cases, the husk is [illegible]o fire the boiler for the parboiling process steam; either a stack heat-exchanger or [illegible] use of the stack gases could be used for the intermediate dryer. In most cases the efficiency of the system is such that steam heat-exchanger drying is feasible [illegible]rboil plant. This system is used in many parts of the world in existing parboil plants.

Considerable work has been done at IIT-Kharagpur (W63) concerning the cost of various fuels. Comparison of costs appears in Table 14. Their use of a step-grate rice-husk furnace has given them 72% recovery in the flue gas, and with a feed rate of 11 kg/hr they can maintain 1000 ft^3/min at 100°C out, with 30°C in. This is a direct-fired step grate with curtain wall and an ambient bleed to control dilution and drying air temperature This general system is followed in most direct-fired installations; excellent examples of this bleed system on a large dryer are near Amritsa (Punjab) and near Lahore (Pakistan), where this system has been in operation for over six years.

Some indirect-fired units have been in operation for 15 or 20 years; in Santo Domingo, Costa Rica, Madagascar, and Bangladesh, indirect-fired column-type dryers were installed many years ago. In Japan in the early 60s, some husk-fired dryers were installed, many of them in the Toyama prefecture, but it was felt that the labour cost of the husk-fired unit was too high, and they were converted to oil. One could wonder if today they might not be reconverted to husk-firing.

In India the government has encouraged considerable work on husk-fired dryers of new design (Kuppuswamy), a combustor using a plate igniter and an air-suspended system coupled with a shell and tube heat-exchanger. These units are undergoing production testing. This project favours the use of indirect (heat-exchanger) operation on parboiled paddy because of the following considerations:

- particulate matter is high in stack gas, and might reduce quality because of impact of particulate;
- discolouration of dried paddy;
- dust nuisance;
- husk in parboiled is split slightly; endosperm is then directly impinged.

In this combustor, 6:1 is given as the air/fuel ratio, and a 20:1 ratio of dryer to combustor air flow is specified. This ratio seems to correspond to most other bleed-air or exchanger-air systems. A 2'6" husk combustor will pass through the heat-exchanger about 6000 ft^3/min of dry hot air. The dryer necessary for a 2 TPH parboiling plant would require 15000/18000 ft^3/min, so that three small combustor units would be necessary.

One deterrent to the use of rice-husk fired dryer units is that because of the variability of supply of husk, a standby oil fuel system--tanks, pumps, burners-- is also needed. The question is whether the fuel saving is worth the additional cost of the furnace, the heat-exchangers, husk-feed and ash-removal systems. In a parboil dryer it appears that it is; in seasonally available raw-paddy drying the use of a husk-fired system is usually not viable. The payout for fuel savings on the parboiled unit would be about 5 times as fast as for a raw paddy unit.

There has been some interest and design work on systems utilizing husk firing with oil as a transfer medium--a thermal fluid system. This would remove many of the objections of fluid heat-exchanger maintenance and problems of steam-boiler maintenance. It would be particularly attractive in a white-milling plant where there was no need for process steam.

A new type of fluid-bed direct-fired dryer (see 6.2.2.1) has been developed in Madras (India). This unit is in current commercial production, but its use as a paddy dryer is limited by the supply of husk. As a parboiler and parboil dryer it is more valid, as it then becomes a piece of mill equipment and has a local husk source.

There has been comment that a classic step-grate system will never be able to give a constant air supply to a dryer. If air is desired for a dryer, it is necessary to have a reasonably constant air temperature into the dryer. The step grate is difficult to control as to the furnace temperature conditions; however, if the temperature control problem could be diminished, the advantages of the traditional furnace (possibility of local manufacture, low-cost material, simplicity in operation, low maintenance and long life) would offer an inducement to the designer to install this system.

One little-known feature of direct firing for drying is that it inhibits insects from the gas stream entering the dryer.

5.2.1.3 Steam heat-exchanger types The use of steam heat-exchanger dryers has been common for many years. Quite sophisticated systems are 35-40 years old and in continuing operation. In a parboil plant it makes good sense to use this type of dryer. The overall efficiency is good. The boilers can be large enough to obtain good efficiency, and the average maintenance cost is low. Further, in a parboil plant the continuous use assists in the amortization of the high initial cost.

5.2.1.4 Use in drying materials other than paddy: The use of husk-fired dryers for materials outside of the rice spectrum depends only on the correct combination, a need to dry, a source of husk and an assessment of the economics to provide a favourable balance. There are many cases where husk can be used as a supplemental fuel for drying, but because of the variability of its supply, which could be out of phase with the drying need, and difficulties in storage and handling, only in special circumstances are there positive factors concerning its use as a prime fuel. But as a supplementary fuel there are many more opportunities. Rice husk could become an important factor in the indigenous fuel supply picture in many countries.

In Japan a rice-husk fueled kiln unit is manufactured (see 6.2.2.2) which is designed to produce an internal temperature of 1000°C, to completely burn the husk with surplus heat for drying paddy or other grains, seaweed, vegetables, fruits, fish, etc.

5.2.1.5 Indirect methods of utilizing husk as a fuel: In Japan and neighbouring countries there has been activity regarding use of rice-husk char as a fuel for rice dryers. A prototype machine for making rice-husk charcoal has been constructed by Liang (267) and a dryer to utilize this has been constructed (private communication).

5.2.2 DOMESTIC STOVES (See also Section 6.7)

In many countries of the world, husk is used as a domestic fuel in one way or another and in varying degrees. This has been normal for thousands of years, and some very good designs have been developed; in the recent past newer types of units have come into use, and with the onset of higher fuel prices there has been renewed activity, both in use and in design, in areas that had drifted away from the traditional practices.

The information available on the amount of use in a given area is almost totally lacking--very little formal information on stove use is available. It is likely, however, that the amount of husk used in domestic areas is much greater, and that its use is much more widespread, than is generally supposed.

5.2.2.1 Types of stoves:

a. Modified step grate: The use of the traditional concept of a step grate enabling a controllable blanket of husk to be maintained and fired in a small furnace-like chamber would be perfectly practical. A design by Bergoni is shown in Figure 4.

b. Pot of burning husk: The most rudimentary form of stove is simply a pot containing the husk with a suitable air bleed for necessary combustion air. This type is seen almost everywhere and exists in a broad range of sophistication of feed control and heat use.

c. Centre burner: The Garbarino design shown in Figure 5 illustrates the simplicity of this design. It is a centre-tube burner type, and would gasify well.

d. Hopper-hearth type: In a design by Pizzi, the control is on the rate of feeding, as there would be an excess of air through the hearth. This was an excellent design, particularly as a space heater. This stove was manufactured in Turin, Italy, beginning in 1912.

e. Briquettes or logs of husk: Great interest has been shown recently in the use of conventional pressing or extrusion techniques to produce a high-density fuel. Two types are the Hullite (Japan-India) and Glomera (Swiss-US), but no commercial applications of either are known to use rice husk.

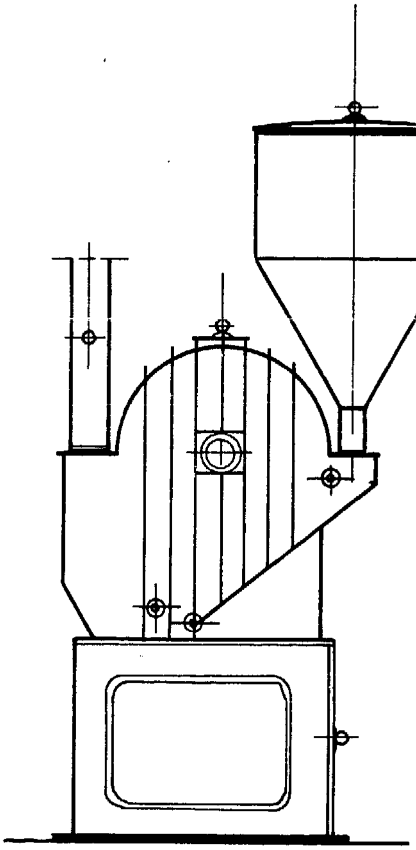


Figure 4 Modified step-grate stove (after Bergoni)

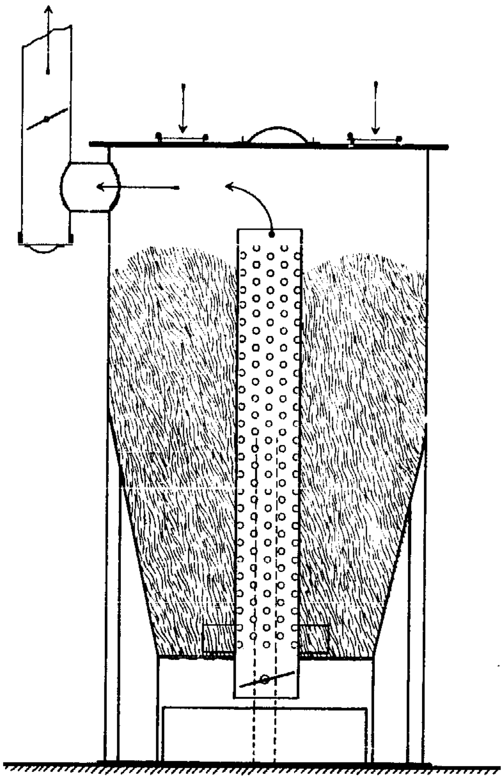


Figure 5 Centre-burner stove (after Garbarino)

f. Briquettes of char: Briquettes of char (both of husk char and mixtures of husk char and another (sometimes coal) fuel) have been used in several countries, both on a development and a commercial basis.

Many of the household stoves built use light and thin components, and with faulty operation the temperature reaches high enough values to melt or burn through the thin sections. Experimental stoves of type b above, are in use in India (W68), utilizing cast sections to minimize this possibility.

The problem of ash disposal has resulted in original systems for removal of the ash from the hearth section. Borasio (Italy) describes an automatic mechanism to effect ash disposal. As in the overall design, the range of complexity in the removal of ash varies widely.

5.2.2.2 The use of stoves in various countries:

China - It appears that for centuries husk has been used as fuel for the home. This gives each family one independent fuel supply. The traditional unit was built out of firebrick like a fireplace, and with a brick chimney. The resultant ash was utilized as a carrier in a mix for fertilizer use on the family's fields.

India - Husk has been used for centuries as a fuel in the household and small hotels, when other sources of fuel are lacking or economies are possible to counter-balance the negative features of husk use. Special stoves have been developed to utilize the husk for fuel. At W68, experimental stoves built by Singh feature a metal stove using loose paddy husk. Two models have been built, and at least one is in operation.

In Kharagpur a stove is made of two concentric tubes - 12" and 3" approximate diameter. A mixture of 25% sawdust and 75% husk is packed and tamped tightly into the space between tubes: then the small tube is removed and the block is lit, burning under self control from the inside circumference, until all of the fuel is exhausted, in a manner somewhat like a solid-fuel rocket motor. This stove has sufficient capacity for cooking a meal, and is on sale at a local hardware store at a very low price.

Also at W68, development work is progressing on a system utilizing a "Hullite" (Japanese design) machine to extrude logs of husk, 10" long and 2 1/2" diameter, one of which, in a "chullah" open-type burner pot, would provide sufficient fuel for cooking two meals for five people. A "Hullite" unit has been installed at the FCI Thanjavur rice mill, but the high maintenance cost of the extruder has prevented the commercial exploitation of this system.

Japan - Domestic heating and cooking units utilizing rice husk as a fuel were popular in Japan during the fuel-short years of World War II. This use faded during the post-war years, until the "oil shock" revived interest in such units, whose sales have risen in rural areas.

An article from a current Japanese newspaper describes a stove used to burn husk. The retail price is the yen equivalent of $102. Farmers having 1.5 hectares of paddy can produce enough husk to cook for five persons for one year. The required husk is stored in a small storage unit requiring 3 m^2 of floor space. The manufacturer (Hitachi Koki Haramachi Factory in Fukushima Prefecture) planned to sell 50 units in 1975, but has already sold 250.

Korea - In a similar but different situation, a hollow-core unit, usually made of coal powder or a mixture of paddy-husk char and coal powder, is used extensively. One of these units, 12" long and 6" diameter approximately, is said to cover the heat requirements of a family for a day.

There has been considerable work by W115 on the addition of 5-10% of rice-husk char to a low-grade anthracite, to improve the intensity and duration of the resulting fire. Details on this work can be seen in a paper provided by Park (266) (in Korean).

Malaysia - No domestic use of husk has been noted, but an interesting project concerning husk utilization has been drawn up, although apparently never executed.

A combination carbonization-briquette plant was proposed and designed for installation in Malaysia, intended for production of fuel briquettes and paddy charcoal for export, apparently primarily for the Japanese market. The specifications of the plant indicated that 80% of the weight of the raw husk would be produced as finished briquettes. This indicates that a large amount, in fact, almost all of the volatiles would be left in the char, and there might be an odour problem from burning these briquettes. This plant was based on Japanese technology and construction practices.

This plant appears not to have been built. The advisability of husk for charcoal in Malaysia is very doubtful; it would seem that a better investment would contemplate using a different raw material that would produce a higher-quality charcoal. The local use of rice-husk char as a fuel is proper and wise, but for export conditions higher-grade (lower non-active components (ash)) products would be preferable and more capable of long-term production because they have a more competitive position.

Philippines - The use of husk-fueled stoves is commonplace. Many homes have storage bins in the house, filled by merchants who haul the husk from the mill and retail it to the domestic user.

The housewives use special, locally constructed stoves--usually block, masonry or mud. Many use the concentric-tube type stove. Normally the rice mills do not charge for the husk, and the retail costs cover distribution only. There is also similar use in restaurants and other public establishments. Information concerning new stove designs can be had from the Industrial Research Center of NIST, Manila. At IRRI (W130) interest in efficient design and development of stoves is shown by Kahn.

Vietnam - In Saigon there has always been an organized market for husk for home fuel use. 50 kg bags are commonplace, a price of 35,000 piastres (US$51) per MT is the normal retail level; the use of polypropylene bags accounts for part of the price.

5.2.3 AIR-SUSPENDED FURNACES

In air-suspended furnaces, the particles are burned while in an air suspension or turbulence, as opposed to grate burning where the air filtres through a bed of husk at a predetermined rate (according to B.R. Wolf less than 1.0 m/sec velocity).

Obviously the air-suspended furnace will have a much higher air/fuel ratio and excess-air ratio, with consequent dilution and lower exit temperatures. However, the heat release is much faster, so that within a given volume of furnace the capacity will be much greater than a grate type. Further, the particulate matter in the airstream is the total weight, because the furnace gas stream is also the conveying stream, and thus could create a particulate problem. However, the smallness of the furnace for a given heat release may offset the complexity of the particulate removal from the gas effluent.

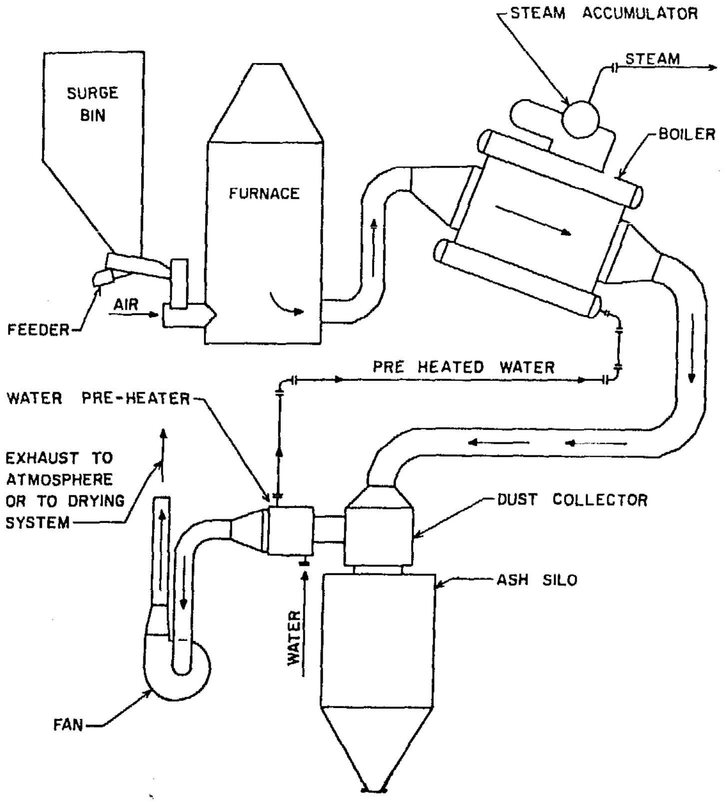
References to these furnaces appear in Kocee (170) in 1959, Gravel (167) in 1964, Finch (168) in 1969 and Mehta-Pitt (72) in 1974. These all feature turbulent combustion, high excess-air ratio and various ideas for collection of the effluent and uses of the residue.

The two which are currently being developed are described below.

5.2.3.1 Mehta-Pitt: Rice husks as a fuel for producing energy. An efficient, low-cost, easily operated method for utilizing rice husks to produce energy has been developed as illustrated by the flow diagram. It was designed to operate in conjunction with a process for producing industrial materials from rice husks (171).

It consists essentially of a feeder, special furnace, heat-recovery boiler, ash collector and draft fan. A continuous flow of husks is delivered by a mechanical feeder from a surge bin to the furnace, where the husks ignite and burn without other fuel. Combustion air is supplied by an induced draft. The hot combustion gases and ash residue pass from the furnace through the heat-recovery boiler to a dust collector in which the ash is removed from the exhaust gases. A granular ash without clinkers is produced.

The furnace is a fabricated steel, refractory-lined vessel having neither grate nor other moving parts. The style of the boiler and dust collector can be varied to suit local conditions and environmental considerations. The entire system has essentially only two moving components: the husk feeder and the draft fan.



SCHEMATIC FLOW DIAGRAM OF PLANT FOR PRODUCING STEAM

Figure 6 Schematic flow diagram of plant for producing steam

When the system is operated to produce commercially useful materials as well as energy, approximately 7,000 lbs of steam, at pressures from 100 to 400 psi, can be produced per metric ton of husks processed. On the other hand, if operated for maximum boiler efficiency solely to produce energy, up to 10,000 lbs of steam can be produced per metric ton of husks.

A pilot plant, designed to produce industrial materials and using this energy-recovery system, has been in operation in Sacramento, California since 1971. It burns 800 lbs of husk/hour and produces approximately 2500 lbs of steam/hour. A large commercial plant with a capacity of 15,000 lbs of husks/hour to produce 48,000 lbs of 200 psi steam/hour, as well as industrial materials, has been completed in Stuttgart, Arkansas, USA and has operated on a test basis.

5.2.3.2 <u>Finch-McIntyre Engineering</u>: Method of making a carbonized product useful as a filtre medium from rice hull. The rice hulls are fed continuously to a combustion zone of hot swirling gases, where the hulls are partially burned and carbonized while dispersed, after which the carbonized particles are removed. The product has a skeletal silica in the form of a lattice structure with carbon dispersed therein (168).

5.2.4 REFRIGERATION FROM HUSK - ADSORPTION SYSTEMS

There appear to be no commercial or experimental systems today utilizing husk for refrigeration in any way; however, the concept is a practical one and in circumstances where the economics are favourable, it should be considered.

The development of a cold-storage system using husk-fired direct-flame type refrigeration units could provide a direct use of husk in an area deficient of fuel and needing cold storage. Ash residue could be used as an insulation filler material.

Considering that rice is normally cultivated in tropical or sub-tropical zones, where cold-storage capacity is needed, and that the milling season is usually in the hot dry months, the feasibility of such a system is shown.

The cold-storage use would offer a direct utilization of husk, eliminating losses due to the use of multiple systems (husk-boiler-electricity-compressor).

That this concept is not new is shown in a letter from B.R. Wolf to Enrico Bianchi of 16 October 1942. Wolf detailed the following: 100 kg/hr paddy husk = 33 kg coal in calorific value; 300 kg/hr - 38-44 HP at 350° - 12/15 ctm.

After producing 38-45 HP from the escaped steam, 300 kg/hr of steam gives 192,000 calories from which one can recover 172,500 calories, corresponding to 450 kg of ice.

This concept has not been neglected in modern-day thinking. In May 1975, Walter H. Higa published "Stirling Cycle Engine and Refrigeration Systems". The Stirling cycle is an external-combustion cycle which could utilize heat from rice-husk combustion to power a Stirling engine.

5.2.5 ALTERNATIVE COMBUSTION CYCLES

Alternative combustion cycles can be fueled by any outside fuel as an external-combustion system. Any heat source will suffice, so that conceivably rice husk could be used to provide energy for the operation of these prime movers.

5.2.5.1 Stirling Engine: It is conceivable and possibly practical to have a large Stirling engine utilizing an external rice-husk furnace as its heat source. There is considerable interest in the development of Stirling engines for developing countries to utilize indigenous fuels. The Ford Motor Company has done experimental and development work on Stirling engines. United Stirling (Malmo, Sweden) has considered a low-cost engine which would use solid fuel or a producer-gas fuel source. Existing Stirling engines are not suitable for low-technology areas, but it is felt by United that less sophisticated equipment could be built to utilize indigenous fuels.

5.2.5.2 Gas Turbine: It is entirely feasible to operate a gas turbine on the energy provided by a husk source. An extended development (W171) is currently under way using as a fuel the local municipal waste (400 tons/day produces 15,000 kw). The energy source could just as easily be an equivalent supply of husk.

There are several methods to convert the raw husk into the energy supply for a gas turbine. Their relationships are shown in Figure 7.

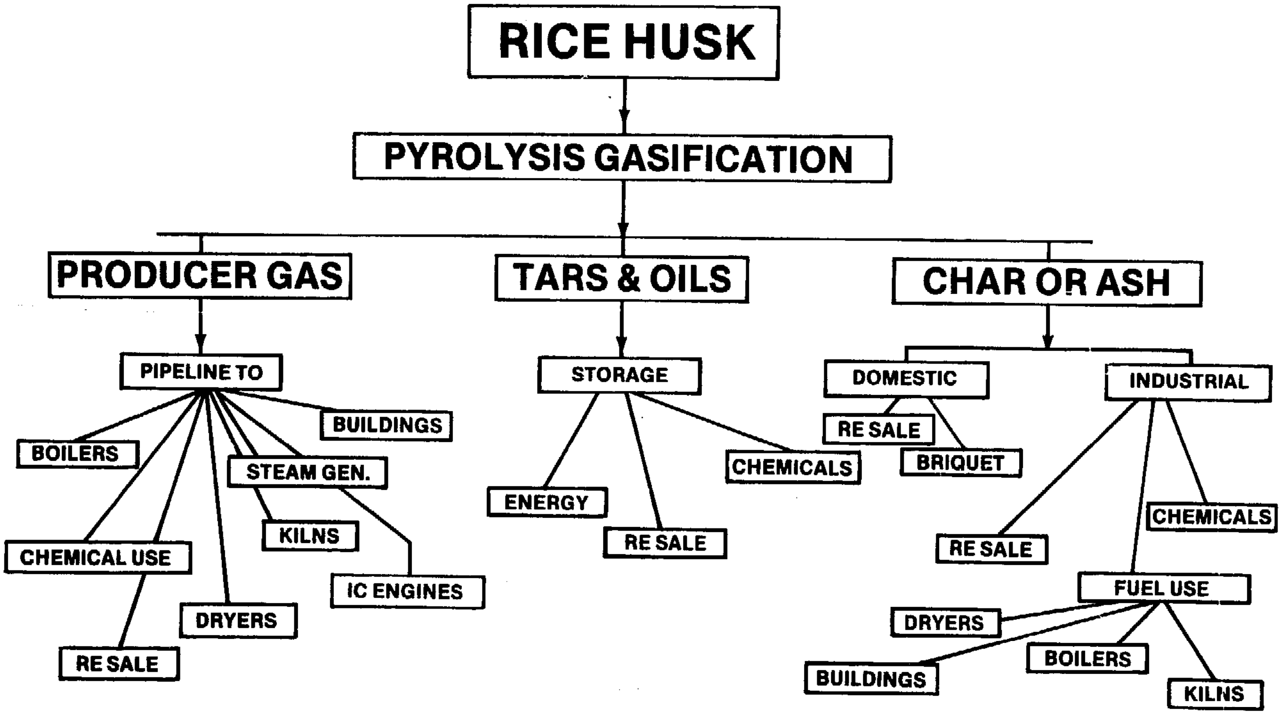


Figure 8 Pyrolysis

One of the economic attractions of flash pyrolysis is the high conversion to volatile products obtainable, as compared to longer residence-time processes. In all laboratory runs, the total volatile content of the products exceeded the volatile content of the feed. Furthermore, in many cases the weight loss from the feed (gas, water and oil yields) was greater than the volatile matter in the feed. This means that during flash pyrolysis there occurs not only devolatilization but also a substantial amount of gasification of the fixed carbon in the feed. This result, demonstrating the advantage of flash pyrolysis over long residence-time processing, is of great economic significance.

The synthetic fuel oil derived from rice hulls was supplied to an independent combustion-testing laboratory for firing in a test boiler. The results were as follows:

1. The pyrolytic oil gave satisfactory combustion in the tests. It is acidic, its properties are fairly easily changed by overheating, and it can form deposits on valves and heating surfaces if the combustion system is not properly designed. However, the system changes necessary to accomodate pyrolytic oils may not be more difficult than, say, the changes needed to accommodate No. 6 heating oil in a system designed for No. 2 oil. (See Section 6.3.2.8.)

2. The pyrolytic oil can be blended and co-fired with most residual fuel oils.

3. U.S. air pollution limitations on new units can apparently be met by using stage combustion.

4. Due to its low sulphur content, no problems due to sulphur oxide corrosion or emissions are anticipated from the pyrolytic oil.

5.3.1.2 Wallace-Atkins: The Wallace-Atkins Oil Corporation (W223) is offering, on a proprietary basis, a cracking destructive-distillation process for the conversion of rice straw and hulls to usable crude oil, "natural gas" and char. They claim theoretical yields of: weight straw and/or hulls: 2000 lbs; recovered crude oil: 1-2 barrels; gas: 16,000 ft^3; char: 750 lbs.

They state that the secret of the process is the use of a catalyst manufactured by them. No other information is available.

5.3.1.3 EES-Georgia Tech: Georgia Institute of Technology (W178) has designed and constructed a mobile pyrolytic converter intended to transform cellulosic wastes to a high-energy char-oil fuel. At the present time the units have not operated on rice husk, but rice husk could be used as an alternative input material.

Economics and commercial feasibility have yet to be proven on this system, particularly as regards rice husk.

5.3.1.4 Infra-red Pyrolysis: The equipment designed and built several years ago had as its prime objective the complete combustion of the organic compounds and the free carbon of the rice husk as a continuous process. The machine is a continuous processor, with raw husk as a feed material and a low-carbon or carbon-free residue that is unique in its physical and chemical properties. It is also capable of varying the degree of carbonization as desired. The ash residue is of low density; no breakage or pulverization of the husk form occurs during the pyrolysis. The generated heat can be utilized through any appropriate system for steam generation or for drying purposes. The machines are modular in concept and have low initial cost, maintenance and operation costs. Further details are available from the author.

5.3.1.5 Egyptian Refractories: The Egyptian Company for Refractories (W11) has developed and is using a pyrolytic-process system to produce a residue suitable for production of refractory brick. In their system, charred husk from the pyrolysis unit is processed in a kiln to produce the necessary white silica. Pyrolysis gas is used to provide energy for the processing, water heating for the hydrolyzers or fuel if desired; fractional distillation is also possible.

5.3.2 GASIFICATION

5.3.2.1 U.C.D. (W219): A current study and development programme (Wii5) is under way at the Davis campus of the University of California concerning gasification of crop residues. One of those being tested is rice husk. Operating producer-gas generators of the downdraft type have been designed and constructed to provide producer gas for the operation of a modified internal-combustion engine of the gasoline type. Development work is also progressing on the adaption and conversion of a used diesel engine to dual-fuel (P.G.Diesel) operation.

5.3.2.2 T.P.I. (W161): Gasification of cellulosic raw materials, one of which is rice husk, is the focus of current work at the Tropical Products Institute at Culham, U.K. A programme resulting in construction of a gas generator and associated prime mover equipment is under way. Use of dual-fuel engines and conversions of low-compression engines are being investigated, drawing on the experience and background of W160 in the design and construction of producer-gas generators.

5.3.2.3 Monticello (W92): Mention of the existing rice-husk producer-gas generator and gas engine prime mover in Monticello (Pavia), Italy, must be made here to describe what is, as far as is known, the only remaining installation of a Balestra gasogeno and complete system in operating condition. In the 1940s there were many of these units powering rice mills in this region of Italy. This is a traditional-style system, of about 60 HP, powering both the mill lineshaft and an electric generator. There appears to be no similar unit in any other country.

5.3.2.4 Thermex: An integrated unit which can use rice husks as a fuel for the production of producer gas has been developed by the Research Council of the Government of British Columbia (Canada), and an exclusive license has been granted to Alberta Industrial Developments, Ltd. for marketing the equipment under the name "Thermex Reactor". This system utilizes a fluidized bed to convert small particles of suitable raw material into a combustible gas with a thermal value about twice as high as that produced by a conventional gas-producer. It is also claimed that the design encompasses safety features not normally found in producer-gas generators. Charcoal and oil are the end products, their composition depending on the characteristics of the desired gas production.

5.3.2.5 Refratechnik Albert: W43 has developed a procedure and an installation for the production of low-carbon ash (<3%C), tar and furfural. This technology, named "Rice Husk Refinery", can decompose the rice husk in one process under production of ash for refractory building materials and heat insulating plates (calcium silicate), tar and furfural, under conditions inoffensive against environment, by integration of the installation into a rice mill. The latent heat capacity of the rice husks is being utilized so that the process passes off without additional energy. Refratechnik has an established know-how for the processing of the ash to refractory bricks and building materials.

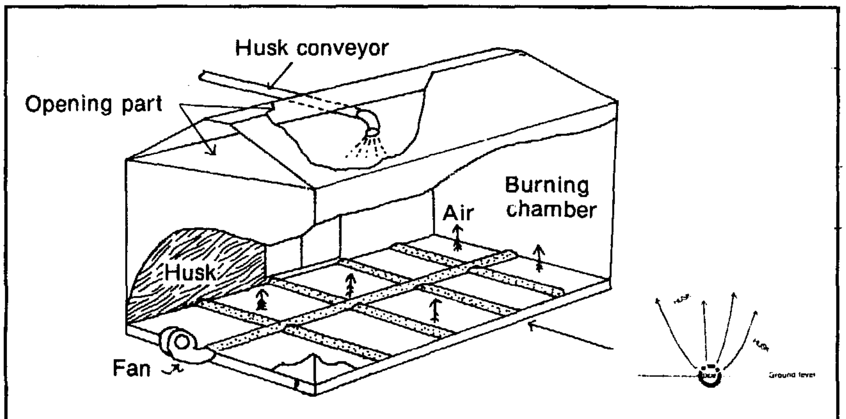
Patent applications for the procedure and the installation have been filed.

Low-carbon, white rice-husk ash suitable for use in manufacturing refractories and building materials is prepared by first removing volatile constituents (furfural, vapour, gas) by heating the husks to a relatively low temperature, below their ignition point. Fixed carbon is then oxidized in the presence of a reagent by heating the husks to a second temperature above the separation temperature but below the crystallization temperature of the SiO_2 in the husks: a heat treatment at a third temperature, above the crystallization temperature of the SiO_2 follows, to produce a uniform SiO_2 crystal structure.

The first pilot equipment was built in 1974. It showed qualitative results for the production of low-carbon ash, vapour, gas, furfural and tar in the discontinuous process. Pilot equipment, with a production of 150 kg husks/hour, is currently being operated in a test regime. (See also Section 7.7.1.1.)

5.3.2.6 Building-burning:

Burning of husk in buildings or roofed walled areas has been done in a great number of countries. It is most frequent today in Japan, in a variety of types of buildings, one type which is shown in Figure 9 after a design by Ban (W103). Somewhat similar ideas, but on a much larger scale, have been used for many years in the United States. Most of the commercially-used ash in France is produced in similar buildings. In many countries, quite sophisticated structures are used in order to control the burning rate and subsequently the ash analysis; a typical building in the United States is 40 feet wide, 100 feet long, about 36 feet high, of steel-plate construction with asbestos roof-sheeting. It is loaded pneumatically to a depth of about 28 feet, and air-supply feeders in the floor are controlled to furnish the correct amount of combustion air for total combustion. The typical cycle, shown in Figure 10, requires 39 days. The building will hold about 200-250 tons of husk, which produces 40-50 tons of salable ash. Air-pollution control dictates the configuration and sophistication of the buildings.

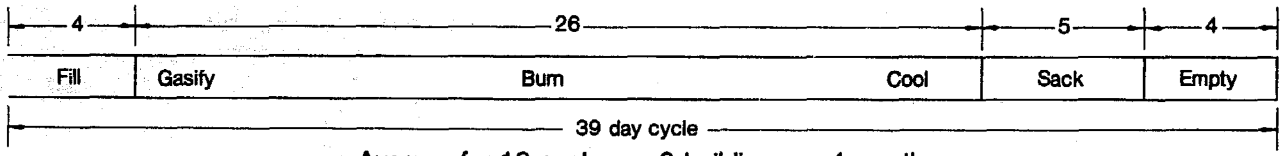


Small building for Husk burning (direct burning type)

Figure 9 Building-burning of husk (after Ban)

Two new mills (Japanese-designed and built) are being installed in Sri Lanka (Uda-Walawe project). Both feature controlled husk-burning as an integrated feature.

The primary feature of the construction is that the burning rate of a mass of husk can be accelerated and a desired end-product can be produced consistently. In areas where rainfall is not a problem, no roof, but only walls and the air-feed system, are needed.



Average for 18 cycles — 6 buildings — 4 months
TOTAL PRODUCTION — 52,257 bags.

Figure 10. Building-burning husk - Time cycle

5.3.2.7 Lantz: A Lantz converter is a hybrid pyrolysis, gasification and carbonization unit (W187). The carbon or char recovery varies according to the gas characteristics desired.

A unit being fed 2 tons/hr of rice husk will produce about 16 million BTU/hr net output, using about 3 million BTU for internal operation of the unit. Operating temperatures normally run 600° to 800°C but can range from 120 to 980°C. Usually the Lantz Converter has been installed as a waste-disposal aid, the heat generated sometimes being used for steam or drying.

5.3.3 DISTILLATION

5.3.3.1 Japanese: Distillation is normally thought of to provide for the production of various fractions from the volatiles and of a char containing essentially the carbon portion of the residue along with the silica content. Carbonization as sometimes carried out in Japan is essentially distillation, but no use is made of the fractions. The whole process is designed for the production of char for domestical or industrial use. Some Japanese carbonizers are of the rotary kiln type, some of them the furnace type.

Work was done primarily by Jacobs (118) concerning distillation and distillation products. Marcusson (125) earlier was concerned with rice-husk distillation. Several times over the past years there have been projects to utilize distillation procedures, but no successful commercial exploitation of any aspect of distillation of rice husk appears to exist at the present time.

5.3.3.2 Resource Recovery Systems (W199): Work is in progress to recover fuel gas and chemicals from agricultural wastes, including rice husk. The chemicals include ammonia, light aromatics, alcohols and ketones. The residue is sterile, inert and odourless. Crane (110A) describes the current results using rice husk as an in-feed material, and states that the state of the art may be considered as ready to progress from a pilot-plant-sized installation to a full-sized resource-recovery operation. The furnace utilizes a molten-lead bath reaction zone, with the feed material falling onto the fast-moving stream of molten lead. The analysis of the husk in feed material was given as: 8.54% moisture, 59.9% volatile matter, 14.24% fixed carbon, and 17.63% ash. The fuel gas has 500 BTU/ft^3, with 21.13% H_2, 33.80% CO, 18.25% CH_4, and 19.30% CO_2.

5.4 INTEGRATED SYSTEMS

5.4.1 PARBOILING

5.4.1.1 Traditional Systems: Traditional parboiling techniques, which often utilize husk as the energy source, include the "chatty" system of Pakistan, which consists in filling small earthenware jars with paddy and water, and standing them on a bed of rice husks mixed with huller bran. The bed is then set alight by sprinkling it with hot ashes. Combustion is slow, and the water in the jars is gradually brought up to 50-60°C. The paddy remains from six to twelve hours in this hot water and absorbs enough to make it ready for the steaming stage. The water is then poured off, and the grain is put in large iron containers, wide and shallow in shape, which are placed over a furnace fired with rice husks. The damp rice is continually stirred, and small amounts of water are added from time to time to compensate for the evaporation. The heating operation may last from 30 to 60 minutes, after which the rice is spread out to dry in the sun on a hard earth or concrete floor.

A second-generation parboiling system of the type described as a "Goya plant", common in Sri Lanka, normally uses rice husk as its fuel, though some firewood is also used. The "Goya" system uses the husk furnace under the tank first to heat the water for soaking, and then for steaming. A small power-driven husk-blower is sometimes used to feed the husk to the furnace area, but in some cases manual flicking of the husk is the method used. Usually the wet paddy is spread on a drying floor to be sun-dried.

5.4.1.2 Modern Techniques: However, "the introduction of mechanized milling in the Far East and the consequent adoption of the boiler and steam-driven engine to produce energy for the processes have altered parboiling techniques by the use of pressurized steam" (Gariboldi). Obviously, the best way to produce this steam is with the husk produced in milling the parboiled paddy.

Later parboiling techniques utilize formal boilers, both horizontal and vertical. There are many variations of the conditions. An illustration of the pressure balances in a modern Italian unit is given in Figure 11.

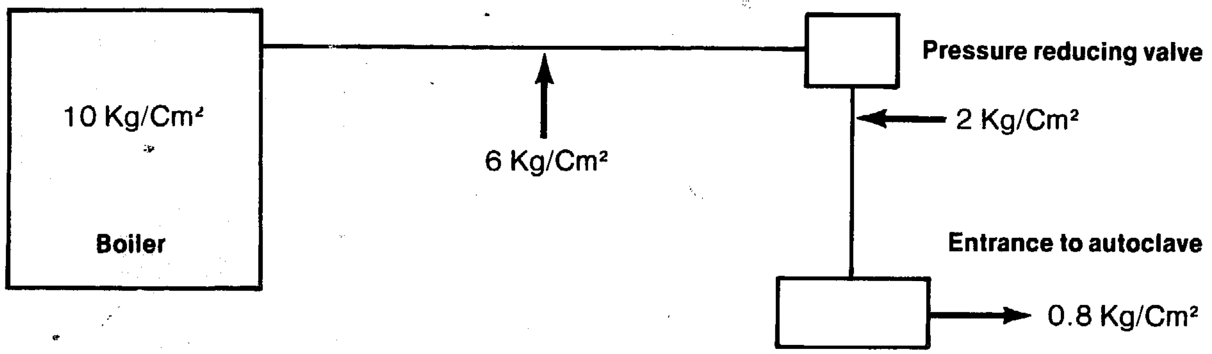


Figure 11 Pressure balances in a parboiling unit

The amounts of steam needed for parboiling also vary, of course, according to the efficiency and sophistication of the installation.

For example, an old report (W60) says that 600 kg/hr of steam is needed for drying, and 200 kg/hr for soaking/steaming, for a total consumption of 800 kg/hr. Processing 1 ton/hr would provide 200 kg/hr of husk and about (at a 3.0 ratio) 600 kg of steam, which would fall short of the calculated need of 800 kg. Another estimate gives 120 kg for soaking, 60 kg for steaming, 550 kg for drying, and 20 kg for loss, for a consumption of 750 kg/ton of paddy. These consumption requirements point up the necessity for an efficient steam-raising system first, and for attention to parboiling system losses and inefficiencies secondly, if full utilization of the husk fuel available is desired.

There is a great difference between Asian and Western parboiling in the consumer demand of quality of the milled parboiled rice. The Asian goal in energy-free parboiling is to provide steam and hot water for soaking and steam; drying; and power for mill operation, using the husk supply as the only raw fuel.

If this goal can be achieved, the Asian boiler can enjoy complete independence. But none appears able to do this, because the only feasible way would be to use a heat-coupling system; while there are many systems which could be set up this way, this has never been done, because of the lack of knowledge of how to do it and the ignorance of the advantages of such a system. There are obviously some situations (due to the method used for parboiling) where an "all three" system cannot be used. If the parboiling process requires much more steam than is available, then a dual use is impossible. However, in almost every case a practical and economic system can be installed that will enable the desired parboiling and drying to be accomplished and will produce adequate power for all milling and ancillary needs.

Most systems use steam heat-exchanger dryers for the intermediate step, although there have been instances of direct transfer designs. One by W110 utilized furnaces for the dryers with a heat release of 1.5 x 10^6 kcal/hr, and a boiler for the steam supply with an evaporative capacity of 750 kg/hr. This was a 2 ton/hr plant on nominal capacity.

The amount of steam needed to heat one ton of paddy varies according to the degree to which the starch in the caryopsis must be gelatinized and also according to the methods of heating. In a modern plant it is considered that 80 kg of steam are required for heating one ton of paddy. If steaming is done in open containers by injection at ambient pressure, the quantity will, of course, be considerably greater. In a modern plant the quantity of steam needed to heat a ton of paddy is a mere fraction of that required for the whole process, because steam is also needed for heating the steeping water and the air in which the paddy is artificially dried. The steam required to produce parboiled rice in modern plants comes from high-pressure boilers and is piped out to the various points where it is needed at a lower pressure. Steam used for direct heating must be saturated when it comes into contact with the paddy, so that most of its heat is transmitted at the lowest temperature corresponding to its pressure.

In high-intake plants the steam can be produced at high pressure and used to power turbines or engines before it enters the heating system of the parboiling plant at low pressure. In this case, before it comes into contact with the paddy every trace of mineral oil coming from the lubricants used in the motor or steam turbine must be removed.

Modern plants use either a continuous or a batch-type cycle. In the former, the steam produced in the boiler is in constant demand, as the individual operations are continuous. In the latter, steam utilization has its peak and off-peak points according to the work to be done.

To avoid the need for large boilers which can produce enough steam to meet the peak demand levels with continuous adjustments to the fuel supply, an accumulator is sometimes placed between the boiler and the plant's piping system. This accumulator takes up the excess produced in the boiler, and supplies it as and when the plant requires it. The quantity of fuel consumed is to a great extent determined by the burner output, by heat insulation and by all the various economizers commonly used in modern steam-generating plants.

The husk obtained from shelling provides the cheapest form of fuel usually available at the mill. If properly utilized and if the plant is efficient, it is enough to supply all the heat needed for the whole parboiling process. One ton of paddy yields 180 to 200 kg of husk; i.e., about 3,000-3,500 kcal/kg, or 5,200-5,500 BTU/lb. The steam obtainable from burning this quantity of husk is 550-600 kg, a quantity sufficient for a rationally organized process.

When used to make steam, the husk is usually burnt in horizontal or vertical smoke-tube boilers. The cheaper vertical boiler has the disadvantage of providing a lower output of steam, as the water surface is much smaller than in the horizontal type of boiler. The latter is usually preferable if the capacity of the plant exceeds one ton/hr.

In India, a very large portion of the rice milled is parboiled, and almost all the parboiling systems, large or small, use the husk as their fuel. In Kollegal (Mysore), a small plant using a vertical cross tube (VCT) boiler (99 ft^2) of about 8 years of age had had no problems during this use. It uses chemically treated water and processes about 2000 kg of paddy per hour, using 10 to 12 25-kg bags of paddy husk to fire the boiler, with a traditional step-grate furnace.

A plant in Madras (W84) uses a new type of parboiling unit, which has 4 cylinders (fluid-bed screw conveyors), two on either side of the furnace, one over the other. The paddy is soaked in soaking tanks in ordinary cold water for about 24 hours. This paddy, with a moisture content of over 30% is fed through the hopper and passes through the cylinders one after the other in a continuous process. In the first two cylinders, the paddy is parboiled, in the third cylinder it is dried, and in the fourth, with the help of fresh cool air, it is cooled. The heat requirements of this parboiler are covered by a centrally located husk-fired furnace of an essentially traditional design.

In Alor Setar, Malaysia, a mill (Thean) used two husk-fired boilers to provide steam for mill motive power and for soaking and steaming. Drying is done on a sun-drying floor. Here two types of boilers are used: a classic locomotive type and a modified marine type. A vertical steam engine drives one mill and a horizontal engine the other. Both parboiled and raw milling is done.

In Thailand, most rice is not parboiled, but the portion parboiled uses husk-fired systems. The leading Thai rice mill (W146) uses a parboiling and drying system of their own design, utilizing husk from the rice mill. Their parboiling resembles semi-parboiling, a rice hardening which penetrates partially and increases the milling yield. This produces a light product with no appreciable change in flavour.

Table 20

Fuel balance for a parboiled-rice mill

Requirements per ton of paddy			Husk equivalent
Water	- 2,200 litres		
Steam	- 250 kg for steam uses		100 kg Husk
Fuel oil	- 25 kg for drying		75 kg Husk
Electricity	(parboiling) 20 kw	60/65 kw	
Electricity	(milling) 40 kg		160 kg Husk
			335 kg Husk

Table 20 shows that with traditional methods it is not possible to operate a parboiling plant fully fueled by husk. However, if heat-coupling generation and steam heat-exchanger dryers were used, it would be possible to operate the complete plant on the husk removed.

Thus, parboiling and drying would use 750 kg steam/ton of paddy, which at the traditional ratio of 3:1 would require 250 kg of husk, which is impractical, while with a modern sophisticated system a ratio of 4:1 is feasible, and this would meet the requirement. (For example, the system at Gimeaux, France (W23), is operating at a 4:16 ratio. The Tulio power plant (W134) operates at a 4:1 ratio, and the Surinam plant (W144) at greater than 4:1.) By using a back-pressure (heat coupled) engine generator system the necessary electrical energy (60/65 kw) could reasonably be produced and the process requirement be supplied from the low-pressure side.

In many Asian countries only one function is performed at present by the use of husk-fired systems. Many low-technology operations use yard drying, and because of the low efficiency of their boiler-furnace system, all of their husk is consumed just to produce the steam necessary for the first steps. While achievement of the desire to perform all three functions is several years away, it is currently entirely possible to perform two. The most practical is to install heat-exchanger mechanical-drying units for the intermediate drying step.

Most boilers are relatively inefficient; many are old vertical cross tube, Lancashire, Cornish or locomotive types, with a makeshift or undersized furnace. Usually, no insulation is provided, the possibly favourable economics being hardly thought of. One outstanding parboiling design at Chavalakade, Sri Lanka, (British design) combines pressure parboiling with excellent steam heat-exchanger units. Husk-fired boilers backed up by oil-fired boilers originally provided steam for all purposes, including power generation for the milling process. Today there is no need for the oil-fired boilers, as the old steam engines were replaced several years ago by grid power, so that the husk-fired units provide the steam necessary.

In France, at Gimeaux (W23), a husk-fired boiler installation provides steam for parallel lines of parboiling and pre-cooking processing. This unit is a sophisticated pass-through type utilizing combustion-tube burning.

In Italy, Bariboldi builds for sale (W90), and uses (W94), efficient pass-through type boilers performing a degree of combustion-tube burning. These are modern, high-technology, sanitized installations that provide completely adequate steam for parboiling, drying and plant heating duties.

Husk-fired boiler units in parboiling mills have been traditionally installed in southern India. There are several experienced, capable manufacturers of husk-fired boilers for this purpose. Most use traditional step-grate systems. None uses air-suspended types which allow much greater heat-release values.

Subject to satisfactory performance of the new installation by Pitt at Stuttgart, Arkansas, U.S.A. the design of husk-fired steam-producing systems can be expected to advance.

5.4.2. MOTIVE POWER - PROCESS-RELATED

Husk can be utilized in the operation of rice mills in the following manner:

1) via boiler-generated steam,
    a) to operate steam engines or turbines and drive the rice milling machines, either
        i) directly by lineshaft or
        ii) indirectly by electricity
    b) to operate steam engines or turbines as in a) above and concurrently produce and utilize exhaust steam for heating purposes in processing (parboiling).
2) via producer gas (gasogeno),
    a) to fire a steam boiler, then as in 1) above
    b) to provide fuel for internal-combustion engines, either
        i) gas engines or
        ii) dual fuel engines (pilot fuel)

When considering rice husk as a fuel for an in-plant power system to compete with mains electricity there are several factors which must be considered before the decision to proceed is made on purely economic grounds.

First is the need to consider that the system selected will only attain a long life, with a continuation of the original output and efficiency, if the proper steps are taken for maintenance and upkeep. In the words of Hawkey (W159), "We find that normally they (the operators) do not clean or maintain the system (boilers, engines, condensers, heat-exchangers, etc.) and the system deteriorates due to a lack of upkeep. The system is dying from the moment of startup."

Unless the proper preventative maintenance is contemplated, it is irrational to install an expensive system that is supposed to pay its way from the savings generated. It is necessary to design the system properly for long life (water treatment being the prime consideration), and then to operate it in such a fashion that the long life is realized.

Secondly, it must always be remembered that there is no need to generate more power (electric or steam) than is required on a purely economic or national-interest basis; in other words, there is no need to have husk left over. One should not strive to install equipment to make a more efficient plant than is practical - there would be husk that would have to be disposed of, and there would be a greatly increased capital cost to reach the higher efficiencies. In areas where mains power is cheap (excess hydro-electric power, for instance) there is no need to install an expensive husk-fired generating system. It also must be remembered that a husk-fired boiler costs about twice as much as a gas- or oil-fired boiler of the same rated capacity, because of the exchange ratio of 15/18 kg of steam/m^2 of surface for the former and 40/42 kg of steam/m^2 for the latter. Also, there is the additional cost of the external furnace.

If, however, the desire is to furnish electricity for other than the rice mill alone and on a continuous basis, it would be best to consider the husk as a supplementary fuel, primarily because of its possibly discontinuous supply. This approach is valid only when the use of indigenous fuel is dictated by national or economic reasons: any use of husk for power alone, based on its fuel value, will result in too high a cost, both for capital outlay and operation, particularly in a smaller plant. Only in a very large plant would husk firing be practical and thus best as a supplemental fuel.

For example, in Germany (1974), a power plant for a 2 ton/hr rice mill was quoted at $106,700, and another 4 ton/hr mill at $432,000 (two different kinds of power plant).

Again, in Italy (1975) the electricity cost for a large rice mill was quoted as about $100,000 per year. They calculate that a husk-fired power plant would cost about $60,000 in labour alone, while interest is at a 15% prime rate. In this situation, there is no question but that a husk-fired power system is impractical.

In order to enable the reader to better understand the details of some factors of husk-powered units, some selected installations are discussed below.

(1) The steam power plant at the SML mill at Wageningin, Surinam (W144) was as originally installed: two Kusters-Aken boilers (1956) with a Mannesman-Meer vertical steam engine driving a 570 kw generator. Pressure was 16 atm, temperature 300°C, and consumption 5.5 tons of steam per hour. The steam plant, built in 1958 with no water treatment, had major problems in 1959/61; in 1963, two water softeners were installed and changes were made in boiler systems. The unit then ran with no appreciable problems until 1971, when cracking of the steel plates of the boilers was experienced. A survey was conducted and decision was made to dismantle the old system and install a new one.

The old steam generator was used in conjunction with several diesel-driven generators to provide an overall plant capability of 3200 kw. The peak requirement of the complex today is 1780 kw, of which the new husk-fired turbine unit furnishes 67%. The present standby diesels are 2-500 kw and 2-450 kw, which barely allow peaking capability on diesels alone but can be used in combination. In the original plans there were two other diesels of 350 kw each, because the husk-fired unit had less than half of the new installation capacity.

The new one has two Lambion furnaces; two Sillers & Jarmat boilers, 27 atm, 450°C, 5.5 tons/hr each, with a 5-stage Terry turbine, 1200 kw AEG generator. The new plant uses 3 tons of husk per hour to produce 11 tons of steam which generates 1200 kw.

The old plant had a much higher maintenance cost because it was non-condensing and therefore needed total makeup water; without the boiler feedwater treatment system, the result was poor. Ash removal was labour-intensive with very difficult working conditions; the new plant has an ash channel for water removal of the ash, which is dumped wet.

(2) The power plant at Tacurong (W134) was part of an overall Buhler - MIAG installation (25 ton/hr mill). The Spilling-furnished power plant equipment has two Lambion dual-mode grates, two Sillers & Jarmat boilers of 20,000 lb/hr each, with three Spilling 640 kw, 4 cyl steam motor-generator sets. These furnaces have a movable two-section grate. Of the electricity generated, about 800 kw are used on plant for mill operation and other plant functions, about 1,000 kw are sold commercially to the local community and 120 kw are available for reserve.

In the design of the plant, three engines were chosen in preference to one large turbine to secure flexibility, and later this proved to have been a wise choice since so far the plant has often operated spasmodically (sometimes at only 20% capacity) owing to lack of paddy.

The furnace performance here is good: it delivers a 25% ash residue, a burning efficiency of 92-93% and a boiler efficiency of 78%. The fuel consumption rate is a maximum of 2500 kg/hr per furnace, the excess-air ratio 1.7:1. For the husk developed within the mill, the cost was .12 peso (Philippines) per kw; outside fuel brought in, where transportation costs are borne by the mill, cost .22 peso/kw.

In order for this plant to be self-sufficient in paddy requirements, a growing area of 20,000 ha is needed. At the present (1975) the mill has only 200 ha of its own and has a surrounding 2800 ha furnishing paddy. The development of the surrounding farming land did not match the requirements of the mill--the shortfall was about 80%. Therefore, the economies of the mill and power plant have not been optimized.

The installation of the three generator sets with two boilers gives however good flexibility to the plant. When paddy is short, the milling operation can be run easily with one boiler and one engine, and the husk stored to provide longer hours of commercial supply, albeit at a lower kw level. Thus the power plant becomes a profit centre that can produce two periods of income for each period of mill operation. The original design also provided for a rice-bran oil-extraction plant, which has not yet been added.

(3) A traditional system installed in Robbio, Italyrun from 1917 to 1970 (when the mill destroyed by fire, the power plant not being harmed), used two Babcock & Wilcox water-tube boilers, 17 atm, and a 750 CV Rateau turbine driving a Brown-Boveri 625 KVA (550 kw) generator. During its operational life, this plant ran smoothly and well. It had available 2 tons/hr of husk to produce the 550 kw; however, not all of the husk supply was used as a fuel, or it was burned in excess as a disposal technique.

Borasio writes that it used 1200-1300 kg per hour, which would indicate an efficiency comparable to, or a little better than, current power plants.

(4) The traditional Lokomobile type engine-boiler was manufactured by B.R. Wolf and also by Esterer. A typical one, at Tiruvarur in India (W69), furnishes 1100 kg/hr of steam with a 140 HP engine using a nominal 400-500 kg of husk per hour; according to Pingale (227) the husk burned is one fourth of that produced, but according to Ramalingam (181B) the 400 figure is nominal. The engine (140 HP) uses about 980 kg/hr of steam; the boiler has an estimated area of 1,000 ft^2, and is superheated. This engine also powers a 30 kw generator in addition to powering the mill. These engines had a load capability ranging widely; a normal 230 HP-rated engine could run continuously at 270 HP and would easily pull 325 HP for extended periods if necessary. They ranged from 25 HP to 430 HP (normal ratings).

(5) Lokomobile units are found in almost every country in the world--some very old, but still performing. They were built from about 1900 until the 1960s, when B.R. Wolf discontinued their production. In Asia many of these engines still operate. In Italy only two are known: one at the Campiverdi mill near Bologna and one at S.A.P.R.I. near Pavia (W96). These units were often used in back-pressure operation.

Schule says that in their situation normal rice-milling requires about 65-75% of the husk available when used in a Lokomobile-type system, with a stepped grate furnace.

According to Borasio (108):
100 kg of rice-milling capacity requires 5-6 HP
1 kg husk = 2.5-3 kg steam
1 HP = 4.5-5.2 kg steam.

Schule says 1 HP = 8-6.5 kg steam.

According to Spilling a Lokomobile has an overall efficiency of 17%.

Normally, such units do not use much over 300 psi because of safety restrictions on fire/smoke tube boilers.

(6) A projected Malaysia installation could take the following form: a 6 ton/hr mill (current LPN installation); installed: 800 HP total; actual requirements at various seasons: peak for drying and handling and milling: 550 HP; half-load drying and milling: 400 HP; milling with some handling: 280 HP; plus 40 HP for lighting and accessory use.

A practical solution seems to call for three units: a steam unit of 350 kw; a diesel unit of 250 kw; and a diesel unit of 50 kw. This combination would provide the lowest overall cost compatible with the feasibility needed. Such a combination would be economically feasible if 1974 fuel costs rose by 50%. The system was said to cost about $675,000, plus about $120,000 for the civil works. (Malinowski, W119).

It must be remembered that such an installation could only be considered at a location where mains power is not available because there is no power grid in the area of construction, or the present mains system does not have the capacity to accept the additional load (in that case it would be best to eliminate the 50 kw generator and service the lighting and small accessories from the mains), or where the design utilizes indigenous fuels in the national interest.

(7) Mention should be made of the use of husk-fired power plants in Thailand and the use of Thai plants in other countries. Most (95%, it is said) of the Thai rice mills are husk-powered, usually with a traditional (Lancashire-Cornish) boiler design and an engine patterned after English (Marshall) or French horizontal engines of 1900/1910 design. These engines and boilers are constructed locally (24 manufacturers in Bangkok alone), usually as an element of the mill construction programme, in individual shops (factories)

specializing in complete rice mills. In some cases the boilers are constructed spearately. Usually these are riveted boilers, heads hand-formed, with hand riveting and hand peening. Several mills in Malaysia have been constructed by Thai firms. One at Butterworth, completely manufactured in Thailand, has a capacity of 6 tons/hr.

(8) General comments. a) Ramalingam (181B) has shown that the running cost of a steam engine and boiler (under 10 HP) will be comparable to that of a diesel engine if the cost of fuel is below $4.20/ton, the 1975/76 figure would be $7.00/$8.00. In a country such as India it would be well, because of national interest, to use an indigenous fuel, even at a higher cost. Moreover, the small steam unit is labour-intensive, a factor that must be considered when calculating costs.

(b) Interesting is the knowledge that a 300-kw generator set run by a waste-heat boiler will provide about 2 million kwh/year; at 1 cent per kw this is equivalent to about $20,000/year.

(c) At the Tacurong plant the power plant represented 32% of the total plant cost; however, it must be remembered that only 31% of the power plant's capacity is used for operating the mill, the balance being used either for running other equipment or for commercial sale.

(d) In India the purchase of a new engine/boiler unit is sometimes not feasible from an economic standpoint or not possible because of political considerations. However, in India there is a goodly supply of used units capable of powering a 2 ton/hr paddy mill. A used 50 HP engine and a matching boiler can be found on the market at the reasonable price of about $14,000.

(e) The efficiency of husk in firing boilers is 35 to 40% that of coal. It must be remembered, however, that husk is almost always used in coal boilers with an external furnace added. The external furnace is almost always a step grate furnace, and the air flow requirements are probably not always matched properly for maximum overall efficiency. These installations are operated in a mode that results in an excess of husk for the assigned task, so efficiency is not thought of as being paramount.

(f) Hawkey (W159) has stated that in 1973-75 15 husk-fired power units were installed in the following countries: Nigeria, Liberia, Sierra Leone, Pakistan, Indonesia, Sri Lanka, Bangladesh, Malaysia, Nepal, Philippines, South Korea, Taiwan. These were in 2 to 5 ton/hr rice mills, and over half were lineshaft mills. It was not clear whether all were new or whether some were reinstallations. Another projected husk-fired power plant is a 5,000-kw unit for a 34 ton/hr (2 unit) rice mill to be built near Palembang, Sumatra. Its present status is indeterminate.

(g) A comprehensive study of the relation of costs incurred in the use of steam and diesel engines has been carried out by El-Mawla (175). Studies such as this, showing comparative values, and in fact any cost relation determination, must always be accepted under current conditions of fuel, investment and operation costs, to be of value in planning.

It was brought out in this study that the factors of availability and cost of qualified operators and the necessary spare parts are important when considering the various options available.

5.4.3 BRAN STABILIZATION

Rice bran stabilization concerns itself with methods to obtain better keeping qualities of freshly milled rice bran. Our interest is in methods utilizing a heat source to inhibit the FFA rise so that the bran can be stabilized at the receiving level.

Some methods of stabilization utilize dry heat, others a transfer medium, but in any case rice husk could easily and logically be used as the raw fuel of opportunity.

In some cases, where moisture is added, a simple method is to use direct application of the steam and then transport in a heated air stream; of course, husk is always used as the raw fuel.

Stabilization using husk as fuel is suitable where 20-40 satellite rice mills furnish stabilized bran to a central oil-extraction plant. The fueling of the stabilization systems at each mill, utilizing their in-house supplies of husk for fuel, would be simple, but there appears to be no commercial bran stabilization plant of this type.

5.4.4. PROCESS STEAM - FURFURAL

In the processing of rice husk for the extraction of furfural, it is common practice to use the residue as fuel or as supplemental fuel for the boilers furnishing the process steam.

The raw husk is used as the raw material, and the reactor residual is then used as fuel. It is in a wet form, so it must be burned in a furnace equipped with a grating system that will allow the use of the wet fuel.

After removal from the furnace the char/ash final residue is sometimes utilized commercially.

There is no furfural plant operating on rice husk that uses the heat-coupling principle to generate electricity as well. In some cases, the rice husk is charged into the reactors along with another available raw material and the residue is therefore a mixture. The mixture of furfural residues has particular properties, and in some uses exhibits better characteristics than either of the residues alone.

There is no general agreement on the equipment to be used in a wet-residue furnace/boiler system. Each of the few operators (four are known) of this type of plant has his own views on the best way to burn the wet fuel.

5.5. OTHER RELEVANT FACTORS

There are several areas of concern that must be considered whenever husk is used as a fuel.

5.5.1. CORROSION (See also Section 6.1.6.4.)

In all heat systems, care must be taken to accommodate the occurrence of corrosive condensation if in the discharge of the heat source the temperature is allowed to fall below the dew-point of the gas. In the practical sense it should not fall below 200°C at the entrance to the stack; otherwise corrosion will be heavy, and replacement of affected parts or the use of corrosion-resistant materials in the original installation will be required.

The loss of efficiency by use of a high stack temperature must be balanced against the maintenance cost of corrosion-related elements. This is particularly true when considering direct-fired dryers. In the dryer, of course, the discharge temperature must, by dilution or in some other way, be brought down to a low enough temperature for proper drying of the product. Obviously, if this is below the dew-point of any conveyed moistures it will then invite corrosive problems. Therefore, in a dryer designed for continued operation the use of corrosion-resistant materials must be considered.

The problem in a direct-fired dryer is not of the same severity as in the stack of a boiler, because in a dryer the dilution of a quantity of ambient air to get the proper paddy-drying temperature reduces concentration to an acceptable level.

5.5.2. FLAVOUR PROBLEMS

Concern has been expressed regarding the flavour change in the rice grain when subjected to husk-fired direct drying. There are widely divergent opinions as to whether there is any flavour change, and if there is, whether it is a problem.

Some feel that if combustion is not complete in the furnace section there will be unburned gases due to gasification, but that if combustion is properly regulated there is no flavour problem.

At IIT-Kharagpur, when direct-fired paddy drying has been studied (179), the workers feel that there are no bad effects on the paddy.

Pingale (W60) feels that on small moisture reduction passes (2% more or less) there would be no problem. Only if a large moisture reduction (6-8%) was attempted would there be an odour.

Bhattacharya (W50) feels that one should not use direct heat on the intermediate drying of parboiled paddy because in parboiling the husk is split slightly, and the endosperm is therefore directly impinged. It is not clear whether direct drying is a good idea, but it is felt that until testing is performed it would be better to use indirect drying in parboiling.

At IRRI-UOP (W130) the husk-fired dryers developed have been of both types, and as yet no results either way have been noted.

Manalo noted in his work on husk-fired dryers (105-106) that the presence of flue gas in the drying air did not lower the quality of the milled rice appreciably. It is unclear, however, whether the quality was considered to be milling yield, etc., or whether it also included a definitive appraisal of taste and odour ramifications.

In the thesis by Acasio (100) quality is mentioned as a function of the completeness of the burning of the husk. Again the meaning of the word "quality" is unclear.

5.5.3. EFFICIENCY CONSIDERATIONS

Usually the lack of definitive specifications on furnace design has been of no concern to the classic designer and builder of steam power units for the operation of rice mills. In fact, the realities of the situation encourage inefficiency. In most areas the resulting char from the boiler is easier to dispose of, and occasionally sell, than the raw husk, so the operator is only interested in an efficiency capable of producing enough steam to operate the mill. If he had a more efficient unit he would then have a husk disposal problem for the unused portion of his husk production. In the case of a parboiling operation, the classic situation is such that the miller has sufficient husk available to perform two of the three essential functions. Where yard (sun) drying is practical, there is only need for two functions; however, where multiple-cropping or weather patterns require mechanical (artifical) drying for the wet parboiled rice, the normal practice is to use the steam produced for two of the functions, and outside energy for the third. In drying in a parboiling operation, it would be beneficial to use a highly efficient system and perform all three functions. The year-round use of the dryer makes the capital cost of the system more reasonable than when husk-produced energy for a raw rice dryer is only used during the harvest. However, in some cases it is necessary to dry the wet-season harvest artificially, so that the cost of a husk-energy related system may not be possible or practical.

5.5.4. DISCONTINUOUS OPERATION

It is a fact that small plants, particularly in the Far East and Africa, must operate discontinuously. The farmer or trader brings in paddy, and the miller operating receives toll in cash or kind. Therefore, the miller must be ready to start at any time. His operation is determined not only by the size of the mill but the method of milling operation. Many multi-stage mills operate on a discontinuous basis. Electric power involves only pressing a button. A steam- or gas-powered operation is of course awkward and inconvenient as compared to mains electric service. Always, when contemplating a husk-fueled installation, consideration must be given to the value of convenience and effortlessness on the part of the ultimate operator.

Chapter 6:

EQUIPMENT AND MACHINERY TO CONVERT RICE HUSK TO ENERGY AND FOR OTHER RELATED FUNCTIONS

6.0 INTRODUCTION

The equipment necessary for commercial installation for conversion of husk to energy is, in general terms, available to the purchaser-user. In some instances a specific item is difficult to find, or the choice is limited for several reasons: the difficulties created by language differences and the resultant lack of information transfer, and the lack of a coordinated comprehensive worldwide "buyers' service". There are a number of national or regional publications that do an admirable job, considering the enormity of the task, but it is often said that nowhere in the world is a certain machine being commercially produced, when in reality there may be many manufacturers of that particular machine in many countries. Admittedly, the choice in the marketplace is sometimes limited, but this is due usually to the fact that the suppliers are not aware of a need by users. Every supplier will build machinery, within his capabilities of manufacture, of whatever type his customers request.

Most of the equipment involving rice-husk utilization has been commercially produced earlier, and only went out of production owing to the advent of alternatives where were cheaper or more convenient in operation or acquisition, or when the consuming industry so changed its pattern of use that certain technologies were rendered obsolete.

It is interesting to observe the effect of changing economic levels of energy cost and availability on the manufacture of equipment. The 1880s saw the formal advent of rice-husk fired furnaces; a 1910 sales catalogue lists and pictures a complete line of boilers, steam engines, gas producers, and gas and oil engines, indicating that at the end of the 19th century development had been fast; steam-powered mills were dominant in South America by 1915, and apparently by 1925 the change to steam power for commercial mills was made complete by the introduction earlier of the Lokomobile-type unit and its relatively high efficiency. But the lower and lower costs of electricity, gas and oil, and the establishment of effective distribution grids dictated the changeover to individual unit drives and the configuration of the "modern" mill as it is known today. This change spelled the demise of the large-scale manufacture of steam and gas motive power equipment and the diminishing use of husk-fired steam systems for process steam.

The current trends in prices and availability of these alternative fuels have dictated a serious reassessment of the possibility of the manufacture, distribution and utilization of equipment using husk energy.

The following discussions of individual types of equipment and the reference list of manufacturers and interested workers should show widespread availability of equipment and give some idea of the types available. Obviously they do not include all usable equipment or all manufacturers. The inclusion or lack of inclusion does not in any way indicate anything more than information or lack of information, and does not constitute a recommendation or lack of recommendation for any manufacturer or type of processor equipment. Again, it is primarily a matter of communication.

6.1 STEAM RAISING

6.1.1. BOILER EFFICIENCY

$$\frac{\text{Heat in water (steam)} \times 100}{\text{Heat in fuel}} = \text{boiler efficiency (\%)}$$

The gases from fuel combustion cannot be cooled to air temperature in the boiler room, and therefore all the heat which is realized by the combustion of the fuel cannot be transferred to the water in the boiler. The efficiency of a boiler is therefore always less than 100%; in a super power station, efficiencies of over 90% have been recorded; 80% is not uncommon in well-operated plants; but in ordinary industrial practice, an average efficiency of 60% is probably not far from the mark, and many boiler plants must fall below even this low standard.

The chief loss is almost invariably the heat carried away in the waste gases. The efficiency of a boiler depends on: i) the design of the plant; ii) the conditions under which it operates (other things being equal, the more constant the load the higher the efficiency); iii) the correct selection of the fuel; and iv) the skill and care expended in maintaining and running the plant.

The conditions under which steam is raised vary greatly; the pressure may be from a few pounds above that of the atmosphere to the critical pressure (3,200 lb/in^2), while the output per hour from a single boiler may be from a few hundred to a million pounds or more. The load may be relatively constant, as in base-load stations for the generation of electricity, or it may vary rapidly over a wide range. In view of this diversity of conditions, the number of types of boiler is very great, but all embody a furnace and a vessel, the boiler proper, which contains the water; the heat of combustion of the fuel is transmitted through the heating surface which forms the partition separating the hot gases from the water. Whatever the pressure and output of steam and whatever the design of the plant, the fundamental principles of its efficient operation are the same.

Straight power generation brings overall efficiency down to about 20%. It can therefore be said that practically, steam should be made from husk only when process steam is required; it would be better to find other ways to utilize energy from husk if electrical or mechanical energy is needed and there is no utilization of the exhaust steam.

However, if process steam is used, the most efficient approach is a combination of power generation and subsequent process use. It should be borne in mind that a husk-fired boiler costs 2 or 2-1/2 times the comparable gas- or oil-fired boiler of equal capacity, for several reasons: the need for an external furnace of large size and considerable use of expensive refractory materials; the generally lower exchange ratio, leading to lower furnace temperatures and gas temperatures when using a passive husk firing system; and the system additions required for collecting the residue and removing particulate matter in the stack gas.

This is not necessarily true when using a turbulent-flow air-suspended furnace, in which a water-tube boiler or a waste-heat boiler design can be incorporated, as in the Pitt-designed (151A) Stuttgart plant.

Comparative figures (Gariboldi) show that a husk-fired boiler will produce 15-18 kg steam/m^2 of surface against 40-42 for an oil- or gas fired one. The ratios are about proportional to the comparative BTU values.

The requirement for an efficient boiler must be considered jointly with the need for husk disposal. For example, the ratio of steam output to husk raw fuel infeed for boilers of various efficiencies (see Table 21) is sometimes shown as calculated by engineers of Greaves Cotton (W77), differently from actual tests (see Section 6.1.3.1.).

Table 21

Steam/husk ratios as a function of boiler efficiency

Efficiency of Boiler/Furnace (%)	Steam/Husk Ratio
50	2.83
55	3.12
60	3.40
65	3.68
70	3.97
75	4.26
80	4.54
85	4.83

Where the maximum output of steam is needed, it is obvious that a most efficient boiler/furnace combination is capable of giving the desired results. Most of the installations using husk for fuel for steam generation are operating at less than the 50% level, either because of inefficient design and construction (Mandya, India) or because of the deterioration of the capability of a good design and well manufactured plant (Chavalakade, Sri Lanka).

6.1.2. TYPES OF BOILERS

Boilers may be conveniently divided into: i) internally-fired, in which the furnace is an integral part of the boiler itself, its dimensions being restricted by the fact that it must be accommodated within the structure of the boiler. These include small vertical, Lancashire, Cornish, locomotive, economic, Scotch marine, and combustion-type boilers; ii) externally-fired, in which the design of the furnace is more or less independent of the design of the boiler proper.

There is a great deal of confusion and overlapping of terms concerning some types of boilers and their firing system. Three basic types exist: smoke-tube, fire-tube, and combustion-tube. A smoke- or fire-tube boiler would be a combustion-tube type if the fuel entered the tube section in a partially or totally unburned condition.

In a smoke-tube boiler, all combustion is completed within the furnace or the under-tank area wherein a shell boiling design is used. The gas analysis should be stabilized before its entrance into the tubes. There is no ash beyond the furnace curtain wall except for entrained particulate.

In a fire-tube, some burning of gases occurs within the tube area, but all the fuel is converted to gas before entering the tube. This includes boilers of the external furnace type or the Lancashire type, but applies in particular to one with a more aggressive gas-flow pattern, as in the smoke-tube: no ash beyond the furnace.

Table 22

TYPES OF BOILERS — CHARACTERISTICS

	VERTICAL CROSS TUBE	CORNISH LANCASHIRE	SUPER LANCASHIRE LOCOMOTIVE SCOTCH MARINE	WATERTUBE
Working pressure	Up to about 120 lb. per sq. in.	Up to a maximum of about 200 lb. per sq. in. 120 to 160 lb. more usual.	Up to 250 lb. per sq. in. Super-Lancashire up to 300 lb. per sq. in.	Up to 1,100 per lb. sq. in.
Steaming capacity	Up to about 5,000 lb. per hour	A 9 ft. 3 in. Lancashire boiler will evaporate about 9,500 lb. per hour.	From 6,000 to 25,000 lb. per hour.	From as low as 400 to as high as 500,000 lb. per hour, or even more.
Setting	Self-contained; no brickwork setting required.	Brickwork setting necessary.	Self-contained; no brickwork setting is necessary.	Boiler suspended from steel girders, with brickwork built between them.
Furnace arrangements	Integral with the boiler	Dimensions rigidly controlled by the dimensions of the boiler shell, unless an external Dutch oven type of furnace is installed.	These boilers being internally fired are subject to the same limitations as Cornish and Lancashire boilers.	The furnace may be designed to suit the fuel; its dimensions are not controlled by the design of the heating surfaces.
Methods of firing	May be fired by hand or mechanically	Lends itself well to hand-firing.	May be fired by hand or mechanically.	Cannot be successfully fired by hand if steam output exceeds 14,000 lb. per hour. Mechanical firing is generally more efficient than hand-firing.
Rate of raising steam	Quicker than in Cornish and Lancashire boilers	On accounts of the great heat capacity of the setting and the large amount of water in the boiler, raising steam from cold is slow.	Quicker than in simple cylindrical boilers.	Since the water capacity is small and there is no heavy brick setting, rate of steam-raising is high.
Reserve of water in boiler		In Lancashire boilers, equal to about 5 hours' steaming.	Less than in Cornish and Lancashire boilers. Probably equal to 3 to 4 hours' steaming.	Equal to from 2 to 3 hours' steaming.
Superheat		Superheaters may be fitted to give 200°F. (or higher) superheat.	Super heaters may be fitted to give any required degree of superheat.	Superheaters may be fitted either in the radiant or the convection portions of the heating elements.
Economizer		Should always be fitted. Cast-iron economizers may be used up to 200 lb. per sq. in.	The extra heating surface provided by the tubular disposition of the heating surface may render the installation of an economizer unnecessary.	May or may not be fitted. In the larger sizes of boiler, economizers are usually integral with and superposed on the boiler.
Floor-space occupied	Relatively little	For a given output of steam a cylindrical boiler occupies more ground space than a water-tube-boiler and the discrepancy increases as the output (and therefore the number of cylindrical boilers) increases and is still greater if economizers are installed.	Less than for Lancashire of Cornish boiler of equal capacity	Less than for equivalent cylindrical boiler, particularly in large plants and where economizers are installed.
Wear and tear, cost of maintenance		Relatively low. These boilers have been known to last 50 years; a life of 20 years is common.	Since the boiler is more complicated than the simple cylindrical boiler, unless skilled attention is provided, the cost of upkeep and liability to breakdown are higher.	Careful and skilled attention are necessary, otherwise the liability to breakdown will rise; maintenance costs may then become high
Skilled attention	Always desirable, but its absence is of less moment in these, the simpler types of boiler plant.			
Feed-water purification		Although desirable, feed-water purification need not be carried as far as with tubular boilers. Moderate scale is less detrimental than in water-tube boilers.	Feed-water should always be treated; moderate scale has serious effects on the wear and tear of the boilers.	
Efficiency		Unless an economizer is installed, the efficiency is generally less than with tubular boilers.	Higher than with simple cylindrical boilers.	

Efficiency depends not only the design of the plant but also to a great extent on the care and attention it receives, the methods of control adopted, the quality of the feed water, and the variation in the demand for steam.

*Fire-tube boilers include also locomotive and Scotch marine boilers. Although the latter were at one time popular for steam-raising on land, they are now seldom installed.

In a combustion-tube boiler some or all of the vapourization and/or conversion occurs within the tube lengths. This is the type of boiler (see Figure) which has no or limited furnace volume or in which not all of the combustion occurs in the combustion chamber. There is an overlapping area of these types--the important aspects are the type of furnace, the ash-removal system, and their effect on the distribution of fuel and ash. The most efficient combination (both output and original cost) is always a matched furnace and boiler design, wherein the boiler tubes and gas flow are matched to the desired performance of the furnace. While it is true that almost any combination will produce some steam, it can be expected that improper matching will create problems in both operating and maintenance costs. By definition, this design would require char/ash collection after the boiler, either in the stack base or in a cyclonic-negative pressure system. Boilers of this type include those with pressure fuel injection into an air-free pre chamber or directly into the internal firing chamber.

The Lancashire boiler consists of a horizontal cylindrical shell with flat or dished ends provided with two internal furnace-flues. The boiler is installed in a brickwork setting arranged so that the hot gases on leaving the rear end of the furnace-flues pass to the front end of the boiler by way of the sole-flue, to the back of the boiler via the two side-flues and by way of the main-flue to the chimney. Cornish boilers are smaller and have a single furnace-flue.

Lancashire and Cornish boilers contain a large volume of water compared with their output of steam (5 1/2 to 6 hours' supply) and can therefore respond rapidly to sudden demands for steam; this is one of the reasons for their popularity in industry. They are simple in design and, within limits, will stand up to a good deal of ill-usage. The large water capacity carries with it the disadvantage that to bring the boiler on load from cold requires several hours.

In the Super-Lancashire Boiler and variations of fire-tube (smoke-tube) boilers, the heating surface is increased by introducing a number of longitudinal tubes through the water-space below the furnace-flues in the boiler. There is thus no sole-flue; the gases from the rear of the furnace pass to the front end of the boiler via tubes at high velocity, so that the rate of transfer of heat is increased. The side-flues are dispensed with and the waste gases travel back to the rear of the boiler through tubes around the outside of which the primary air for combustion is passed. In consequence of the increased heating surface, time is shorter for a given output of steam, and pressures up to 300 lb/in^2 may be carried. The Super-Lancashire Boiler is self-contained and requires no bulky brickwork setting, so that it occupies less space than a Lancashire boiler of equal evaporative capacity.

When the fire-tube (smoke-tube) boiler is equipped with an external furnace, this is usually a shell boiling type with the furnace heat just meeting the bottom shell of the tank and then passing through the tubes in one, two or three passes. The earliest designs were simple horizontal-return tubular boilers, with shell boiling and a single return pass through tubes. The Scotch-type boiler had an internally-fired large tube with small return tubes above. Later types were a combination, as in Figure 12, and then a modern multi-pass design as in Figure 13.

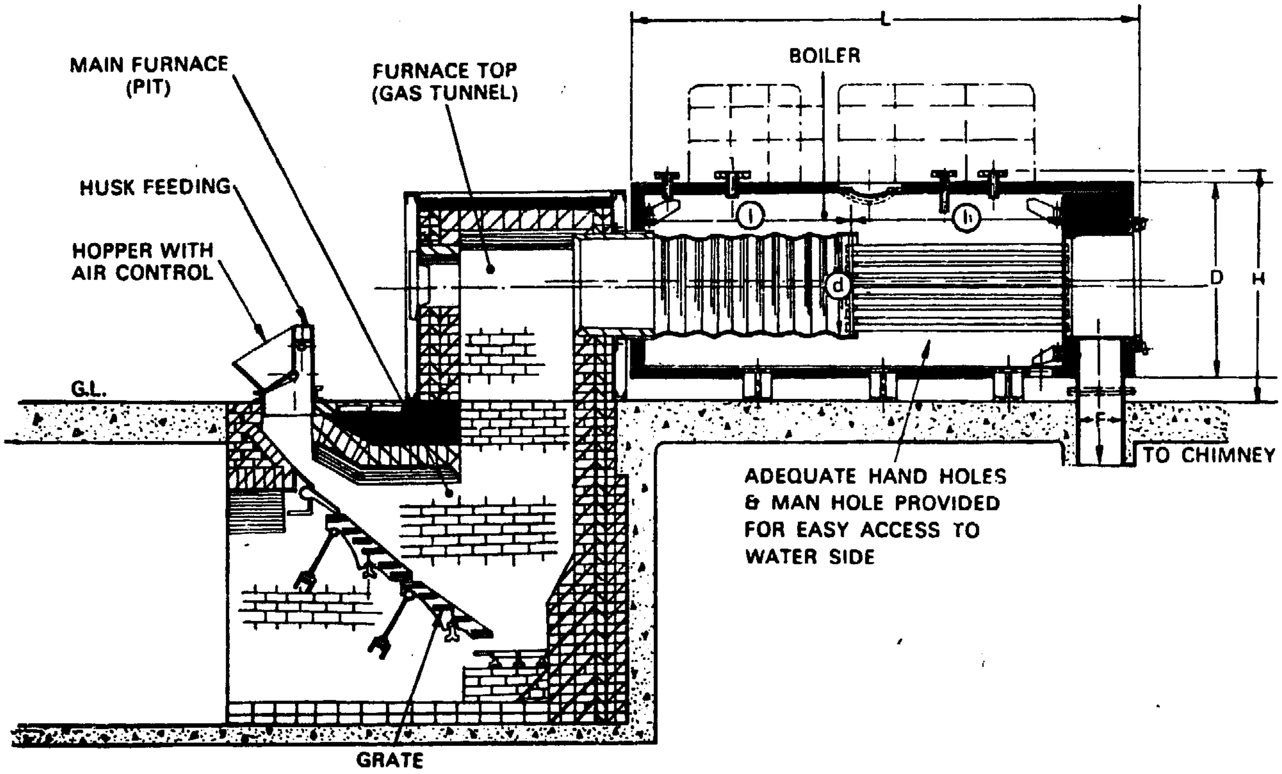


Figure 12
A currently-offered boiler design, patterned after a traditional "Locomobile" design (under- floor furnace installation)

<u>Vertical boilers</u>. For outputs of steam up to about 5,000 lb/hr and for pressures up to 120 lb/in^2, vertical boilers are frequently employed. They are completely self-contained and require very little preparation of the ground on which they are to stand, beyond levelling. Of the many types which are available, one only is illustrated: the Cochran fire-tube boiler (see Figure 13).

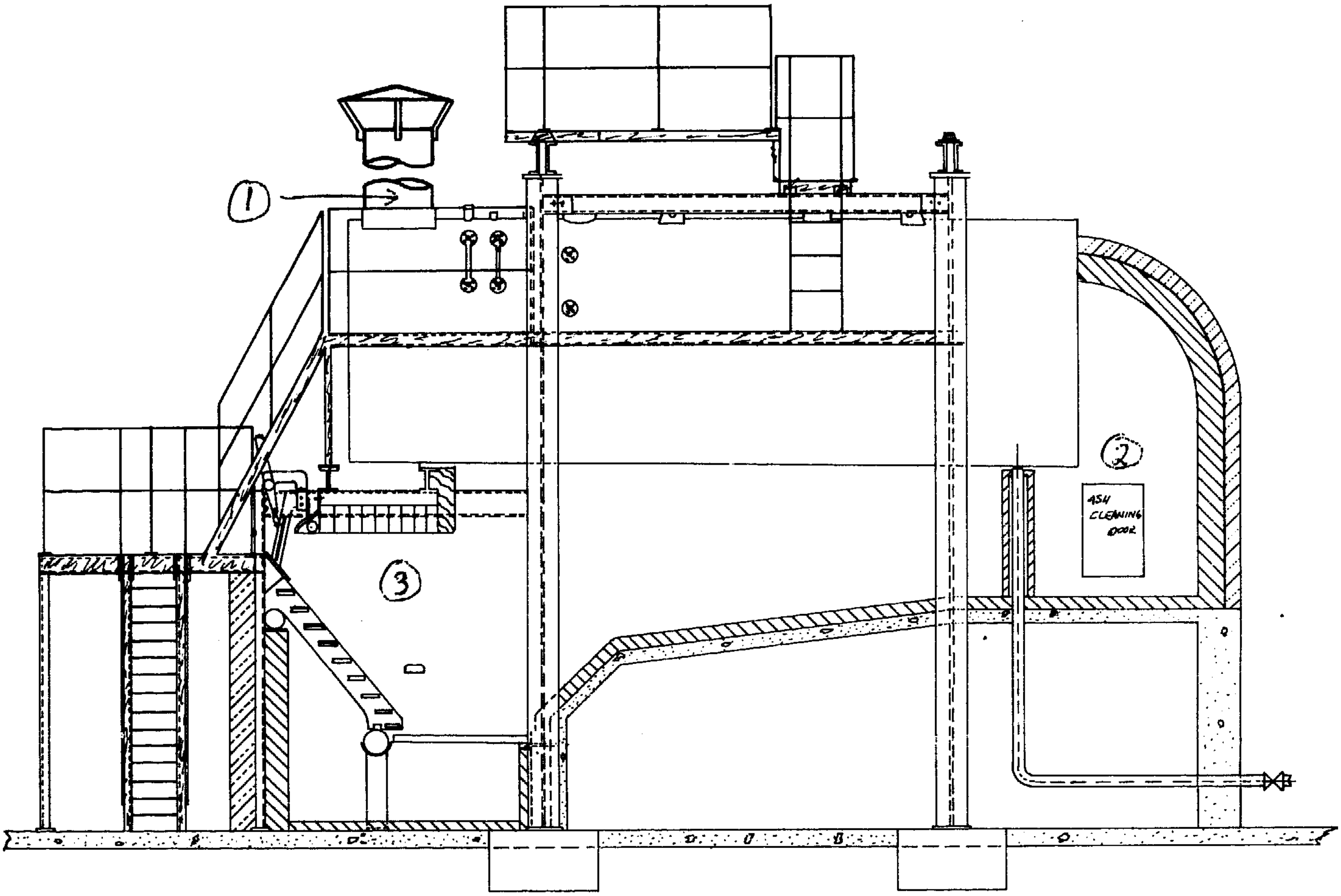


Figure 13
A shell boiling multi-pass design (Above-floor installation)

Water-tube boilers. While internally-fired boilers are available in capacities up to 25,000 lb steam/hr and for pressures up to 300 lb/in^2 according to the type of boiler and the quality of the workmanship, where larger outputs of steam are required from a single unit, or where higher pressures must be carried, water-tube boilers are universally employed. These boilers are fired externally; therefore, the shape and dimensions of the combustion chamber are practically independent of the steam-raising unit proper and great flexibility in design is possible.

Designs include four-drum, two-drum and single-drum, cross-drum, long-drum, integral furnace, Stirling open-pass and radiant. Because of erosion problems when using husk as fuel, it is best to use a single-pass two-drum boiler with low gas velocities.

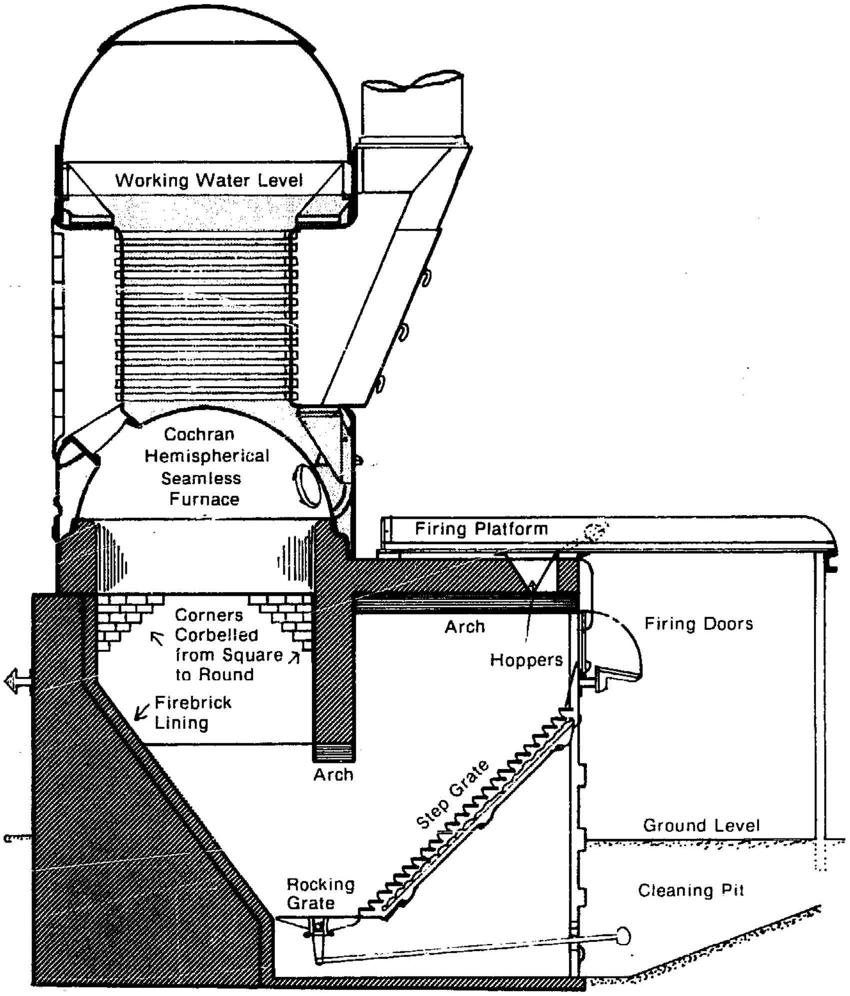


Figure 14
The Cochrane fire-tube boiler

Ample cavities must be provided in the unit for the placement of retractable soot blowers to keep the surfaces clean. Designs must be conservative to provide for this service.

The combustion-tube smoke-tube arrangement varies according to the manufacturer's preference. There seems to be no accepted "best" arrangement. In surveying a small percentage of all boiler manufacturers, no agreement or common arrangement of the components was found. Each manufacturer tries to make the best and most competitive product that he can, particularly in three-pass boilers. Every conceivable configuration exists. Water-tube boilers also vary. The only one of somewhat common construction is the vertical cross-tube.

A waste-heat boiler can be installed downstream of any external furnace, either a passive grate system or a turbulent air-suspended (cyclonic) furnace. Waste-heat boilers are in essence gas/water heat exchangers with provision made to extract the steam produced. Waste-heat boilers can be of both smoke-tube and water-tube types. There are no definite design configurations. They can be adapted to any set of circumstances.

Multi-fuel boilers. There are many possible configurations of a multi-fuel boiler. The one shown in Figure 15 can accommodate three forms of fuel: gas/oil with the furnace at the right end; wood, blocks, coal on the conventional internal grate on the left end; and pulverized fuel, such as husk, through the pneumatic injection system from the top. This is a three-pass unit, primarily for low-pressure operation, but the fuel feeding systems could be adapted easily to intermediate-pressure units.

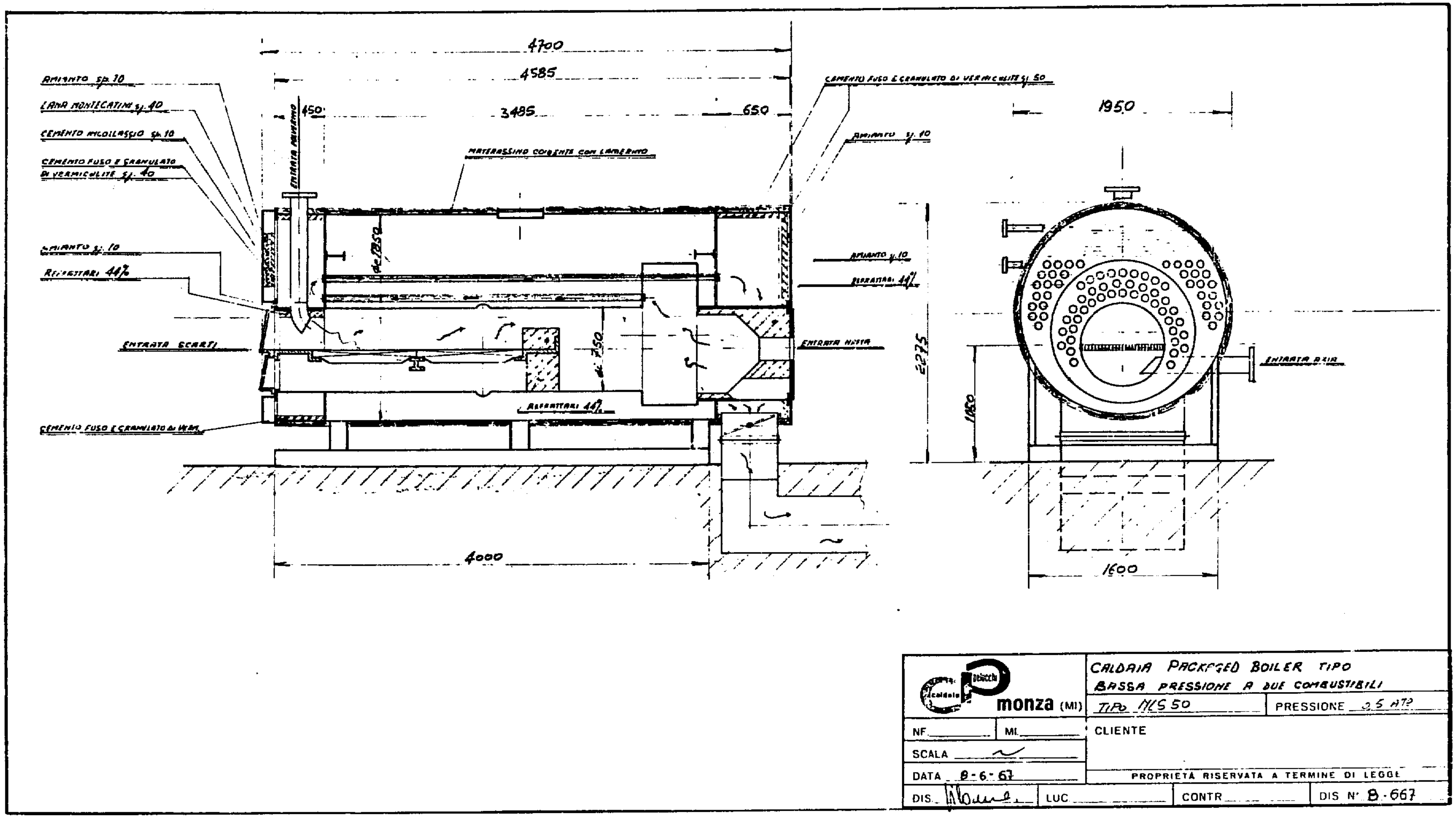


Figure 15
A multi-fuel boiler

6.1.3. DESIGN DETAIL

The U.K. Ministry of Fuel's Fuel Efficiency Bulletin No. 37 states that "the small vertical cross-tube boiler is probably the most inefficient steam raising unit employed today." This boiler is cheap and simple, but it has a low production of steam for a given size because of its low reaction-water surface.

Husk-fired units are generally more successful in boilers that have greater volumes of water, which help to take up the variation in fuel characteristics. This type of boiler can be used only below 30 atm (400 psi) working pressure; above that pressure it is advisable to use a water-tube unit.

Dry-back boiler. In the smaller multi-pass units it has been found that the greater accessibility for maintenance and cleaning in the dry back more than offsets the gains from having a wet back. Therefore, normally boilers up to and including 160 HP are constructed on the dry-back principle.

Wet-back boiler. Experience has shown that a point is reached where benefits can be obtained by changing from dry-back to wet-back construction, as refractory walls become more sensitive as they increase in size. Boilers above 160 HP are therefore normally made in wet-back construction.

Temperature considerations. Assuming 60-75% excess air, the following spot temperatures have been estimated, using rice husk as fuel, at the points shown in Figure 12:

Temperature point	Jaya	Greaves
(1)	650°F	300°C
(2)	1200°F	900°C
(3)		1150°C

6.1.3.1. Performance and characteristics of typical husk-fired units: Published performance figures of a vertical cross-tube boiler and of a multi-pass fire-tube boiler appear in Tables 23 and 24 respectively.

Table 23

Performance of a vertical cross-tube boiler

Evaporation capacity at 100°C (kg/hr)	Heating surface (m^2)	Grate area (m^2)	Husk consumption (kg/hr)	Empty boiler weight (tonnes)
282	9	0.71	150	6
470	15	1.04	230	7.5
785	23.5	1.50	380	9
1255	36	2.00	610	11
1725	50	2.54	850	12

Evaporation Capacity from at 100°C kg/hr	Heating Surface m 2	Grate Area m 2	Husk Consumption kg/hr	Empty Weights Boiler Tonnes	Empty Weights Furnace Grate Hoppers Tonnes
500	19	1	200	6	3
750	38	1.5	300	8	3
1000	55	2	400	10	3
1500	75	3	600	12	3.5
2000	100	4	800	14	3.5
2500	125	5	1000	16	4

Table 24

Performance of a multi-pass fire tube boiler

In an actual test of a modern multi-pass, mechanically drafted, combustion-tube boiler (1974), a nominal 1500 kg/hr steam rated boiler producing 1200 kg/hr had a fuel rate of 333 kg/hr of husk, a 75% efficiency at full output, with an effective husk/steam ratio of 3.66 kg steam/kg husk. The vacuum at the stack entrance was 70 mm water, and at the firing area 6 mm water. The stack temperature was 238°C. Steam produced at 6.6 kg/m^2 was at 167.5°C, and the actual evaporative capability was 15.7 kg steam/m^2 of surface.

A boiler properly installed can be operated at 200% of rated capacity for extended periods. However, the problem is not the boiler, but rather the furnace. To get the required heat release to produce the overload boiler transfer is another matter.

Passive grates will normally provide 8.5-10 boiler HP per square foot of grate area. It is very difficult to double this figure, particularly with a fuel such as rice husk, because of the physical limitations of the feed rate and the ash-handling system.

Usually the boiler manufacturer specifies the performance of the boiler at 100°C, but in most practical operations somewhat less than that is fed, often at an ambient level. Performances are reduced accordingly. Figure 16 shows dramatically the derating due to low feedwater temperatures.

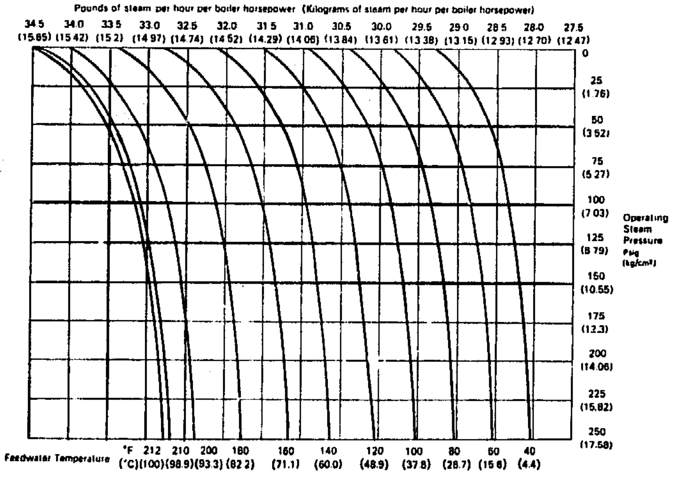


Figure 16

Steam output and pressure as functions of feedwater temperature

6.1.3.2. Efficiency requirement. Sophisticated installations will, of course, include an economizer and possibly an air heater, both of which increase the efficiency of the overall installation. In many husk-fired installations the efficiency of the system is of no great concern, because there is adequate husk to use as fuel to provide what steam is necessary for steeping and steaming for parboiling. Most rice-husk fired installations can be said to be low-technology units, and the losses are taken as a matter of course.

6.1.3.3. Water treatment. For good boiler performance and long life, with low maintenance, a sophisticated water-treatment plant is mandatory. Regenerative, cationic treatment systems are usually required. The necessary chemicals are not always available, and of course this requirement adds to the original cost and the operating costs. Where the steam is solely for process use, there is obviously no reuse of condensed makeup water, and a simple, easy to clean, cheap boiler is the most economic solution.

For power-generation units, pressures and temperatures are usually higher, and the use of non-condensing engines creates many problems. For example, the SML plant in Surinam operated seven years as a non-condensing plant with no feedwater treatment, and its performance record was poor. After the installation of a treatment plant, performance improved noticeably.

6.1.3.4. Automatic operation. In fully automatic boiler operation using husk as the primary fuel, it is necessary to use a small amount of oil/gas as pilot fuel, and to ensure constant capability the boiler should be equipped for full-capacity dual-fuel operation. With this equipment a number of combinations are possible:

Programme 1. Ignition flame oil with husk injection. With this fully automatic programme, the oilburner starts, and after a short interval the husk injection comes in. When the husk is ignited and a sufficient firing temperature is reached, the oil burner is shut off, and only the husk injection and possibly the oil burner ventilator remain on. Should the temperature in the combustion chamber fall below the safety ignition temperature, a thermostat shuts off the feeding system and injection blower.

Programme 2. Husk injection and oil burner. This fully automatic programme is used only for peak demand. Oil burner and husk injection are both running with permanent ignition.

Programme 3. Oil burner alone. This fully automatic programme is used when no husk is available. The oil burner has to supply the full load demand.

Programme 4. Husk injection alone. In this programme the boiler-room operator has to start the base fire before the husk injection can be started. The following sequence is much as in Programme 1. The combustion-chamber thermostat acts as an injection safety, and the grate fire is self-sustained for full boiler capacity.

6.1.3.5. Miscellaneous:

India - The Government of India has sponsored work to develop a 5 HP vertical boiler and a matching steam engine/water pump for farm pumping chores, utilizing as fuel indigenous production, either a residue product (such as husk) or a specifically grown wood or straw material. A cost of about 15,000 Rs ($2,100) is envisaged for the complete package. The development units have been built.

Ricardo - In the 1950s the Government of the United Kingdom (NRDC) sponsored work on a small boiler/engine designed by Ricardo (185). A number of units were built and tested under varying conditions and locations. The system did not attract further commercial interest at that time. It is possible that under today's economic conditions a reappraisal of this engine development should be undertaken.

Mini-boiler - Many manufacturers in India are manufacturing a low-cost, small, "mini-boiler", usually for parboiling or other operations requiring a small amount of steam. These boilers are under the legal size (5 gal holding capacity at 50 lb/in^2). They are especially popular in southern India for continuous parboiling operations.

A small water-tube boiler could be constructed locally in India - 26 atm at 450°C is practical. Its cost would be 2-3 times that of a fire-tube boiler, but the higher the temperature and the pressure, the higher the efficiency. On the other hand, it is not always necessary to be highly efficient, but only to do the job.

An Italian 2500 lb/hr steam boiler, complete with all accessories, was quoted in 1975 at about $86,000, including all brick, water treatment systems, feedwater systems, stack, char collection and handling machinery and bins. It was said that this cost could be amortized in about 1.5 years on fuel savings alone.

6.1.4. CONSTRUCTION AND MAINTENANCE DETAIL

One concern prevalent is the wear of the inner surface and entrance curve of the tubes of combustion-tube boilers. In this type of boiler all the fuel and all the residue pass through all the tubes. In inspecting a boiler of this type with 70 mm diameter tubes, 6 mm walls on 110 mm centre line, no wear was discernable. This installation was six years old and is inspected once a year; there never has been a noticeable wearing of the entrance curve of the tube. In this boiler all combustion occurs in the fire tubes. There is no effective furnace volume.

In the Buckau R. Wolf boilers the tube diameter was 120 mm, and the velocity was low enough so that no particulate matter was maintained in suspension. The step-grate furnace had a maximum air-flow velocity of 1 m/sec, and this did not entrain any appreciable material in the gas stream through the boiler. In the Gariboldi design there is a minimum of 3.5 m/sec, ensuring sufficient velocity to obviate any need for cleaning the tube sections.

Traditionally, F.H. Schule would never recommend a 3-pass boiler because of the many troubles with ash buildup in the fire tubes. Improved design eliminated this problem, and for the past 15 years Schule has recommended 3-pass boilers, either on a negative-pressure system or with blower-steam soot ejectors.

It has been said several times that one reason why western-designed boilers are not popular in South Asian installations is that welded-end boilers are difficult to clean and require sophisticated water-treatment practices. This is not necessarily true. It oversimplifies the comparative features and costs of two types of boilers.

Several boiler factories were visited in Bangkok. The Huay (W148) factory builds boilers to match the size of the engines acting as prime movers for Thai-built rice mills. They are Cornish type, requiring one month to complete. They are hand riveted and peened, the ends being forged by hand. All work is done by hand on the premises, the raw material being Japanese steel in sheets 16 x 1524 x 6096 mm. The 5' x 20' boiler costs about $9,000. In Thailand it is said that 95% of the rice mills are steam-powered, utilizing their husk as fuel. This practice has been of long standing in southeast Asia; many Lokomobile units were furnished to these countries, and in the late 1800s and early 1900s great utilization was made of husk-fired power units in the whole area. Even as late as 1940 it was common practice for new Asian rice mills to be powered in this way, and until the advent of individually driven machinery there was hardly any question of the configuration of the mill.

In Milan, a parboiling mill, with steam produced by a husk-fired primary oil-fire supplemental boiler system, uses the steam for all process work and for heating all buildings in the area. Oil firing is utilized if the mill is not running and the husk supply is depleted, or if the raw husk has a greater value when sold commercially. This system utilizes a reduced-area grate with a capacity ensuring that sufficient combustion occurs before conveying begins, so that entrance temperatures are not raised too high. Continued burning takes place in the central (Lancashire type) tube and continued combustion in the second and third passes. All residues are collected in the cyclonic collector, and none go through the fan that provides both the combustion and conveying gas. Because of the necessity for additional protection against air pollution, a secondary collector or filter or scrubber is fitted to the fan discharge.

In India, Jaya (W78) and Westerworks (W87) have built many husk-fired boilers for use in India. These include packaged and bricked units with single and three-pass boilers, with a variety of furnace location options.

At Kollegal, India, a mill with a small (99 sq ft) vertical cross tube (VCT) boiler, furnishing steam for parboiling, was visited. This unit had been installed new, eight years before and had operated without problems. A 57 ft^2 boiler, (VCT), 3.5' diameter and 8.0' tall, used husk as a fuel to produce steam for a tyre recapper. The step grate was inclined at 45° with an arc of 2.5' x 5.8' or 14.5 ft^2.

At Coimbatore, India, a two-pass smoke-tube boiler was built for an FAO project in Sri Lanka. It was a 1000 kg/hr, 7 kg/m^2 (100 lb/in^2) natural-draft unit, with a 60' high stack, a surface area of 496 ft^2, and a husk consumption calculated at 350 kg/hr with an estimated 2200 Kcal/kg recovery from the husk.

At Gimeaux (W23), a parboil/precook process plant obtains steam from a Parent (W21) boiler of 2500 kg/hr, using 600 kg of husk as fuel, a 4.16 recovery ratio. This is an induced-draft unit, with all fuel and residue passing through the tubes and being collected in a primary filter; a bag-type secondary filtration takes place at 100°C. Cooling of the stack gas is accomplished by an automatic fresh-air bleed system. There is a formal furnace section with a controlled feed, using screw conveyors into the furnace volume.

At Mandya, India, the efficiency of a Texmaco (India) Cornish boiler, 6' x 20', with about 500 ft^2 of heating surface, was estimated at 45%, but information about the husk handling practices indicates the actual efficiency is less. The boiler furnishes steam for parboiling during part of the year.

The Srinivas Rice Mill, India, uses a Westerwork 750 kg/hr boiler. The actual fuel consumption for this unit during a test period was 154 kg husk/hr, which would indicate a conversion ratio of 4.9; this is probably an error, because the boiler is not delivering, and the parboil plant is not using, the rated 750 kg/hr. The quoted efficiency for this boiler/furnace unit is 50/60% and a reasonable calculation of the ratio is about 2.76, which is probably closer to actual performance. Husk-consumption figures must be relied on only when checked against actual feedwater consumption or steam-flow measurements.

Scopa Chemicals (W83) use rice husk as an alternative fuel in their VCT and fire-tube boilers. They find that with husk as a fuel the steam generation capacity of their boiler is about 60% of the output when coal is fired. They feel that a mixture of the two would be a very good system. The buildup of ash in the tubes of the fire-tube boilers was their only problem, frequent cleaning being required (48-hour intervals). If a grating system designed for husk is used, of course, this is no problem. The desirability of using husk arises from the cost of steam; Scopa's cost records show, for extended periods, a cost when using coal of $2.83 per 1000 lb of steam at 100 lb/in^2, against $0.91 when using rice husk. They believe that with alterations, and not very costly ones, all existing small-scale industries which require steam up to 1 ton per hour and VCT or fire-tube boilers using coal as a fuel could convert.

6.1.5. ACCESSORIES

A simple boiler may consist of only a furnace/boiler container and a means of injecting feedwater. However, if there is a requirement for higher efficiency than can be obtained with a simple system, various additions to the system can be included.

6.1.5.1. Economizers. An economizer consists of a number of sets of cast-iron or steel tubes placed vertically, horizontally or inclined in the path of the waste gases; the feedwater passes through the tubes and the gases pass over the exterior of the tubes in a a direction substantially opposite to that of the water. Roughly, for every 11° or 12° increase in the temperature of the feedwater, resulting from the recovery of heat otherwise wasted, the saving in fuel is 1% (see Figure 16). Apart from the saving of heat, there are contingent advantages in feeding a boiler with hot water: the rate of steaming is increased, and thermal stresses set up when cold feedwater is used are eliminated. Since the draft available in the furnace is reduced when an economizer is installed unless mechanical draft is employed, maximum savings are not likely to be realized because the the economizer will generally be too small for the plant. Where there is mechanical draft, the economizer can be proportioned to give the maximum recovery of heat. It is important not to chill the gases below the dew-point, or serious corrosion of the tubes is almost certain to take place, as the liquid deposited consists of a weak (and therefore very corrosive) solution of acids. Moreover, when condensation occurs, adherent deposits of "fly" ash and particles of unburned carbon are likely to be formed on the tubes of the economizer, and these impede transfer of heat to the water.

6.1.5.2. Air heaters. Where the gases leaving the economizer are insufficiently cooled, further recovery of heat may be effected by installing extra heating surface for preheating the air required for combustion. The advantages of this are: (i) direct return to the furnace of heat otherwise wasted; (ii) more complete combustion with less excess air, since the temperature in the furnace is increased and the velocity of reaction augmented; (iii) higher rates of transmission of heat to the water in the boiler arising from the higher temperature of the furnace; and (iv) greater steaming capacity of the boiler--increases of up to 50% have been attained.

With pre-heated air, in addition to the increased load that can be carried by the boiler, the negative effects of high loads on efficiency are reduced.

Air heaters are of two types: recuperative and regenerative. In recuperative heaters transfer of heat from the gases to the air takes place in a normal heat exchanger. In regenerative heaters the transfer takes place through a transfer medium.

Air-cooled furnace walls or floors, sometimes used as sources of heat to improve combustion conditions, are not normally included in the term "air heater".

6.1.5.3. Superheaters. While a superheater affords extra heating surface (and therefore increases the ratio of heating surface to grate area) the object of superheating steam is not so much to increase the efficiency of the boiler plant as to enhance the value of the steam after it has left the boiler. The degree of superheat will depend on the use of the steam. Some superheat is always desirable for the following reasons: (i) dry steam is delivered to the plant in which it is to be used and the heavy loss of heat which results when condensation takes place in the steam-pipes is thereby avoided; (ii) higher velocities are admissible with superheated than with saturated steam, so that smaller pipes can be used; and (iii) there is less wear and tear on valves, and loss of steam by leaking joints in the mains.

As regards rice-husk fired boilers, the most notable use of superheaters occurred on the Buckau R. Wolf type of Lokomobile boiler/engine combination.

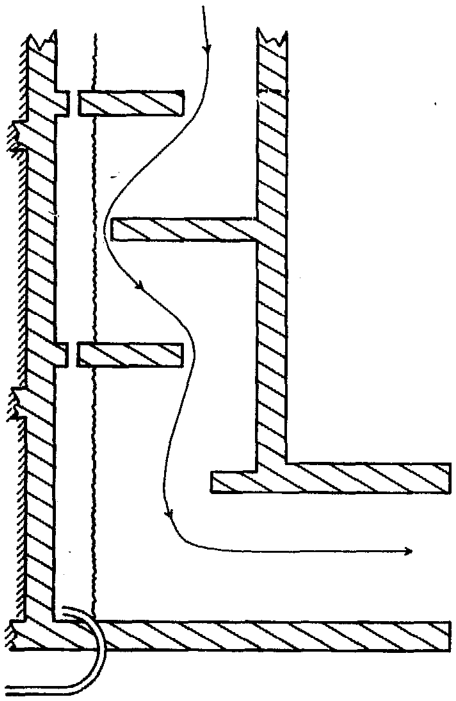


Figure 17. Simple water scrubber

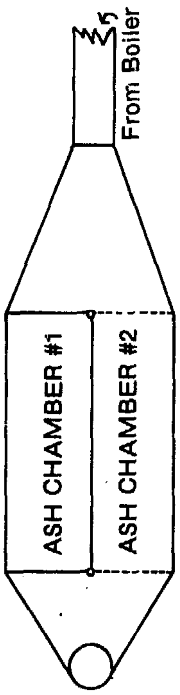


Figure 18. Ash chamber installation

6.1.5.4. Scrubbing. The particulate matter entrained in the gas flow through the boiler and out to the stack must, in some situations, be removed before effluent discharge. A simple two/three-pass water scrubber that can be constructed locally of diverse materials is shown in Figure 17. The water should be removed by the system as shown. Adequate access for cleanout must also be provided.

If water scrubbing is not necessary or desired on a natural draft unit, an ash chamber can be installed at the base of the stack. With proper sizing of the chamber one can expect 95% of the particulate matter to settle out. An alternate flow/cleanout is suggested in Figure 18.

6.1.6. CONSTRAINTS

Regulations and restrictions concerning boiler construction and operation vary considerably from country to country. The various types, sizes and construction features are in most cases in use because of local requirements. For example, some countries today are still governed by the English boiler law of 1922 which says that all boilers must be riveted. Therefore, the cost of a boiler, and of course the feasibility of a project,is in some ways wholly dependent upon the location or country and not necessarily on the quality of the husk as a fuel.

Operation of the boiler and the staffing of the plant depend to a great degree on the pressure developed by the boiler. In most cases a high-pressure boiler requires the constant attendance of a qualified operator, the cost of which will vary widely. However, for moderate-pressure boilers (for instance, in Italy, those with a working pressure below 12 kg/cm^2), no boiler man is needed if three independent, cascading safety devices are fitted and a licensed employee is in attendance in the plant.

In some cases the requirement is based on a combination of pressure and volume of water contained, so various methods have been devised to build legal units. Steam generators and the Indian mini-boiler are examples.

Because of legal restrictions there are instances of one-way traffic in boilers between countries. Thus, a Thai boiler may not be used in Malaysia or Singapore, but many used boilers are shipped to Thailand, which has no effective boiler code.

Of course all these considerations directly affect the cost of the boiler, and indirectly the decision whether husk-fired units would be practicable. For instance, Frugone & Preve's decision not to reactivate their long-used, very successful power plant in Robbio, Italy was almost entirely due to the labour/mains electricity cost ratio.

Any new plant in a country that has stringent regulations and high labour costs must be sophisticated enough to operate without attendants and to conform in safety features to the local regulations. To justify a boiler/straight power generation unit is difficult; only when there is a process steam requirement is it possible to consider a husk-fired boiler plant.

6.1.6.1. Losses. The operation of a boiler system for long life and high efficiency depends not only on the original design but on the continued proper operation and maintenance. If, as said by Hawkey (W159), "the system begins to die the day it is started up", excessive cost increases because of deterioration are not tolerable. For example,

dirty boilers can cause losses up to 25%,
leaky settings up to 15%, and
poor firing up to 40%.

These are all directly due to poor operation or maintenance, or to insufficient maintenance. As an example, one plant in India (Mandya) had a husk consumption nearly twice what was to be expected of an originally low-efficiency (Cornish) installation. At the opposite extreme, an Italian parboil plant (Garisi) improved its conversion ratio over the original installation through good maintenance and improving the system in the normal course of operation.

6.1.6.2. Stack losses in boiler operation. The chief loss of heat in steam-raising almost always derives from heat being carried away in the waste gases, and if the highest efficiency is to be attained, the stack loss must be kept down to the irreducible minimum; it can never be entirely eliminated, since it is not practicable to reject the gases at the temperature of the atmospheric air.

6.1.6.3. Effects of excess air in boiler operation. While a certain amount of excess air is necessary to ensure reasonably complete combustion, an undue excess is deleterious, quite apart from its direct effect in increasing chimney losses. The effect, moreover, depends on the point at which the air enters the system and is more serious when the leakage is at the furnace than at some later stage. Excessive introduction of air into the furnace may cause combustion to be less complete than it otherwise would be, by reason of the cooling of the gases below their ignition temperatures; transmission of heat is also impeded owing to the lowered temperature, and if chimney draft is employed, the chimney may be overloaded and the rate of combustion decreased.

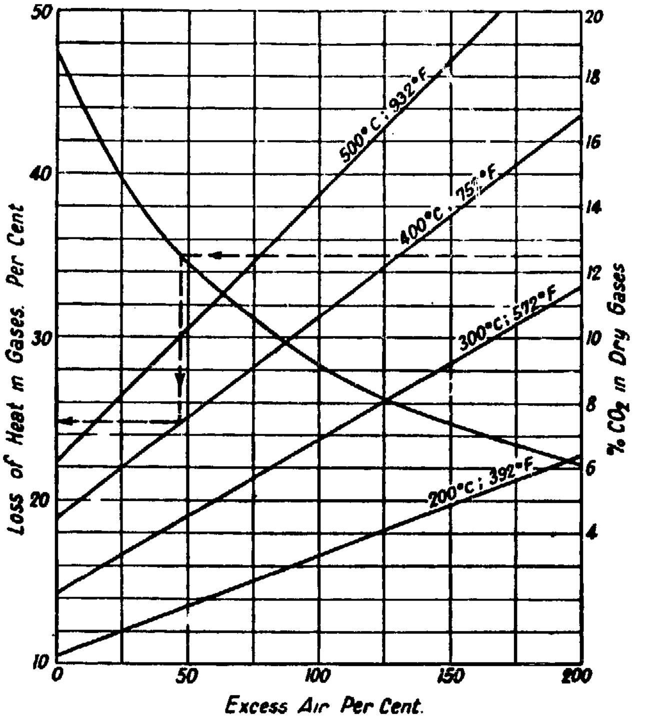


Figure 19 Effects of excess air in boiler operation

6.1.6.4. Corrosion (See also Section 5.5.1.) In designing the boiler system it is important to maintain the stack temperature above 200°C at the discharge end of the tubes, in order to control corrosion. If the temperature in the stack falls below the dew point the condensate causes excessive corrosion.

Since the efficiency of the boiler is directly affected by the stack temperature, the cost of efficiency must necessarily be balanced against corrosive effects, but some of these can be offset by a higher capital cost created by the use of corrosive-resistant materials.

6.1.6.5. Radiation losses. Another aspect of the installation is the cost of insulation of components to reduce the losses due to radiation from the furnace shell and boiler shell.

6.1.6.6. Conclusion. Almost all factors concerning the design and use of rice-husk fired boilers are in a balancing situation. The most important factors are the size of the unit, the duty for which it is intended and the country in which it is to be located. Relative economies depend wholly on the cost and availability of competitive fuels, the capital cost of the installation, the relative cost of operation (mainly labour), and the direct cost of alternative methods of husk disposal or utilization of the raw husk, char or ash.

6.2 DRYING (See also Section 4.3.5.)

Drying of paddy by use of husk-devised energy was discussed in Section 5.2.1. This section deals primarily with the equipment available for this purpose. Because of wide differences, it will be considered in two categories, 1) box-type or batch-type dryers; 2) continuous-flow dryers. Three methods of implementation will be envisaged: direct-fired, indirect (heat exchange) fired, and steam-heat exchanger types.

6.2.1. BOX-TYPE OR BATCH DRYERS

This type of dryer today is an Asian development, though in the early development stages of mechanical drying (around 1914), box-type dryers almost identical to today's design were produced in serial production in Italy. Most of the building of this type of dryer is now concentrated in the Philippines or Japan. Both direct and indirect units are manufactured in the Manila area (W129, W132, W133, W134), primarily as an outgrowth of development and popularization work by IRRI (W130) and the University of the Philippines (W156). A number of experimental variations of husk-fired furnaces for the box dryers have been developed: Manalo (105-6) established a usage of 1 kg husk/cavan (44 lbs) paddy to dry from 22.5% to 14% moisture. Batch time for 1144 kg was 4 hours.

The cost of the husk-fired box dryer complete, by Nation (W128) was 10,000 pesos in 1974, while a comparable kerosene-fired unit cost 6,000 pesos. Only under certain circumstances could the fuel saving justify the additional cost of a box dryer, because its utilization factor is low. Kamalig (W137), in their Philippine operation, uses about 150 box-type dryers, of which a portion are husk-fired, along with kerosene and multi-fueled (wood, straw, etc.). The earlier husk-fired units were not satisfactory, but the deficiencies have been corrected. The primary factor in the utilization of husk-fired units is that the dryer is to be operated in proximity to a source of husk. At one installation east of Los Baños (Philippines), a normal step-grate furnace furnishes heat for a UOP-designed box dryer. One advantage is that the dryer assembly itself can be knocked down for storage in the off season.

A great number of Japanese box dryers have been sold, but all appear to be kerosene- or oil-fired. The Japanese practice does not seem to be indicative of the effectiveness of husk-fired box dryers. Most of the stimulus for this development is generated by DePadua (W135) and Khan (W130). For all intended purposes the box dryer is satisfactory, and the only real development could come through improving its capability of using indigenous fuel. The control of the temperature is important; in practical situations, the husk-fired furnace must have an attendant to monitor the fuel firing to keep the temperature within limits, and to remove ash. An automatic husk feed-control system would be awkward and expensive, and no practical system has as yet been developed. (An oil-fired unit can be unattended and controlled automatically.) However, the husk-fired unit's main drawback is the fact that usually, where the dryer is used, there is no husk available, so practically the main problem is husk acquisition, although the higher initial cost of the unit is also a major obstacle.

6.2.1.1. Rotary husk-fired dryers. A novel type direct-fired dryer using a centrally located rice-husk furnace which furnishes hot gases to a fluid-bed progressive dryer has been tested and marketed for several years in India (W84). It has porous bottom-screw conveyors to move the drying paddy and maintains a temperature of 120°C with the use of 50 kg of paddy husk/hr. It has a capacity of 3 tons/hr of wet paddy when using 24% intake paddy with 16% discharge after 3 passes. This would indicate a use of 50 kg of husk for fuel for each ton of paddy ultimately dried. This usage corresponds to the usage of husk as fuel as reported by Manalo (105-6) using an IRRI-UOP type box dryer.

6.2.1.2. CeCoCo (Japan) (W101) offers a Japanese-type kiln furnace which will produce a 1000°C working medium; as an external-furnace assembly, the heat generated is used to dry grains, seaweed, vegetables, fruits, fish, etc. The firm also represents Kansai Sangro (W102), offering carbonizers and allied products. The stack discharge from these carbonizers makes an excellent source of heat for drying purposes.

6.2.1.3. Husk charcoal as a fuel. In Asia, there has been considerable interest in the use of husk charcoal as a fuel for drying. A dryer by Faith Eng. Co. Ltd. is specifically designed to utilize the husk charcoal fuel. Work has also been done on a concentrating machine (W9) to briquette or extrude the product for transport and handling advantages. (See section 6.7.3.)

6.2.2. CONTINUOUS-FLOW DRYING

Continuous-flow dryers range widely in size. A typical manufacturer (Schule) offers a range of dryers whose performance data appear in Table 25.

Table 25

Capacity of continuous-flow dryers
(kg paddy intake per hr)

Dryer	Type	2	3	4	5	6	8	10	15
1-pass	L	2200	3500	5100	6500	7900	10500	13200	18700
	R	1760	2800	4080	5200	6320	8400	10560	14960
2-pass	L	1100	1750	2550	3250	3950	5250	6600	9350
	R	880	1400	2040	2600	3160	4200	5280	7480
3-pass	L	733	1166	1700	2166	2633	3500	4400	6233
	R	586	933	1360	1733	2106	2800	3520	4988
4-pass	L	550	875	1275	1625	1975	2625	3300	4675
	R	440	700	1020	1300	1580	2100	2640	3740
Dry air m^3/h		7200	10800	14400	18000	21600	28800	36000	50000
Htg Cpy (kcal/hr)	max.	105000	155000	205000	255000	300000	410000	515000	710000
	min.	72000	107000	143000	179000	205000	280000	358000	495000
Husk Cons. kg/hr	max.	31.5	46.5	61.5	76.5	90.0	123.	154.5	213.
	min.	21.1	32.1	42.9	53.7	61.5	88.4	102.4	148.5
kw Cons		3	3.5	4	5	6	8	10	15

L = long grain   R = round grain

Any heat source may be used, but while the husk consumption data are correct theoretically it would be prudent to increase the consumption by 10-15% to allow for furnace inefficiency not planned.

Large husk-fired dryers, both direct- and indirect-fired, have been and can be furnished by many firms. They are in use in Bangladesh, Pakistan, Dominican Republic and elsewhere.

In Japan there are many dryers (not only for paddy) using husk for fuel. One type of furnace (almost a gas producer design) is shown in Figure   . It burns 340 kg of husk per hour, providing 745,000 Kcal/hr; the exchanger has an efficiency of 53.5%, transferring 399,000 Kcal/hr. The stack discharge represents 31.5% or 235,000 Kcal. The indirect-air product balances at a temperature of 230°C. Manufacturers (W107, W111, W112) are varied, usually in conjunction with a carbonization plant or equipment. Determining the extent of husk-fired drying use is difficult.

In Thailand the general practice is to use steam-exchanger dryers with coils from India (W146). One local manufacturer offers a complete line of heat-exchanger dryers. A 4 ton/hr 2-pass dryer providing 8% removal was under construction in Bangkok at Sathorn (W152). There appear to be no direct-fired dryers in Thailand.

In India again there are many steam-heat exchanger dryers, probably because there are always other uses for process steam in the parboiling plant. The heat-exchanger coils are usually manufactured in India under a Swedish license, but British-built heat exchangers are also in use.

At ITT-Kharagpur, Ojha-Maheshwari (W63) built and tested a direct-fired continuous dryer and showed that the gas/air mixture is nearly as good as heated ambient air. The step-grate/curtain-wall furnace used a feed rate of 11 kg/hr to supply 1000 ft^3/min of heated air-flue gas mixture maintained at 100°C. The furnace provides a combustion with no traces of smoke in the flue gas. This corresponds to Acasio's comment: "For ideal drying conditions, the exhaust gases must be completely burned before they can be used directly for drying grain crops." That their combustion was good is shown by Maheshwari's flue-gas analysis of 3% CO_2, 16% O_2, 0% CO, balance N_2.

The comparative cost chart in Table 14 developed from Ojha-Maheshwari work at IIT-Kharagpur covers fully the range of options of fuels and necessary processes concerned with the drying of paddy rice.

6.3. FURNACES

Any burning-type conversion of rice husk to energy must be done in a reactor of some sort; usually this is thought of as a furnace. The complexity and sophistication of such furnaces can vary widely, from the pile of husk under a dished pan in a "chatty" parboiling operation, through a pile of husk on a flat grate, to an inclined step-grate--a sophisticated pitch movable grate--to a fluid-bed furnace. All of these are furnaces whose only purpose is to combine fuel and air under the most efficient and controllable conditions to provide heat for some beneficial utilization of the raw husk.

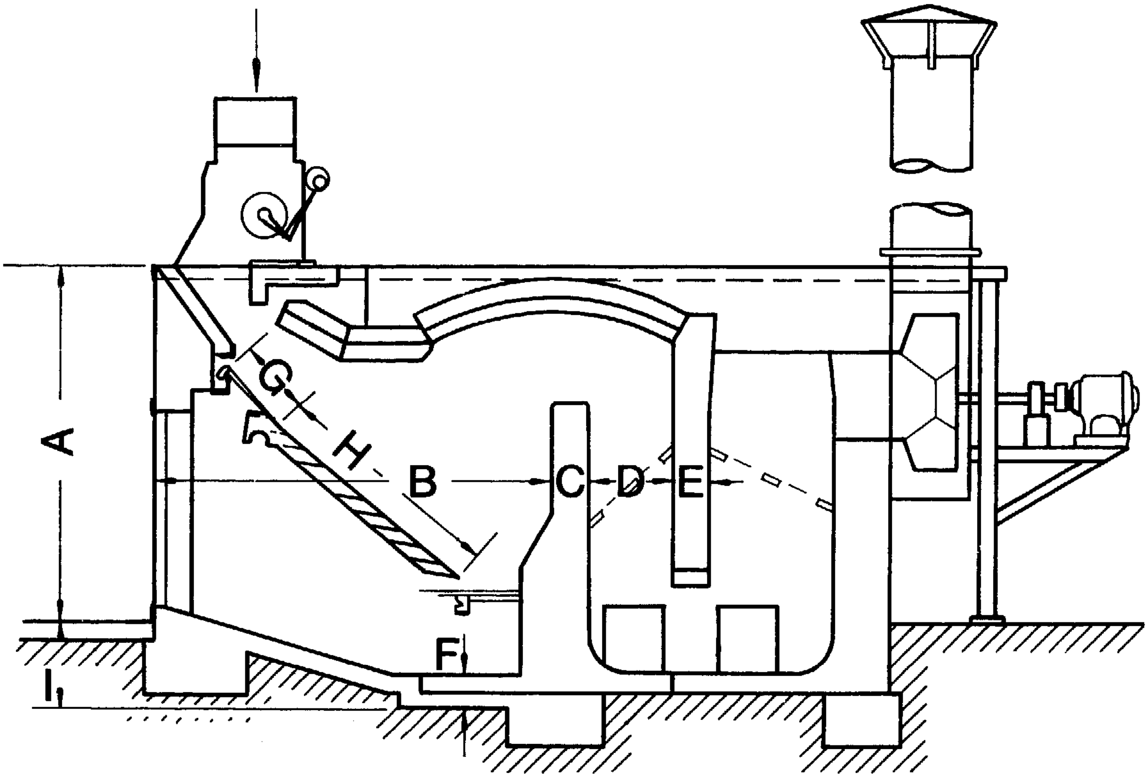
There are several types of furnaces with fundamental differences. They include fixed-bed, flat-grate, inclined step-grate, movable inclined step-grate, fluid-bed, air-suspended, gas-combustor (Takano) and dual-fuel system furnaces.

Methods of stoking (feeding) the husk vary with each type of furnace. There are several commercial types of underfeed stokers, some designed for coal (W90, W44) and some designed for wood chips/sawdust (W10). The use of rice husk in an underfeed stoker is possible. The underfeed stoker of the Argusfyr type has an added advantage of needing no grate or underground fire box when used with a floor-mounted boiler. One boiler manufacturer (W33) states that the use of this type of underfeed stoker attained, in his tests, a 4.8% higher efficiency than a classic inclined-step grate. Possibly this was due to greater containment and therefore less radiation loss.

The husk can be fed into an internal furnace chamber of a boiler pneumatically, into a safety chamber, the combustion occurring in suspension and probably partially in the tube. Transport air will be in the range of 60 ft^3/lb of husk. About 95 ft^3/lb of husk are required for proper combustion. There are several methods of addition; the difference is determined primarily by whether the installation is on induced draft or natural draft.

The air speed behind the ejection nozzle should be more than 45 ft/sec in order to avoid back-firing. As additional protection, two safety ports are installed before the injection nozzle. These valves are opened by the flow of transport air and close automatically when the air speed is reduced.

The traditional method for burning husk and high-humidity materials has been by an indirect step-grate. A classic design (Kampnagel) of a fixed-angle step-grate furnace is shown in Figure 20. Feed to the top of the step grate can take place by gravity slide, rotary valve or vibrating feeder--any method of ensuring the necessary sealing of gas/air and desired metering of the husk feed material.



Fixed-angle step-grate furnace
(Kampnagel)

A movable step-grate is fed in the same way.

A fluid-bed furnace must have an in-line pressure feed.

An air-suspended cyclonic-type furnace injects the husk either with the full amount of air or with separate feeds, tangentially, for the air and the husk fuel.

In his 1952 paper Lathrop (223) described a furnace fed by a screw conveyer which droppe the husk into a jet stream of air directed at a small target. This is somewhat similar to the unit developed by Kuppuswamy (W66), in which the fuel is injected toward a small hot plate target which ensures ignition.

6.3.1. THERMAL ACCUMULATION OF HEAT IN A FURNACE

To have certain and steady combustion it is necessary to design the furnace so that when more output is required, calling for additional air and fuel, the drawdown of the heat-sink cannot reduce the temperature below that necessary to ensure good gasification and burning of husk. Several methods are possible. One is to preheat the air coming in, using air passing over the furnace so that the furnace radiation can be utilized. Also, if it is impractical to install an economizer, the feedwater inlet can be plumbed so as to use waste heat from the furnace area. For details on the importance of feedwater heating, see Figure 16.

6.3.2. TYPES OF FURNACE

6.3.2.1. Fixed-bed furnaces. The fixed-bed furnace has no grate. The husk burns in a pile on the floor, or ground, or any other surface. The ash is removed manually, although in some cases the work is moved instead.

6.3.2.2. Flat-grate. Normally, when a flat grate is used on a rice-husk fueled furnace, the husk is being used as an alternative fuel. The use of a flat grate with rice husk requires a special firing technique to be successful. Usually, the husk is added as a supplemental feed on top of a bed of wood or coal. A typical user of husk on a flat grate, Scopa describes their method of firing as follows:

> "If the husk is allowed to burn completely, the fire bed either chokes or falls through the grates. First the boiler is fired with coal so that a base for husk is formed. The husk is then periodically spread over the fire bed and fed after every five minutes. The grate is also agitated so that partially burnt husk falls out. The burning bed forms a loose porous layer. If the husk burns completely the bed cannot be sustained. We later on made a hopper which had a sliding door. This door was adjusted and the husk was sucked in by the draft. The ash removal was accomplished by means of bent steel rod from below the grates."

Many attempts to utilize husk as a fuel on flat grates have failed, because a sustained fire bed could not be established.

6.3.2.3. Inclined-step grate. This is the traditional design which, since its introduction in Burma in 1880 (Cowie), has dominated installations for rice-husk burning.

There are three basic variations:

Under floor level Above floor level	These stationary furnaces are employed for all boilers that have no withdrawable tubular system.
Pull-away	Sometimes called Portable.

Under-floor: This is illustrated in Figure 12. In this case the boiler chasis is possible at floor level, but rice husk can create problems with ash removal.

Floor-level: As shown in the classic design in Figure 21, the floor-level grate also has a floor-level boiler. Only the ash removal system is sunken. This (Bergoni) design shows a small external volume for the furnace and a rather large combustion tube in the boiler, which apparently is a Cornish type that would allow this configuration. Figure 13 shows a more modern above-floor grate with a second-level boiler installation.

Pull-away: A traditional style of pull-away furnace feeding a locomotive-type fire-tube boiler is shown in Figure 22. The portable furnace is appropriate when the boiler has withdrawable tubes or the cleaning of the tubes cannot be effected otherwise.

There are also several variations in style with emphasis on the special form of the grate bars and the proper inclination of the step grate, an economical and sufficient combustion to depending a great extent on these features:

- Single-section grate
- Multi-section grate
- Multi-section, variable-pitch grate

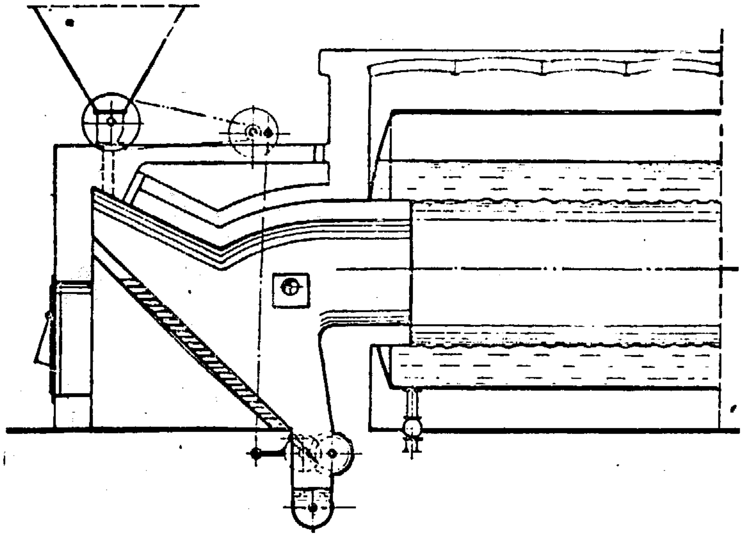


Figure 21 Floor-level inclined step-grate furnace (Bergoni)

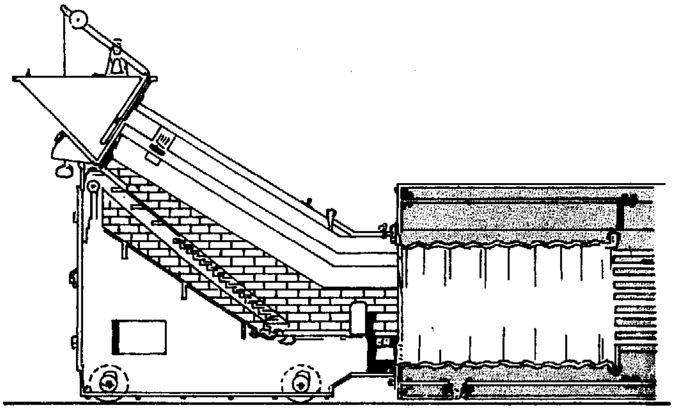


Figure 22 Pull-away furnace

The angle of repose of rice husk depends upon several factors: the variety of paddy, the moisture content, the type of sheller (disc, rubber, centrifugal) used, the amount of extraneous material (dockage), whether parboiled or raw rice milling, and within the furnace the amount and stage of gasification, which depends on the design and internal radiation of the furnace and the actual density of the husk furnished.

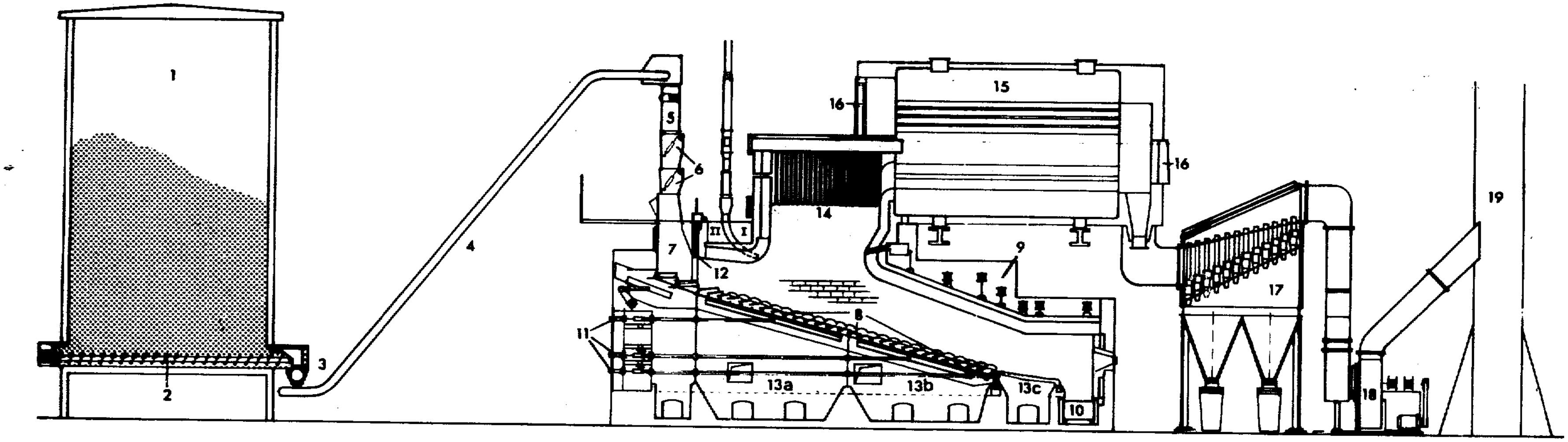
Very important is the necessity to have a uniform draught through the grate (B.R. Wolf says not over 1.0 m/sec) and therefore a uniform porosity of the layer of husk and derived products further down the grate. It can be necessarily different, and can change at any time when the characteristics of the in-feed of husk change. Therefore it is always necessary to consider a multi-section, variable-pitch grate that can be adjusted as desired to tailor the angle to the proper conditions. The slope can be changed to accommodate the installation in a variety of ways and with varying degrees of ease.

6.3.2.4. <u>Movable inclined step-grate</u> (Lambion W39). Experimental values show that satisfactory high-yield combustion is impossible by means of a fixed grate. For this reason, revisions have been made to the feed grate with special regard to the combustion of husk, as only this type of grate makes it possible to control the introduction zone, the combustion zone and the residue zone separately. A hydraulic drive for the motion of the different combustion zones ensures a maximum range of control. The grate covering is designed so as to meet all these demands in the best possible way, and it has proved to be very successful in many plants.

The combustion air is divided according to the different grate zones and can thus be supplied in concentrated form into the main burning zones. Furthermore, special attention is paid to correct planning for the combustion chamber in order to achieve maximum burnout and optimum ignition.

A section depicting this type of grate design is shown in Figure 23. Two highly efficient power plants (W126, W134) utilize this grate system to reach a quite high conversion ratio. Both are three-section units and consist of:

- a rigid grate part, the angle of inclination of which can be regulated; and
- a mechanically operated feed-grate, part which is longitudinally divided into two zones of motion.



(1)	bin
(2)	travelling screw conveyor
(3)	screw collector
(4)	conveyor belt
(5)	fuel distributing apparatus
(6)	fuel feeding flaps-type apparatus
(7)	feeding chute
(8)	grate
(9)	furnace bloc
(10)	ash pit
(11)	hydraulic cylinder and connecting rods
(12)	fuel layer thickness regulator
(13)a,b,c,	undergrate blast zones
(14)	intermediate casing
(15)	three pass boiler
(16)	cleaning doors
(17)	flue gas dust extraction plant
(18)	induced draught fan
(19)	chimney

Figure 23

Movable inclined step-grate furnace

Obviously the major disadvantage of this grating system is its cost. But when balanced against the increased efficiency it appears that in moderately sized units (10,000 lb of steam and larger) the cost is justified.

6.3.2.5. Fluid-bed. No large fluid-bed furnace installations operating on rice husk are known. A typical design of a 26'-diameter fluid-bed reactor operating at 1100°C would consume about 24,000 lb/hr of rice husk and develop 80,000 lb/hr of steam. The conversion ratio would be 3:33. Exhaust gas exits at 75°C. (See also Section 3.1.3.3.)

6.3.2.6. Air-suspended. Cyclonic turbulent flow furnaces can be either external (Pitt) (W185) or internal (Gariboldi) (W90). The external cyclonic furnace can be designed to produce either heat alone or a residue product alone or a combination of these. Designs of air-suspended furnaces are shown in Figures 14 and 15. It has been said that a husk-fueled furnace does not furnish a temperature high enough for efficient boiler operation at high steam pressures and temperatures. This is not true when a properly designed air-suspended furnace is used ahead of a suitable waste-heat boiler.

In a pneumatically fed internal combustion boiler, when husks are blown into the combustion chamber, no grate is necessary because combustion takes place completely in suspension. The fuel is blown through the injection nozzle into the fire tube in such a way that it moves in a spiral path through the combustion chamber, ensuring better burning and combustion. Here, however, the entire amount of the combustion air required must be blown in. Total air volume is made up of the transport air and secondary air supplied by a fan. In these furnaces it must be possible to operate with variable load. The secondary air fan is controlled as contingent upon the fuel volume. A high air volume must be used, since there is no grating, and the ash residue must be conveyed through the tube section. An induced-draught fan is helpful in maintaining proper control.

The furnace designed by Kuppuswamy (W66) utilizes air-suspended burning.

A new project at IIT-Kharagpur is concerned with an air-suspended furnace. It is a pressure-feed, tangential pre-combustion chamber with side extraction. Ash removal takes place through a bottom hopper with an interruptible discharge.

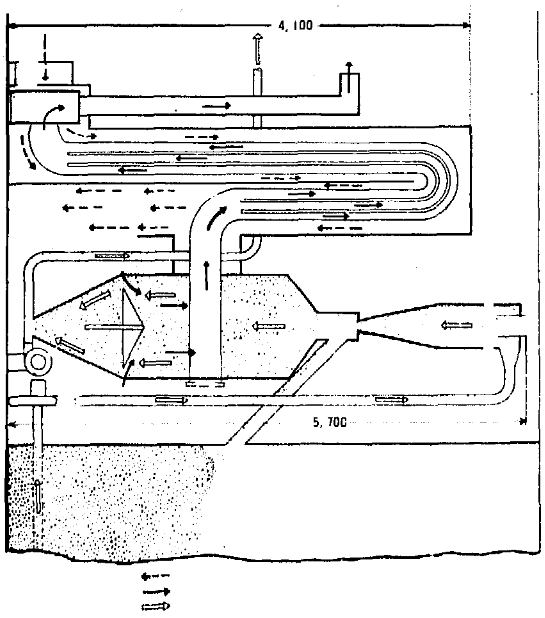


Figure 24

Gas-combustor furnace (Takano)

6.3.2.7. Gas-combustor. Figure 24 shows a typical Japanese furnace (Takano), which produces heat for use in drying or processing 340 kg/hr and generates 745,000 Kcals/hr; the residue produced is a char of approximately 50% carbon and 50% ash. The tested efficiency of the heat exchanger is 53.5%. This furnace is really a carbonizer utilizing gasification. The core section action is like that of a gas producer. It produces heat for various purposes as a by-product. Its main usage is as a carbonizer.

The suction-system rice-husk combustion furnace sold by Yamamoto (W112) is similar. Considerable development work on types of combustion equipment has been done by Shimizu (W104). Test data produced by the Institute of Agricultural Machinery, typical of their type of combustion furnace, are shown in Table 28.

6.3.2.8. Dual-fuel furnaces. In furnaces with pneumatic injection, by far the greater part of fuel burns in a state of suspension, while coarse particles fall partially burned onto the grate and complete their combustion there. An oil burner for No. 2 fuel or, at high operating pressure, for Nos. 5 or 6 fuel[1] can be fitted to the end plate of the boiler fire-door. For automatic operation the oil burner is used to start the fire, since the husk cannot be lighted by an electric spark; it also supplements the fuel supply during the peak season or when not enough husk is available for the desired output.

In compact boilers and combustion-tube boilers, muffles are installed before the combustion chamber. The oil burner is mounted in front of the muffle, and the husk is blown into the muffle area around the path of the boiler flame, so that it passes the muffle area and combustion chamber in a spiral path. The oil burner functions as pilot burner and can provide additional fuel at peak loading.

6.3.3. DUST CONTROL

It can be said in general of furnaces that the amount of combustion air they require depends largely on the type of firing. In general, the air capacity should be great enough to ensure that only a very faint trace of exhaust gas can be seen rising from the chimney stack; there should never be black smoke.

To meet stricter pollution codes, the secondary air should be regulated. The area underneath the grate should be sealed air-tight and the air needed for combustion injected by an air blower, governed by an electronic-emission gas meter, located behind the furnace.

In very strict air-pollution control areas, the environmental contamination due to the dust contents of the flue gases is subject to legal regulations concerning the emission of solid matters.

The typical flue gas has a dust load of between 1 and 2 gr/ft^2 that cannot be extracte at the prevailing temperature of approximately 1000°C. It is necessary to cool the flue gases below 300°C before they penetrate the dust extractor. For this purpose, a three-pass somke-tube boiler is generally used.

In order to comply with emission regulations, various dust extraction systems of well-known manufacturers are used. Installations can be equipped with the following typica flue-gas dust-extraction plants:

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[1] No. 2 fuel is distillate with maximum Saybolt Universal 100°F rating of 40. Nos. 5 and are residual-type oils with minimum Saybolt Universal 100°F ratings of 150.

- multiclone dust extractor (0,2 gr/ft^3 12% CO_2)
- three-phase dust extractor (0,1 gr/ft^3 12% CO_2)
- electro dust extractor (below 0,065 gr/ft^3 12% CO_2)

6.3.4. ASH REMOVAL

One of the most important factors in furnace selection is the manner in which the ash-char is removed. The under-floor systems usually depend on water removal methods, mechanical or manual lifting of ash to discharge height, or vacuum conveying methods. Several typical examples are shown in Figures 14, 21 and 23. It must be borne in mind that when rice husk is used as a fuel, ash-char production is greater than with any other type of fuel, and that when the ash-char comes out of the grate area it will most likely be at a high temperature unless provision is made to percolate a portion of combustion makeup air through it to cool it.

When a combustion-tube induced-draught boiler is used, in which all of the husk enters the combustion chamber and the ash continues through the tubes, the char-ash is collected by one- or two-stage cyclonic collectors before the discharge gases are passed up through the stack. If necessary, a scrubber or a bag filter can be used in the fan discharge dust.

6.3.5. MISCELLANEOUS

The Punjab Agricultural University (PAU) at Ludhiana (W68) is working on a developmental furnace and dryer combination. This project has been under way by FCI for some time, but no results have been released. PAU is surveying the practices of all regional mills and is trying to develop an improved standardized furnace design for rice mills.

In Thailand, Imasuri (W146) has installed a new furnace of proprietary design at his mill near Bangkok, to furnish heat to a parboiling process-steam boiler.

For details of a furnace suitable for drying or other heat uses, the paper by Ojha (179) contains a detail of construction and test that includes all necessary information.

6.4 STEAM PRIME MOVERS (ENGINES AND TURBINES)

The engine of the steam cycle may be of either of two general types: the reciprocating engine, commonly referred to as the steam engine; or the turbine engine, commonly referred to as the steam turbine. Given the same initial conditions of the steam and the same exhaust conditions, the ideal thermal efficiencies of the steam engine and the turbine are exactly the same. The use of one or the other for a specific purpose is determined by practical or economic considerations. The measures of efficiency and performance are applicable to both the steam engine and the steam turbine.

Steam prime movers are exceptionally well suited to operation in combination with paddy-rice parboiling processing, because line steam is used for steeping, soaking, steaming, drying and other activities.

Where relatively low powers are involved, the choice of the steam engine rather than the steam turbine (often produced by the same manufacturers) is due to the favourable steam consumption of an engine when working under the steam conditions required by the process. To obtain the required temperature in the process-steam supply, the prime mover should exhaust saturated steam at a pressure of 35-45 lb/in^2 (2.5-3.2 kg/cm^2).

Using the limited fuel availabe from rice husk, a steam engine will drive a mill satisfactorily, in addition to furnishing its full process-steam requirements, by operating with dry saturated steam at a pressure of 225 lb/in^2 (16 kg/cm^2) at the inlet valve.

On the other hand, a single-stage turbine operating under the same steam conditions requires 33% more steam than the engine, and there could conceivably be insufficient husk available to perform the desired operations.

It is, of course, possible to reduce the turbine's steam consumption to an acceptable level by using higher-pressure superheated steam, but this can only be obtained at the cost of complications and is inadvisable in remote areas, where simplicity of the plant and maintenance procedures is a vital economic factor.

For example, the additional equipment required to reduce a turbine's steam consumption to that of a steam engine would include:

- more comprehensive water treatment and deaerator plant
- more expensive boilers
- superheaters
- desuperheater (with associated control equipment) for the exhaust steam when the turbine is running on a light load
- desuperheater (with associated control equipment) for the make-up steam that bypasses the turbine

Furthermore, these items require skilled operators or maintenance engineers, expensive and undoubtedly difficult to find and keep.

According to Spilling (W46) "The economic borderline in the range of applicability between a steam motor and a back-pressure turbine varies between 1000 HP and 2000 HP per engine unit. As changing steam throughputs and energy demands often require three sets or more, a comparative rentability calculation with plants of 1000 to 5000 kw has to decide whether a steam motor or a steam turbine is more adequate. The back-pressure turbine has a lower thermo-dynamic efficiency up to 1000 to 2000 HP, especially under partial loads, if compared to the steam motor. The same quantity of steam therefore allows a higher output with a steam motor than with a steam turbine."

These points support the view that while the initial cost of a steam engine is higher than that of a single-stage steam turbine, the overall cost of the complete boiler plant/ power station installation is generally lower.

6.4.1. THE STEAM ENGINE

The two earliest "modern type" steam engine designs were the Willans (built 1884) which, before it was rendered obsolete by the steam turbine in 1904, had a formidable rival in the double-acting engine built by Belliss and Morcom (W154) (pattented 1890), which is still being built by the same company in Birmingham, England.

Other non-marine engines built today are few. The only modern type is the steam motor, a vertical unit by Spilling (W46). There is a Brazilian Lokomobile unit by Mernak, and there are a number of Thai engines built by individual shops in Bangkok. These are mainly compound engines based on a classic design (about 1900), probably by Marshall.

6.4.1.1. Steam engine types. A simple steam engine is one in which the expansion of steam is completed in one cylinder. A compound steam engine is one in which the steam progressively expands in two or more cylinders. The term compound, without qualification, refers to the two-cylinder arrangement. Triple expansion means that the expansion is completed in three stages or cylinders, and quadruple expansion that the expansion is completed in four stages or cylinders. Compound engines may have the cylinders arranged in various ways: tandem-compound (cylinders placed one behind the other in line), angle-compound, (cylinder axes placed at right angles to one another), cross-compound (cylinders arranged side by side), and vertical triple-expansion (three cylinders placed with axes vertical).

Engines with expansion-valve gear with single, compound or duplex configurations were built up to almost 300 HP.

Engines with drop-valve gear were built as single cylinder, two-crank compound, tandem compound and triple expansion engines up to 3000 HP.

"Lokomobile"-type semi-portable engines were built as single cylinder and compound engines up to 800 HP.

Uni-flow engines with positive drop gear were built to supply up to 2000 HP.

6.4.1.2. Belliss & Morcom engines. The presently built series of engines has been continuously in production since 1890. These engines are two-cylinder vertical engines, in the 100 kw to 500 kw size range. If oil-free exhaust steam for process use is desired, engines can be operated as NCL (no cylinder lubrication) on dry saturated steam.

Typical steam consumption figures for these enginges in back-pressure operation were presented in Table 16.

6.4.1.3. Mernak. The only engine of the Lokomobile type built today is manufactured in Brazil by Mernak (W7). They offer two series of engines with the following specifications shown in Table 26.

Table 26

Specifications for Lokomobile-type engines (Mernak)

Nominal Rating	120/140 HP	170/190 HP
Stroke & bore	1600 x 350 mm	1800 x 350 mm
Speed	220 rpm	230 rpm
Pressure	12 atms	12 atms
Wt of unit	16500 kg	19800 kg

Not much is known about these engines outside of South America, although Balerdi (W1) is using them and is familiar with all their aspects. The design appears to follow closely the older Buckau R. Wolf engines, one of which Bianchi (24) had installed: a 195 HP, 12 atm, 340°C unit that used only half of the husk produced to drive the mill. He purchased a second Buckau R. Wolf engine in 1955: a 380 HP, 18 atm, 340°C unit which gave an excellent performance, pulling more than the 380 HP load using one ton of husk per hour. This compares closely with the performance of both the Tulio (W134) and the SML (W144) modern plants, with their conversion ratio of 400 HP ton of husk, or about 4 kg steam/1 kg husk, but it is a considerably higher figure than earlier reported consumptions of Buckau R. Wolf engines.

6.4.1.4. Spilling. The steam motor furnished to a great number of modern installations is built in Hamburg by Spilling (W46). These engines range from 1 to 10 cylinders, with 70-1700 lb/in^2 (5/114 atm) inlet pressures. The back pressure is one half of the inlet pressure or less. The bore of the engine is changed to match the desired power output to the available pressure differential. These engines can also be furnished NCL.

6.4.1.5. Thailand. In the workshops of Bangkok, a great number of steam engines can be seen under construction by the rice-mill manufacturers who furnish most of the equipment for the mills. As most Thai mills are still lineshaft driven with husk-fueled steam plants, and as there are no other engine manufacturers still operating (in these sizes) in the Western countries, the Thai shops have used a tried and proven (probably Marshal) design and constructed a matched engine to accompany their rice mills. In some cases the boiler is also built by the same shop (W150), but elsewhere (W149) the boiler is built in another independent shop (W148) and is purchased by the contractor to go in with the new mill and engine. Imasuri (W146) states that there are at least 24 shops in Bangkok capable of supplying a complete rice mill. Two such shops build single and compound, single- and double-expansion engines with specifications shown in Table 27.

Table 27

Specifications for Thai-manufactured steam engines

	Lee (W150)	Kwang (W149)
Horsepower	75 (for 10" engines)	?
Bore-large	18" or 14"	15" - 10" (2 cyl.)
Bore-small	12" or 10"	10" - 6"
Stroke	24"	?
RPM	105	?
Inlet pressure	150 lb/in^2	?
Cost	\$14,000 (280,000 baht)	?
Rice-mill paddy capacity	4 tons/hr	?

It is said to take two months to complete the steam engine and six months to build the complete rice mill. The crankshaft billets are forged in Singapore, but all other pieces are apparently made in Bangkok.

An adequate number of used engines are said to be available on the market.

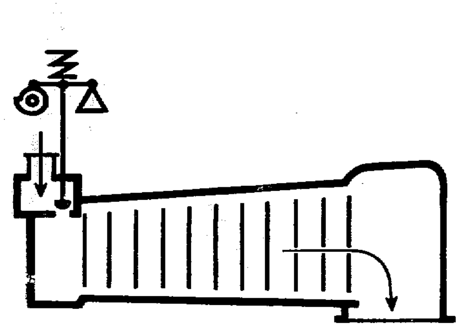
Thai engines and rice mills are exported (newly installed Thai engines exist in Malaysia), but their boilers are not.

6.4.1.6. India. No engine manufacturer appears to exist in India, but a large number of used engines and generator sets, mostly from other industries than rice, are to be found on the market. Newspaper advertisements request engines and alternators; one calls for a 150/200 BHP, 140 lb/in^2 engine and another for a Belliss & Morcom, 250/350 kw generator set, 140 lb/in^2; this indicates that a viable market exists for this type of equipment, and that the market requirement can be expected to be filled.

6.4.2. STEAM TURBINES

The availability of turbines for husk-fueled applications is much greater than that of engines. In the traditional rice mill, most prime movers were engines and from a numerical point of view, engines still outnumber turbines in new installations today. However, in any planned, sophisticated installation, the engineering studies should include parameters reflecting all facets of the proposed installation. Only after a wide-ranging consideration of the mill requirement, the process requirement and cost balancing factors, should the selection of the components be made. While no such installation has ever been attempted, it would be interesting, since all individual-drive rice-milling machines are designed for electric motors, to consider an installation using small individual steam turbines.

6.4.2.1. Types of turbines. Figure 25 shows the principal types of turbines manufactured today for commercial applications. The turbine may have from one to many stages, according to the design requirements of the installation.



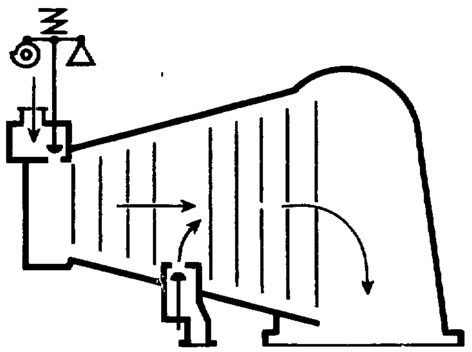
Non-condensing

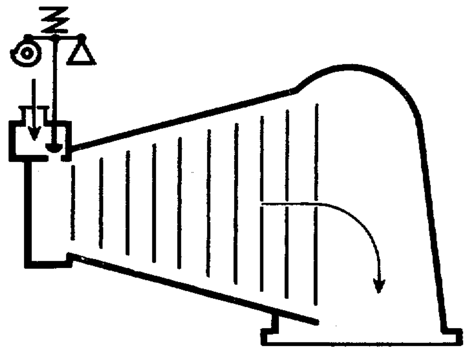
A straight non-condensing turbine is the economic choice when all exhaust steam can be used for process or heating.

If high-pressure steam is available for the turbine and the lower pressure exhaust can be used to supply other prime movers or a process, a non-condensing turbine can be applied to increase power output for the same fuel consumption.

Condensing mixed-pressure

A condensing mixed-pressure turbine automatically uses as much low-pressure steam as available, supplementing it with as much high-pressure steam as required to carry the load. This type is used when more power must be generated than is possible with the available low-pressure steam.



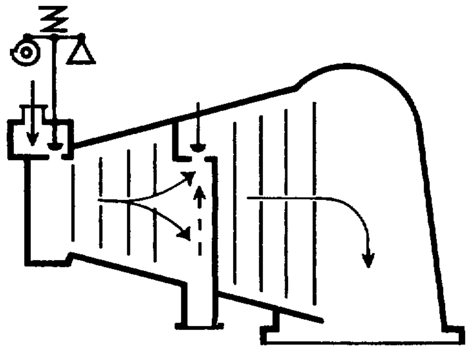


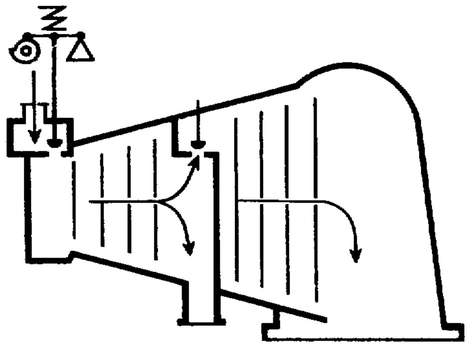
Condensing

A straight condensing turbine is used when electrical power generation is the only concern and it must be produced on a minimum amount of steam. To improve the plant's efficiency these units can be provided with multiple uncontrolled extraction openings for feedwater heating.

Mixed-pressure extraction

This unit operates either as a mixed-pressure or an extraction turbine, depending on steam balance. As the turbine generates power, it holds constant pressure on the low-pressure steam line, extracting or admitting steam as required.





Condensing controlled extraction

A condensing controlled extraction turbine bleeds off part of the main steam flow at one (single extraction) or two (double extraction) points. It is applied where process steam is required at pressures below the inlet pressure.

Non-condensing controlled extraction

A non-condensing controlled extraction turbine bleeds part of the main steam flow at one (single extraction) or two (double extraction) points. It is applied where process steam is required at several different pressures with variable or intermittent flows.

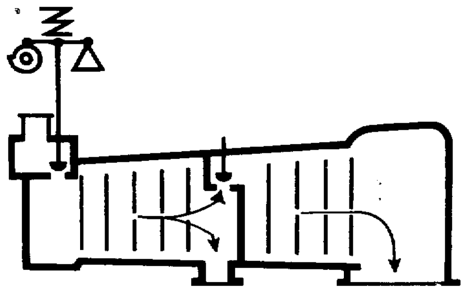


Figure 25

Principle types of turbines (after Worthington)

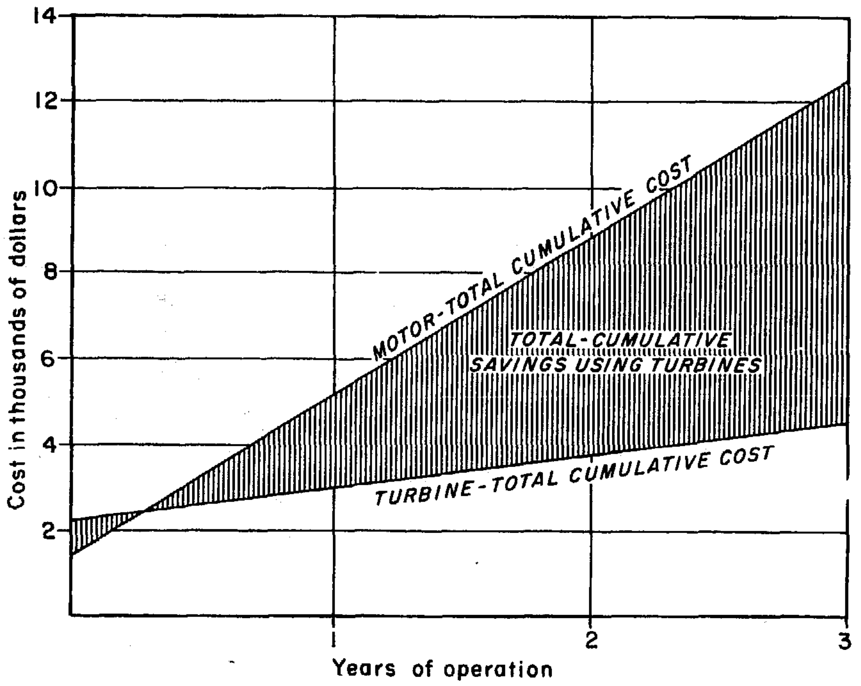


Figure 26

Cumulative costs: turbine vs. electric motor (400 HP)
(after Coppus)

6.4.2.2. Turbine applicability. The use of a steam turbine in preference to other prime power sources (such as electric motors) will not only help conserve a precious fuel supply but will effect significant reductions in initial capital investment and overall operating costs. For a cost comparison, see Figure 26.

Wherever high-pressure steam is available and there is a need for low-pressure (zero to 50 lb/in^2 gage) steam for heating or process work, a steam turbine can save a high percentage of the cost of energy required to operate other types of mechanical drives by developing practically "free" horsepower while acting as a pressure-reducing valve. Historically, the "free" horsepower has been evaluated in terms of financial savings, but with the present energy shortage, it is critical to evaluate steam turbine characteristics on the basis of fuel conservation.

Steam turbines are manufactured to specifications according to various parameters such as inlet steam pressure, comparative desired extraction points, exhaust or back pressure, brake horsepower output, speed, etc. Economic steam rates over a wide range of power requirements can be obtained. The various factors which affect steam rates are:

- speed - high turbine speeds afford improved steam rates;
- total temperature of steam - high total temperatures (degree of superheat) improve steam rates;
- inlet steam pressures - high inlet pressures improve steam rates;
- exhaust pressures - low exhaust pressures improve steam rates.

The use of the steam turbine as a motivating power for rice milling with required steam is highly advantageous in cost-saving and supplementation of critical energy. Various turbine manufacturers indicate that the present turbine design can be readily adapted to the use of steam from a rice-husk boiler. Boiler manufacturers can also modify their boilers to accept husk as fuel. In various countries, most of the steam generated by many small boilers in use is used to provide steam for parboiling, as these units are rudimentary and inefficient. Fire-tube boilers which produce steam pressure as high as 378 lb/in^2, which is suitable for turbine operation, are being used in Surinam.

6.4.2.3. Size and cost of turbines. Discussion is always possible concerning the practicality of a turbine as an engine and the availability of a full range of sizes for the different machines. Engines are available from small (50 HP) to moderately large (3000 HP) units. Turbines are available worldwide in a complete range: micro (less than 1 HP) to leviathan (500,000 HP). The range of sizes suitable for using rice husk as a fuel runs from 1-5 HP small, individual-drive machines to 300-500 HP prime movers, and on up to 5,000 kw power generators. The largest rice-husk fueled power-generation unit that has been proposed (Indonesia) is 5,000 kw. The largest husk-fired power plant that has been built (Philippines) is 1920 kw, and the largest turbine unit appears to be the 1200 kw Surinam unit.

Several years ago Schule (W44) studied in considerable depth the eternal question of engine or turbine. Their best judgement was that the crossover point was at about 500 HP, under this figure the engine being preferable, and above it the turbine.

Blohm & Voss, a reputable turbine manufacturer, feels that 500 HP is the minimum practical size.

However, Triveni (W85), Indian licensee of Peter Brotherhood, U.K., builds much smaller turbines, down to 200 HP, as do many other manufacturers. Terry-Kuhnert (W49) offers models down to 35 HP.

As for cost, a February 1975 Nadrowski (W41) tender quoted a 900 HP turbine generator set at $54,000.

6.5. GAS-PRODUCER SYSTEMS (See also Section 6.3)

Systems for the production of gas have been used since about 1900. Their designs and layout can be classified simply: classic (traditional) and modern. The flow pattern of both is similar, but some of the components have slightly different functions.

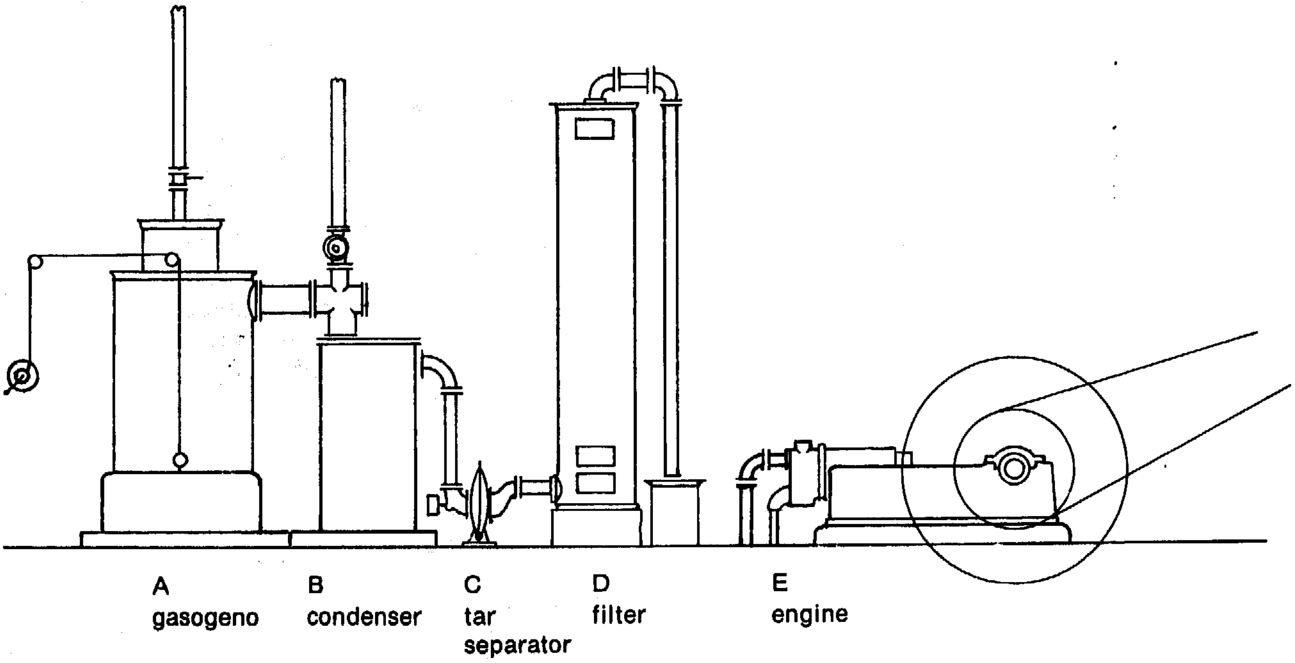


Figure 27

Classic gas-producer system (Monticello)

The classic layout shown in Figure 27 reflects almost exactly the existing unit at Monticello (W92). Balestra designed the gasogeno, which was constructed locally in 1940; it requires about 200 kg of husk per hour to provide 60 HP, adequate to drive the small rice mill. The engine is Italian built--Langen & Wolf--60 HP, 300 rpm.

6.5.1. MODERN SYSTEMS

The modern system can have the same flow pattern as the traditional, or it can include the features of a dual (pilot) fuel system. This concept was explored by the British (134, 135, 136) in the 1950s. The concept is commercial today using fuel other than rice husk, but there is no reason for not using rice husk if an adequate supply can be obtained. Many of the constraints of design and cost surrounding the traditional system are eliminated when dual (pilot) fuel operation is selected. Duvant (W20) has pioneered the installation of dual (pilot) fuel engines, normally of larger size than would be used in driving a small rice mill, but this only because commercial demand has been for units as generator sets in the 1000 kw range.

Italian gas generators have been built from 20/220 HP sizes. Some are provided with devices allowing fully automatic unattended operation. Once started up by a properly instructed operator, no further attention need be paid to the unit until shutdown. On a stationary unit, starting is no problem; if no other method is available, a hand-operated fan will initiate operation.

6.5.2. GASOGENO (PRODUCER-GAS GENERATOR)

A gas-producer consists of a vessel arranged to hold a fuel bed having gas-tight means of charging fuel and facilities for removing ash. The vessel must be capable of withstanding high temperatures and must incorporate features to admit air and steam or water for the process and to take off the gas which is produced.

Producer-gas is made by burning fuel to ash by means of a mixture of air and steam, the resulting gas being a mixture of burnt and combustible gases. The combustible portion of the fuel consists mainly of carbon. When air comes into contact with hot carbon, the latter is burned to a mixture of carbon monoxide (partly burnt carbon) and carbon dioxide (completely burnt carbon), together with nitrogen from the air. If air only is used, the producer becomes very hot and the ashes melt and form a fused ash.

Steam or water added to the air blast prevents the temperature in the oxidation zone from rising too high, thus reducing the tendency to fused ash formation. At the same time is itself preheated until it reaches a temperature sufficient for the steam to be decomposed to form a mixture of hydrogen, carbon monoxide and carbon dioxide. Thus the primary reduction zone is formed.

In producer plants delivering cold clean gas, the termal efficiency, usually expressed as the cold gas efficiency, is the ratio of potential heat in the gas produced to the heat available in a unit weight of fuel. The sensible heat in the gas leaving the producer should be used as effectively as possible for preheating the fuel, so that as much as possible of the original heat in the fuel appears as potential heat, and not sensible heat, in the gas.

A full range of cellulosic wastes, including rice husk, has been used as fuel for producer-gas generators. The first successful gas-producer is generally attributed to Bischof of Germany in 1839. An improved design was introduced into England in 1861. Table 3 shows constituents of producer gas manufactured from rice husk.

Rice-husk gas-producers were in use in the early 1900s; as the Schule 1910 catalogue was advertising for sale a suction gas-producer for engines with an output to 120 HP.

There was also use in Burma, but details are unavailable. The earliest details found in the literature are in the Italian (142A) and French (120) journals, which in the 1920s reflected considerable activity on gasogenos. It was not, however, until Balestra, in the 1930s, designed an improved gasogeno that the use of rice husk as a producer-gas fuel became a commercial reality. Producer-gas generators using rice husk as a fuel, the driving of rice mills with internal combustion engines using that gas, and the blending of rice-husk gas with other commercial gases, are purely an Italian accomplishment of the 1930s and 1940s. One unit at Monticello is representative of many of the units of that period.

6.5.2.1. Design of gasogenos. In order to realize the full potential of the use of rice husk as a gasogeno fuel, the gas-producer must be designed -

- to give a gas having the highest calorific value;
- to enable the use of a fuel carrying a maximum volatile content;
- to have a controlled gasification and fire zone, embodying a sufficiently high temperature, to convert the substances produced from the volatile matter in the fuel into fixed gases, so as to ensure that purification of the generator gases will occur satisfactorily;
- to give the foregoing results without complicated mechanisms calling for skilled operation and adjustment, and also without heavy refractory linings requiring frequent replacement in the fire zone.

Attention must be given to rendering the gasogeno regenerative by utilization of otherwise lost heat to raise the temperature of the feed water to steam or to the highest temperature possible. The use of a wet-gas producer, when combined with the necessary in-line filters and scrubbers, affords an 11% increase in the BTU value of the gas produced and a 14% increase in the percentage of combustible gas. Any stationary gasogeno can easily be arranged as a wet-gas producer with the necessary accessories.

In order to provide a cool, filtered gas product, it is best to use a two-stage cooler for the hot gas from the generator: first the feedwater steamer, and second the cooler/scrubber-washer.

The hydrogenation of the fuel while it is undergoing gasification gives rise to reactions that are of a very intricate nature due to the complex substances treated, and many of them are not fully understood. The aim of every designer of a gas-producer is to encourage and assist the chemical changes which result in the production of the combustible gases CO and H_2, at the same time keeping the non-combustible gases, CO_2 and N_2, in as small a volume as possible.

The classic arrangement and the one from which all subsequent variations have been forthcoming, together with the fundamental reactions, is shown in Figure 28.

6.5.2.2. Types of gas-producers. There are three fundamental types of gasogenos (see Figure 29):

a. updraught type
b. downdraught type
c. crossdraught type

Maheshwari (W63) describes these various producer-gas units as follows: "In updraught producers, the flow of air and gas is in an upward direction; it is in a downward direction and current-wise with the fuel flow in down draught producers. In cross-draught producers, the flow of air and gas is across the producer, though not necessarily in the same horizontal plane. The fuel flow is downward.

"The first gas-producers were very simple, consisting of vertically mounted cylindrical steel shells lined with fire bricks, an opening at the top for charging fuel, and an opening at the bottom for cinder removal. A third opening at or near the top of the cylinder provided an outlet for the discharge of gas. Grates were installed inside the shell near the bottom to hold the ash bed and to secure an even distribution of air through the fuel. The air was admitted either by suction or forced draught. It was called a built-in producer with horizontal grate.

"The next development in producer construction was the semi-extended type, which partially projected from the main setting. It was more accessible and permitted easier charging and leveling of the fuel.

"The attached gas-producer further simplified its operation by eliminating the difficulties encountered with other types. The attached producer was equipped with water-cooled step-grates and curtain walls, and could be operated with either natural or forced draught."

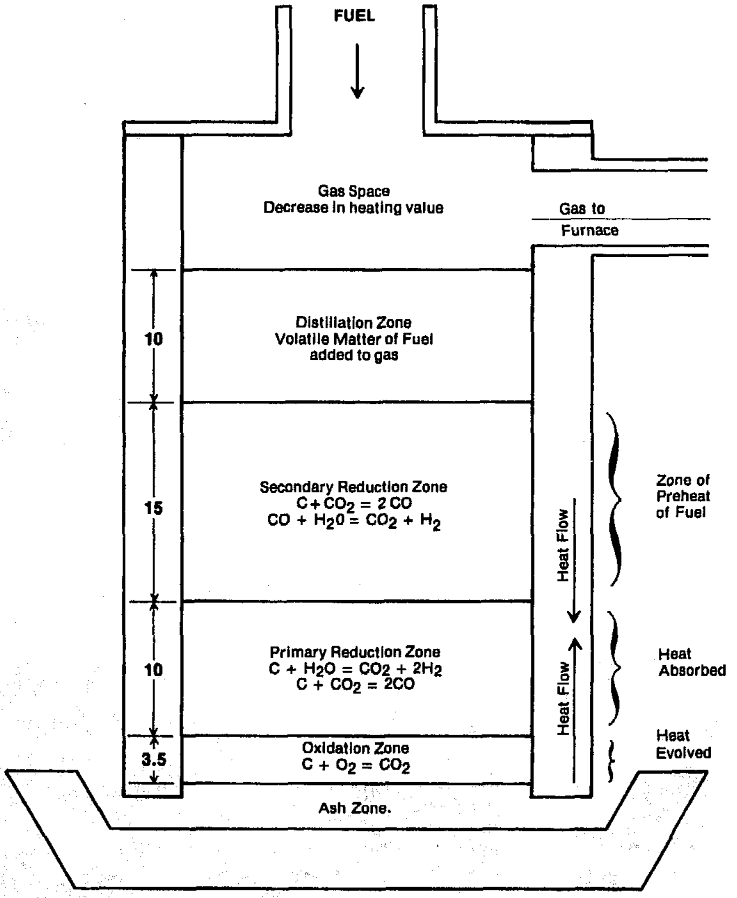


Figure 28 Gas-producer arrangement and reactions

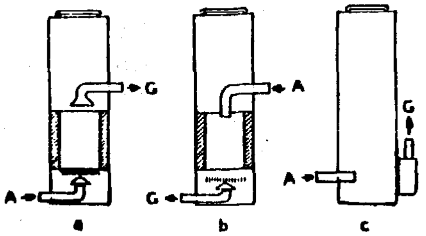


Figure 29 Types of gas-producers

6.5.2.3. Manufacture and design.

a. Deutz (116, 117). Pre-World War II activity involved the use of alternative fuels, and this resulted in the design and subsequent patenting of a rice-husk fueled gas-producer in Germany.

b. Romana (131). Developed a converter of rice husk to produce gas. The generator was equipped with a continuous-feed arrangement, a gas scrubber, a tar extractor and a gas-receiving tank. The gas generator consisted of a steel cylinder lined with fire bricks. The rice husks were charged from the top onto a grate at the bottom. The generated gas was the product of incomplete combustion of rice husk in a deep bed of several feet. The gas produced was withdrawn at the top of the gas generator and passed through a wet scrubber for cleaning and cooling. From the top of the scrubber, the gas was sucked into a centrifugal tar extractor and then was collected in the gas-receiving tank. A 10 HP engine was run on the producer-gas supplied by the generator.

It is not known whether any further development or commercial use was made of the Romana effort.

c. Neil & Spencer (W160). During World War II, this company was a major manufacturer of automotive coal-fired gas-producer units. They have recently designed a modern unit for use on trucks or buses. Their expertise concerning gasogenos is available whenever a commercial response to gas power-generation from rice husk appears.

d. Powergas Ltd (W157). The pioneer company of producer-gas technology was formed in 1901 to exploit the patent of Dr. Ludwig Mond. After that date Powergas was the builder of a full range of producer-gas installations utilizing every conceivable fuel, including rice husk. Their standard units ranged from 50 to 1000 HP - 3800 to 7500 ft^3/hr. As the commercial demand for these units dwindled in the face of the availability of oil and natural gas, manufacture ceased. Today the expertise and capability of the company lie with their former engineers and designers, Brockwell and Milner (W156).

e. Wellman. Lustig (122) indicates that this company has manufactured gas-producers for many years. A typical Wellman gasogeno has a 72-inch inside diameter and a capacity of 51,600 ft^3/hr. This unit is a double fire-zone producer with internal gasification and cracking of tarry heavy hydrocarbons. Average BTU value for produced gas is 135 BTU/ft^3 or about 7,000,000 BTU/hr. Efficiency is 70 to 75%, and consumption of rice husk is about 1700 lb/hr.

A low-pressure gas engine consumes 10,000 BTU/HP/hr, while a dual-fuel engine on the diesel cycle requires only 8,000 BTU/HP/hr, 20% less than the gas engine. Of this, 80% can be considered as coming from the gas portion of the fuel, representing a power output of 1100 HP from the use of 1700 lb/hr of rice husk, or 1.5 lb/HP/hr.

f. Dual-zone producers. It is possible to take advantage of local use factors in dual-zone operation of a producer-gas unit, wherein the gas produced in the hot zone is used for internal-combustion engine purposes and the lower BTU gases are channeled to a furnace or drying system.

g. Lacotte (W19). Gas-producers utilizing the "systême de Lacotte" have for many years been operating in France and other countries. This system has advantages both in efficiency and in maintenance costs, particularly when charcoal is desired as a by-product. The system utilizes a split gas-stream from an external combustion area that in cracking the tarry components delivers an essentially clean gas from the gasogeno. The high ash content and silica nature create some conditions in this gasogeno not previously encountered This system has thus far never utilized rice husk as a fuel, and possibly some design changes would have to be incorporated for this use. Testing of rice husk as a fuel has been arranged.

6.5.2.4. Constraints. One of the problems of gas-producer systems is the use of a water scrubber to clean the gas; the treatment or disposal of the effluent must be taken into consideration if a water scrubber is being contemplated. The earlier practice was to dump the water mixture, but that approach may no longer be possible.

On the other hand, in the scrubber hot water is produced which might be utilized for some benefit. The production of tar and tar oil is a factor if the system is large enough to make the commercial aspect of tar production a viable consideration.

In earlier times, problems of corrosion created design difficulties, but the proper selection of construction material easily solves them. Some 45-year-old operating gas-producers show no evidence of corrosive deterioration.

In some of the early gas-producers in which the engine was connected direct, when the engine was necessarily or accidentally shut down, this caused the gas to build up at the top of the gasogeno. Air coming in at the bottom, an explosive mixture resulted. Balestra designed a cheap workable design that solved this problem; therefore, this type of unit even today carries his name.

6.5.3. PRIME MOVERS FOR USE WITH PRODUCER-GAS SYSTEMS

The low-BTU gas generated by a gas-producer may be utilized in several ways: a) as a fuel for boilers, kilns, dryers or any other equipment in which the gas is burned in a suitable burner and the heat is directed to its end use; and b) as a fuel for a prime mover, an engine (internal or external combustion) or turbine that can provide either power for driving the rice mill, or for another use (electrical generation, etc.) outside of the milling operation.

6.5.3.1. Internal-combustion engine. Producer-gas has been used in conventional combustion engines at low efficiency. As for conventional fuels, air must be mixed with the producer-gas before it can be burned in a conventional (6.5:1 compression ratio) engine. The heating value of this mixture is approximately 68 BTU/ft^3, while petrol is rated at 94 BTU/ft^3. This means that an engine operating on producer-gas develops 30 to 40% less power than when operating on petrol (see Heywood (115)). To compensate for part of this power loss, the most common practice is to increase the compression ratio. By increasing the compression ratio from 6.5 to 8, about 70% as much power can be expected from producer-gas operations as from petrol. A higher ratio could be used, but this would introduce difficulties in petrol operation. The requirement of equivalent power gives an advantage to the consideration of burning producer-gas in a diesel engine.

It appears that a properly designed turbo-charged intercooled dual-fuel diesel would therefore be the most capable of dealing with the need of producer gas for higher compression ratios. However, when the efficiency of the systems can be lower (because of the high availability of fuel) the use of a derated low-compression spark-ignition engine, new or used, may be the best overall choice. The capital cost will obviously be much lower, and this alone may justify the use of such a system.

In deciding the gas feed for use in internal-combustion engines, the primary consideration is that the calorific value of the gas should be high; its composition matters comparatively little, and provided that the content of combustibles is high the saturation temperature of the blast is immaterial. Gas which is to be used in internal-combustion engines must be completely rid of tar and dust, and it should be cooled to atmospheric temperature before entering the engine.

6.5.3.2. Available engines. There are many manufacturers of small oil- or gas-engines which could be used as rice-husk fueled prime movers. The usual choice would be a traditional horizontal engine of the Ruston type, built in the first half of the century in almost every country. Today this type of engine is being built in India: Kirloskar (W80) and Greaves (W77) are among many others currently building it in series production. The use of modern higher-speed engines for use with low-BTU gaseous fuels is being further developed by Horsfield (W219) and by Paddon (W161). There are a number of manufacturers of diesel engines throughout the world whose engines would be suitable for conversion to dual-fuel operation utilizing producer-gas as a fuel. However, only one, Duvant (W20) is known to be currently offering engines and accessories "off the shelf" for producer-gas operation. As soon as there is a demonstratable commercial demand, the availability of the necessary engine types should be widespread.

6.5.3.3. Engine conversions. Some of the features of engine conversion and its problems are cited by Giffen (113) and the Ministry of Fuel (136). Conversion of any internal-combustion engine to producer-gas or dual-fuel operation is in fact possible.

One advantage of the development of techniques for engine conversion to producer-gas operation is to enable the utilization of used engines that are commercially available. In many countries, used diesel engines have been utilized to power rice mills for many years. These engines would be very easy to convert for dual- or pilot-fuel operation. To modify a petrol spark-ignition engine, new or used, is more difficult if a comparable power output is desired. Therefore, in any study of the use of gas-producer engines for prime movers, the existence of used or second-hand diesel engines should be a favourable factor.

To compensate partially for the reduced volumetric efficiency and lower calorific value of producer-gas, spark-ignition engine conversions should theoretically be accompanied by an adjustment to increase the compression ratio.

However, for practical reasons this compensation cannot be arranged because -

- it entails expensive major engine modifications unlikely to be practicable in an emergency;
- to create the initial draught through the fire bed of the gas-producer, the engine must be started up on petrol of a quality suitable to its compression ratio. If the compression ratio is increased beyond the detonation point of this petrol, serious damage to the engine may result.

In high-speed engines, the slower burning of producer-gas in the combustion chamber necessitates a greater advance in the ignition timing, although this is affected in some degree by the hydrogen content of the gas: the lower the hydrogen content, the greater the amount of advance tolerated by the engine. As a general rule, about ten degrees of ignition advance over the normal petrol setting should be made.

When converting a compression-ignition engine to producer-gas, ignition problems are simpler to handle, and to overcome the slower burning of the charge the injection timing of the fuel pump is advanced to approximately 32 degrees before top head centre. This may vary slightly with the type of engine being converted. But as the sole reason for these conversions is to compromise in the use of liquid fuels, modifications to the fuel pump itself are necessary.

6.5.3.4. Dual (pilot) fuel engines. Dual-fuel engine development by the British (136) in the 1950s has shown that commercial development of this system is possible on a large scale. In 1947 Lustig (122) described design and development work on dual-fuel engines and improved gas-producers by Wellman Engineering Company. The use of a Bruce MacBeth engine proved successful and provided on rice husk a fuel rate of about 1.7 lb BHP/hr. Current investigations by Paddon (W77) are further enhancing our knowledge and expertise on such engines. Commercial utilization in France, such as the engines built by Duvant (W20) show the economic possibility of use of producer gas derived from cellulosic fuels.

The dual-fuel system implies a true alternative fuel utilization, in which any amount or proportion of the available gas supply is intended to be used. Most installations within this concept comprise liquid fuel use at about the 20% level. To be preferred, however, is pilot-fuel operation, wherein the pilot fuel is used mainly to start the engine easily, and to be available in case of overload of the gas fuel availability, or of non-availability of the gas fuel. Thus, under normal conditions, the basic concept is to use the pilot fuel (usually diesel) for lubrication and cooling of the injection system at a 5 to 10% level of total fuel requirements.

Advantages of dual-fuel engine operation include:

- normal starting;
- total power available (instead of 60% on straight engines);
- lower engine cost (through the use of low conversion cost production diesel engines).
- wear and tear on engine much less (see Section 6.5.3.5.);
- ability to utilize high compression ratio and therefore high efficiency (tests[1] have shown that low BTU fuels work best at compression ratios of 14:1 or more)
- a marked decrease in fuel cost, as only about 10 to 20% of fuel needs to be purchased.
- complete engine/power system availability even if no indigenous fuel is available. This would be advantageous for operation as a power system; in case of need for continous operation, rice husk is an entirely adequate supplemental fuel.

6.5.3.5. <u>Wear in producer-gas engines</u>. It has been said that increased wear on the cylinders and bearings of the engine is inevitable, because of the abrasive dust carried over with the gas, and also because of the increased compression ratio. Such fears are not justified. Experience has proved that the wear and tear of engines run on producer-gas is less than that of petrol engines because:

- the heat of the explosion, or detonation, of gas is very much lower than that of petrol vapour.
- the detonation of gas is not of the same intense explosive character, but rather more of the nature of heat expansion;
- the gas being dry and relatively cold, dilution of lubricating oil does not take place as in petrol vapour which, if not properly vaporized, enters the cylinders as a liquid;
- no carbon deposit is occasioned by the burning of producer gas, and, consequently, decarbonization of cylinders and valve grinding is reduced to a minimum;
- the purification and filtering of the gas is, and can be, so effective that a gas more than 99.5% pure can be expected; with the use of correct filtering procedures, this ensures that no deleterious or corrosive gases are carried over with the combustible gas.

6.5.3.6. <u>Starting of producer-gas fueled engines</u>. The drive can be started in one of several ways:

- In dual-fuel/pilot-fuel diesel operation, the engine starts as a diesel and uses the producer-gas as supplemental fuel up to a point of 10% diesel, 90% producer-gas.
- Petrol engines with lower compressions start on petrol; after temperatures and gas production have leveled off, the petrol is shut off completely. This is necessary where the initial gas flow of the gasogeno is induced by the engine vacuum.
- Compressed-air starting and gas-flow induction is normally used only on larger engines. It requires a gas holder.
- Electrical starting motor systems are normally used only on smaller engines. It requires a gas holder and an adequate battery.

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[1] S. Neyeloff and W.W. Gunkel, in a paper presented at the 1975 Agricultural Waste Management Conference at Cornell University.

6.5.4. GAS TURBINES

The success of gas turbine technology is a well-known fact. The more common image of a gas turbine is for propulsion, but there are numerous successful installations of gas turbine driven electric generators. There appear to be none, however, fueled by rice husk.

Investigations indicate that to obtain hot combustion gas produced by the burning of rice husk is highly feasible and practical. There exist at least four proved methods of burning husks to produce gas which reaches an adquate (930°C) temperature, the first three of which require excess air for combustion: 1) burning in conventional furnace; 2) burning in suspended air; 3) burning in fluidized bed (for simplicity, a fluidized bed may be classified as burning in suspended air); and 4) producer-gas generator. (See Figure 7.)

However, the practicability of a generation system such as 1, 2, or 3 above, using rice husk as a fuel, is doubtful. The low efficiency of the turbines and necessary use of a low-BTU gas, coupled with the filtering problems ahead of the turbine because of the detrimental effect of particulate matter on the turbine, are negative factors.

The big problem facing any nation contemplating such a utilization would be the choice between constructing large incinerators or relatively small packaged units to minimize transportation costs. Only in a very few isolated circumstances would it appear practical to use such an installation for rice-husk utilization.

The only known project that resembles a conceivable rice-husk fired gas-turbine power system is that of Combustion Power Co. Inc. (W171). Its federally assisted development project features a 15,000 kw gas turbine generator set. Hundreds of such units consume 400 tons per day of solid waste--the amount generated by 160,000 persons--to produce between 5 and 10% of the total power consumed by the same number of people.

No consideration has been given to the utilization of rice husk in this unit.

The advantages of utilizing rice husks to produce heated gas which in turn drives a turbine engine to produce electricity are obvious; however, gas produced by most incinerators contains abrasive particles and requires filtering before it can be introduced into the turbine. Removing particles from the gas stream at a temperature of approximately 930°C requires an expensive filtering system.

The producer-gas generator (system 4 above) could provide a simple soultion as a gas supplier to a combustion system incorporating a gas-turbine prime mover. The producer generators can be expected to provide efficiencies in the 70-75% range, and this would increase the feasibility of such a system.

6.6. CARBONIZERS

Carbonizers, as differentiated from gasifiers, normally include only the units having both the form and the purpose of the carbonization units currently being built and used in Japan, which are processing primarily for husk disposal the recovery of the char, or carbon, rather than for the gas produced or for a combination of these. In some cases the fuel gas derived from the unit is utilized as a drying fuel, but generally it is not. It can be expected that there will be a gradually increased utilization of the fuel gas and an incorporation of more efficient processes in the near future.

It is an error to consider the residue from these carbonization furnaces as a charcoal in the same sense as a wood charcoal. The rice-husk char contains a large percentage of ash, considering that the normal analysis of husk is 10% moisture, 20% ash, 50% volatiles, and 20% carbon. A carbonizer burning no fixed carbon would produce about 50% of ash. If 50% of the available carbon is burnt out, this would leave about 65% ash in the char.

However, the product produced today in Japan is marketable and serves its market well.

6.6.1. CHARRING

Usable char can be produced in either of two primary methods:

1. Burning or incineration - excess of air
   The husk can be ignited in a suitable burner-incinerator in which the heat of combustion is utilized to maintain ignition. In this event, volatiles and smoke would be emitted, and must therefore be trapped or entrained in suitable condensors and/or precipitators in order to avoid air pollution. The products of the incineration process are then -

   a) the charred husk, consisting primarily of silica and carbon;
   b) the solids and liquids separated from the exhaust;
   c) exhaust gas, principally carbon dioxide and water vapour.

2. Pyrolysis or distillation - controlled atmosphere
   Husk can be heated in an inert atmosphere to drive off all natural and pyrogenic volatiles. In this event, heat is required (e.g., by combustion of natural gas), and the volume of condensed products will be considerably increased since none would be burned off. The products of the destructive distillation are -

   a) the charred husk, essentially the same as above;
   b) the distillate, consisting of water, organic liquids and tars, together with some particulates;
   c) additional solids entrained in a downstream precipitator;
   d) exhaust gas, principally carbon monoxide and/or hydrocarbons, that can be cycled to the fuel gas.

Most furnaces can be used as char producers by allowing the combusting husk to cool before all of the carbon has been burned from the silica maze. However, there is a great difference in the char produced by the burning-type units as compared with the pyrolysis units: the homogeneity of the residue can vary widely in incinerators, whereas the controlled-atmosphere units enable much closer control.

Furnace burning units have been described in Section 5. The residue from any of these systems is or can be char.

6.6.2. DETAILS OF CARBONIZERS

6.6.2.1. Institute of Agricultural Machinery (IAM). Ban (W103) and Shimizu (W104) have developed and tested the IAM system combustion furnace.

The test data in Table 28 indicate results, with varying parameters, of this continuous, low-cost unit.

Table 28

IAM combustion furnace (test data)

Air feed rate	m^3/min	0.18	0.17	0.48
Feed rate	kg/hr	5.44	10.47	8.00
Residue outturn	kg/hr	1.24	2.41	3.42
Residue as % of input	%	22.8	23.0	42.8

Table 28 clearly shows the increase in yield of char upon the increase of feed air. This result is entirely in line with expectations.

6.6.2.2. Nichiyu-Koki. Equipment designed by this manufacturer (W107), described as "rice chaffs baking equipment" makes chaff charcoal by a forced reduction process while the husks move through a U-shaped gutter. Subsequent to the initial ignition by oil, the husks burn and carbonize themselves without auxiliary fuel.

6.6.2.3. Satake. Equipment for carbonization of husk is furnished by a subsidiary of Satake (W110) on the island of Hokkaido and by another subsidiary, Nihon-Kanetsu, in Tokyo. The unit at Shimodate City, manufactured by Nihon, is a rotary-kiln controlled-atmosphere distillation unit without waste heat utilization and with two stages of product cooling. This same system is used for making activated charcoal from coconut husk.

6.6.2.4. CeCoCo (W101). This company offers six sizes of carbonizers, from 75 kg/hr to 1125 kg/hr capacity, weighing 1200 to 51,000 kg. The four smaller units are designed for outdoor installation. These units are of adequate design and many have been installed.

6.6.2.5. Yamamoto (W112). This company offers equipment described as a "suction-system rice-husk combustion furnace" that produces char and also makes provision for utilizing the stack gas for heat, usually for drying or water heating.

6.6.2.6. Takano (W111) manufactures a suction-system furnace, similar to that in Section 6.6.2.5., with a design somewhat between a producer-gas generator and a controlled-atmosphere furnace. These units have heat exchangers for utilization of the stack heat. Details of heat data when operating at its design feed rate of 340 kg/hr will be found in Section 6.3.2.7. Char production is at 30% of feed rate.

6.6.2.7. Kojima. This system is produced by Kansai Sangro Co. Ltd. (W102) and is offered in a range of sizes. It has been built for the last ten years and to date over 120 units have been constructed, all for installation in Japan. This firm also builds units for CeCoCo (W101).

6.6.3. CONCLUSION

The use of carbonizers is involved in handling about 10% of the husk produced in Japan. There have been many designs of units and methods of processing, most of which show some heat exchanger methods to utilize the hot stack gases, but in actual installations, the exhaust gas is discharged to the atmosphere.

6.7 DOMESTIC STOVES (See also Section 5.2.2.)

There are several general classifications of husk-fired domestic stoves.

- use of raw husk, loose or compacted fill
- use of carbonized husk or husk charcoal
- briquetting

6.7.1. LOCALLY-PRODUCED UNITS

In many countries husk is used for domestic purposes. The stove is either made of local materials or a factory-made unit, but little is known of the latter, which are locally produced. Fabricated units exist both in Japan and India; the Japanese is a pot-fixed grate type, similar to a Hibachi, while the Indian construction is a canister with open centre tube. In Italy, about 50 years ago, there was considerable development of heating units, but those exist today only as drawings and descriptions.

Many countries have both cooking and heating units made from local materials, usually of brick construction with a metal grate and metal lid.

6.7.2. VARIATIONS

The use of carbonized material as charcoal is practical in some areas, sometimes as an additive (266) to other materials, to improve either their burning characteristics or their BTU factor.

6.7.3. BRIQUETTING

There have been several developments concerning briquetting. At least three briquettors have been used or tested in producing rice-husk logs:

- Hullite machine
  Japanese manufacture - this machine has been used to briquet husk; in India there has been a concerted effort to adapt the machine to local conditions, but as yet there has been no commercial application.

- CeCoCo machine (Miike) (W101)
  Japanese manufacture - this machine has been normally used to briquet charcoal.

- Fred Hausmann Briquettor (Glomera) (W162)
  Swiss manufacture - this machine, normally used on wood products, has been tested on rice husk, but no commercial rice-husk applications are known.

Two other machines are known to exist, but details on them are not available.

The use of briquettes or extruded fuel logs has long been common in the utilization of waste wood products. However, their application to rice husk is not without some problems, both in physical manufacture and also in burning. The primary reason for the operation is to provide a cleaner, more easily handled, denser fuel. However, the lack of a binding/bonding component (e.g. wood resin) in rice husk increases the cost of production; the abrasive nature of husk causes accelerated wear of the pressure and conveying sections of the machine. Satisfactory logs from a wood standard of homogeneity are hard to kindle, sustain combustion poorly, have a high (20%) ash content, and do not burn with a pleasant odour. They work better with a movable grate which scrubs the ash from the burning surface as it builds up, allowing a fresh surface to be offered to the combustion air. Some machines feature a product with a hollow core that promotes somewhat better combustion, but only scouring of the surface ash (either external or internal buildup) allows satisfactory use.

7 CONCLUSIONS

7.1 GENERAL

7.1.1. NEED FOR DATA COLLECTION

Data regarding the full cycle of rice production through to its final point of offal utilization are generally lacking or inadequate. No effective, centralized, or worldwide system for accumulating such information, especially that related to rice-husk utilization, exists. This situation also broadly prevails in most of the individual rice-producing countries of the world and is very detrimental to the thousands of persons now participating in projects related to husk-energy research and development or to residue utilization. The single most negative factor in the extension of the use of the energy from rice husk is the inability of interested processors or workers to obtain definitive and accurate information pertinent to their investigations.

Practices in one country do not become used or even known in neighboring countries. Further, in some cases a use known in many countries but the knowledge of its use is totally lacking. Thus, husk, char or ash is used in the steel industry in almost every part of the world, but in most countries the users believe that they are alone in using it. Sometimes it becomes a situation of "reinventing the wheel", wherein a sincere worker believes he has developed a totally new, very comprehensive technique, and will scarcely believe that in nearby countries the very same technique has been standard practice for decades.

7.1.2. UTILIZATION TRANSITIONS

There is greater utilization of rice husk throughout the world than has been generally estimated, but usage for enegery purposes over the past 50 years has fallen by some 80%. The availability of low-priced oil and gas after World War II caused the disappearance of the use of paddy husk as an energy source, as the result of economic pressures and considerations of convenience. During and before World War II there had been great utilization of all such cellulosic products because of shortages and blockades. Even where almost all of the rice husks are still used to produce energy for milling operations, as in Nepal and Thailand, there is less than full beneficial usage because there is no appreciable utilization of the residue.

In other countries, such as Japan, the reverse is true, in that almost none of the rice husk is utilized to produce energy, but is burned to produce char, much more of which than is generally known being channelled into beneficial use.

7.1.3. UTILIZATION OPPORTUNITIES

On the surface, in almost all countries, vital interest is expressed in seeking technologies and processes which would allow utilization of rice husks as a renewable energy resource. However, the introduction of new processes may prove to be very difficult in a number of areas because of traditional considerations. There is an inherent resistance to the adaptation of any new or revised concept that might conceivably damage the innovator. Everyone may agree that a new or reintroduced technique may produce spectacular advantages and results, but no one wants to be the innovator within his own field. The selling of the idea of the first conversion is the hardest task of all.

Actually, in many countries, political and social influences have exerted a negative effect upon rice milling, both from the aspects of yield and milling efficiency. This is especially true where fragmentation of the industry by the emergence of smaller growing and milling units has resulted in reducing the number of medium or large commercial mills. The problems of utilization of husk from a small mill are far greater than in a larger unit, which has many options open to it for utilization both of the energy and of the residue. The small and very small mill has almost no option other than that of on-the-spot utilization, and usually this is not made because the amount of material involved is trifling.

7.1.4. LACK OF PADDY

There are a number of large, sophisticated milling complexes that are not operating for various reasons. One major reason appears to be that some large mills are not viable where they are located because of the inadequately uniform paddy availability for efficient operation. This is especially true where a large number of varieties are grown in the supply area and are such that co-mingling is not practicable.

7.1.5. PLANT UTILIZATION

Adequate technology appears to be available to provide reasonably full utilization of the rice husk produced in the world and of its derived residue providing some means can be found of acceptably levelling off the high rice-husk production variances which now exist. There has been considerable discussion of the physical characteristics of rice husk, of the variations in production schedules and in the size and concentration of processing mills. It must not be overlooked that most of these problems are overcome when the husk is used as a raw fuel material, generating power or heat to provide at the mill, and in sequence with the mill operation, a concurrent utilization system. If the residue is utilized, a closed-circuit situation exists, in which the husk is considered to be a raw material for a necessary milling function.

7.1.6. MANUFACTURING CAPABILITIES

Manufacturing capabilities for rice-husk energy related equipment are, on a general worldwide basis, greater than previously believed. Manufacture is however more or less concentrated in specific areas. Difficulty is experienced in an "off the shelf" capability of competitive equipment. Only in Thailand is there an integrated competitive supply capability, with 24 producers of heat-related equipment and/or complete rice mills. Five of these 24 are known to be capable of producing adequate, though traditional-type, mills and power plants. In no other country does there appear to be integrated manufacture of components, though several would contract on a turnkey basis. In Japan, furnace and carbonizing equipment is quite highly developed and competitive, though no general use is made of the heat liberated.

7.1.7. HEAT-COUPLING

Technology exists and expertise is available to transform every process-steam user into a highly efficient, completely integrated and self-sufficient supplier of all energy requirements of his milling and processing operations, fueled entirely by the husk available from his milling operations. The physical problems of handling, storing and processing the husk are minimized by this integrated approach. At the same time, a valuable salable residue is produced which when marketed properly can provide additional income, either for amortization of the process plant or for the operator's overall margins. In every rice-milling operation using process steam, the "heat-coupling" possibilities must be considered: this concept can give overall efficiencies of about 65%, whereas the maximum available from normal power generation is not over 22%. Therefore, the motive power used to drive the mill, etc., is obtained at almost a zero cost to the miller, who need cover only charges for amortization, interest and maintenance. Either a turbine or an engine will be equally efficient as the prime mover under equal conditions, but the cost and practicability of the unit must be determined before a choice is made to fit any given set of conditions. In some cases the determining factors are water-treatment problems more than any other single factor. In the case of a condensing, closed system, however, water treatment is of minimal importance.

7.1.8. PRODUCER-GAS

Producer-gas generators of proven technology exist which utilize rice husks as a raw fuel. This gas can be used for a wide variety of industrial heating and process purposes. In particular, it can be used directly in internal combustion engines to generate electric power at a higher overall thermal efficiency, particularly on a smaller scale, than the most advanced steam turbine installation. In white-rice milling in small and medium rice mills where there is no requirement for steam, the use of producer-gas generators is the only feasible method of utilizing the heating potential of the derived husk. In a small mill with a producer-gas generator the motive power can be supplied in two ways: (1) directly from the prime mover, using a lineshaft mill drive; or (2) indirectly by generating electricity and using individual drives for the rice-milling equipment. The prime mover can be one of three types: (1) an ordinary petrol engine, slightly modified, which on producer-gas will produce about 50 to 60% of its rated power output on petrol; (2) a natural-gas engine of high compression ratio specifically designed for such installations, which will give 100% of its rated output; and (3) a dual-fuel (pilot-fuel) standard diesel engine with minor modifications, running on a fuel mix of 90% producer-gas and 10% diesel fuel, which will give 100% of its rated output. These producer-gas generators are simple. In-country fabrication would be possible, even in areas with the most rudimentary manufacturing capabilities.

Units of this type using rice husk as a raw fuel have been used in powering rice mills for at least 75 years. Admittedly, since 1945 the number of units has declined, in most cases because of the existence of convenient and low-cost electric power or the availability and low cost of diesel fuel. Pilot-fuel engine operations are not new. The first general use was during World War II, though designs and use date back to the early 1930s. Very little modification (only to the induction manifold and injection pump) is necessary to any new or used diesel engine of any size to adapt it to full-scale producer-gas operation. The residue from the producer-gas generator is usable as a char or ash in the same way as the residue from the steam-producer unit.

7.2 LONG-TERM ACTION FOR DEVELOPMENT

7.2.1. INFORMATION TRANSFER

This survey has provided an integrated view of the main problems which affect rice husk utilization and has identified some of the measures which are required to stimulate development. At the global level, a definite need exists to intensify the transfer of information and this, perhaps, could best be attained by a rice-industry data centre, an international clearing-house for all information related to the rice industry. Its publications should include technical bulletins and manuals tailored to fit the practical needs of small, medium and large operations in various parts of the world. Energy-related publications could be modeled after the fuel efficiency bulletins published by the British Ministry of Fuel and Power. Special, early emphasis should be placed upon research.

7.2.2. INITIAL AREAS OF RESEARCH

The following three energy-related areas of research offer the greatest potential for providing maximum benefits for the cost involved:

- Furance design and construction should be analyzed and tested to accumulate useful data that can be applied in selecting the highest-potential design for any specific application;

- Heat-coupled producer-gas generator process steam systems should be developed and installed to provide the necessary electrical or motive power while covering the process-steam requirement in small and medium parboiled-rice mills, both existing and newly designed;

- A new generation of producer-gas generators should be developed and built, utilizing modern materials and techniques as well as the excellent technology accumulated in this century. This development offers maximum potential for benefiting all types of rice mills, especially white milling, where process steam is not required. At the same time, there is need for appropriate commercial development of suitable engines or necessary modification of existing ones, including both petrol and dual-fueled (diesel/producer gas) engines using a pilot-fuel system. This recommendation is realistic, because the technology for producer-gas units, particularly those utilizing rice husks as the raw fuel, now exists. Similar considerations apply to the engine: one World War II-vintage producer-gas generator engine system continues to operate in Italy after some 35 years. This 60-horsepower system provides motive power for a two ton/hr rice mill and utilizes rice husks as the raw fuel source. There appears to be little danger of error in predicting that it can easily operate for another 35 years without serious problems.

7.2.3. IN-DEPTH COUNTRY STUDIES

While a host of recommendations could be made for individual countries from casual observation alone, few would be genuinely constructive or professional on such a basis. To properly develop activities, an in-depth study of the conditions in each country is essential. This involves full knowledge of the country's rice production, a complete inventory of its rice mills and their capabilities, the overall energy outlook, the economic situation, and a study of available markets, both domestic and foreign. Obviously, this can be accomplished only with the active cooperation of the appropriate government agencies, institutions and knowledgeable individuals within the country. If this is forthcoming, such a study is not difficult in itself. Its completeness would be limited only by time constraints and the actual availability of information.

Some countries are making maximum use of rice husk to produce energy. Thailand is one of the best examples. In almost every instance, rice husk is used to fuel the boiler which provides the motive power to operate the mill. Even in the small percentage of parboiling which takes place, husk-produced steam is used in the process. However, this utilization does not reflect maximum beneficial usage because there is almost no utilization of the residue. It is in this latter area that the greatest potential for improvement in Thailand lies.

Neighbouring Malaysia presents an interesting contrast, in that only a small percentage of the rice husks available are used for fuel, and this largely in the older mills only. The more modern Malaysian rice mills have no provision for husk utilization at all, and the quantities being produced are becoming a serious disposal nuisance. Malaysia could benefit from encouraging the design and construction of a furnace-type incinerator to produce char. While the production of power from rice husk does not appear to be feasible in Malaysia because of electricity availability from a public grid, and there is no need to raise steam since milling is white only, there is a long-standing utilization of char for agricultural purposes. The minimum amounts currently available from the older steam-powered rice mills are eagerly sought after.

In those countries where rice milling is a developing industry and parboiling is desired, serious consideration should be given to installing husk-fired power units and process-steam producers at the outset.

7.2.4. INCENTIVES

Since it is in the best long-range national interest of any country to utilize its indigenous energy sources, it would be beneficial for each country to establish financial agencies to make available long-term loans, credits, or incentives at reasonable interest rates to encourage the construction of power plants permitting the utilization of indigenous renewable natural resources. The initial effort should include investigation of the feasibility of using available husk as a supplemental fuel. This concept could make it worth while for a cooperative of rice millers to go into the power-generation business. Husk could be collected centrally from a number of mills. Husk should be cracked; this can be accomplished at a very low cost and makes transportation and collection feasible because the density is raised to some 17 lb/ft^3. The collected husk then could be utilized as an energy source to produce steam for immediate consumption or for electricity.

In cold-storage plants, such a utilization could efficiently provide power by using the husk as it becomes available or storing quantities for use as a supplement during high-demand periods or when the gas or oil supply is interrupted. Cost feasibility depends upon the availability and costs of electricity for power generation, as well as of natural gas, oil, or coal for steam generation. This general application also is possible using a producer-gas generator located at the individual mill and featuring a piped collection system for distribution or to blend with the primary fuel as a supplement. A likely area for this utilization would be in the Punjab area of India. Ideally, the system, if a steam-powered plant, could provide process steam to an adjacent industry such as an oil mill, dairy processing plant or similar process-steam user.

7.2.5. A WORD OF WARNING

No rice mill can be made more efficient than local circumstances warrant. Beneficial efficiency requires the maximum utilization of all available rice husks as a source of energy and their residues for other purposes. To provide a more sophisticated boiler and engine that accomplishes the mill operation using less than all the available husks only creates a disposal problem. Any extensions of capability must be suited to the realities of the local situation and be accomplished in a smooth, slow and rational manner.

7.3 SHORT-TERM ACTION FOR DEVELOPMENT

While there is scope for systematized, long-term development activities, two practically-oriented projects could lead to valuable results within a limited period. The objective here would be to utilize existing technology to build prototype power units respectively based on producer-gas generator and heat-power coupling, especially designed for smaller mills.

7.3.1. PRODUCER-GAS

At mills where paddy is milled raw, without parboiling, the basic problem is to obtain mechanical power at the lowest cost of conversion by means of simple equipment. To help solve this problem, a prototype power unit including producer-gas generator, internal-combustion engine and electric generator should be constructed; it should develop 100 kw to operate a two ton/hour mill. The producer-gas generator should be simple in design and suitable for local fabrication. The internal-combustion engine should be a currently produced model, with suitable adaptations to facilitate converting second-hand liquid-fuel engines into dual-fuel engines. Such a project would imply the evaluation and selection of existing equipment, design and construction, testing the unit in a developing country and preparing a "do-it-yourself" manual. The goal here is to provide a means for developing construction and operation capability in areas completely devoid of infrastructure.

7.3.2. HEAT POWER COUPLING

The second project is conceived to assist small millers who parboil and mill paddy. Their problem is that of using husk efficiently enough to obtain heat for both operations: thus, a down-scaled heat power-coupling system should be designed and constructed, consisting of furnace, boiler, steam engine and electric generator capable of operating a two ton/hour mill. The prime mover should produce all the power required for milling and should discharge exhaust steam at suitable pressures and temperatures for the mill's parboiling and drying requirements. The project would imply designing the best possible combination of components to fit selected specific requirements. When one or two representative heat-coupling systems have been designed and constructed and are operating under proof conditions, a manual of theory, design and practice should be developed by personnel of the project for use to interest and instruct others who have similar requirements. The first one or two units would be well able to develop the parameters necessary for designing any applicable systems and to show the differences and/or advantages that may accrue from using rice husk as a raw fuel.

7.4 RESIDUE UTILIZATION

7.4.1. CURRENT STATUS

In every case of utilization of husk for energy, the residue remaining has a value if properly collected, processed and marketed. Presently, in many countries, good use is made of the residue, in some cases char and in others ash. The energy conversion process is the primary consideration and the form of the residue is secondary. Therefore, the utilization of the residue is usually a matter of opportunity. In such situations, marketing efforts are the prime consideration, with a determined, intelligent campaign to bring eventual success.

7.4.2. CURRENT OPPORTUNITIES

There are available today existing technology and markets to utilize all residue produced with only three limitations: 1) that the quantities produced be sufficient to match the requirement of the market available; 2) that transport to the market be available and economically feasible; 3) that long-term and sincere support be given the marketing effort and an intelligent and knowledgeable selection of the potential market areas be included.

APPENDIX A

OTHER UTILIZATIONS OF RICE-HUSK CHARS AND RESIDUES

A.0. INTRODUCTION

Whenever rice husks are converted to energy a residue remains. At the lowest level, this can be the percentage of ash in the variety being converted, usually 17 to 22% of the weight of the paddy husk. The upper limit of this residue is about 35% of the initial weight; it represents conversion only of the volatiles present in the raw husk and the retention of the full content of carbon.

The utilization of the char/ash residue has taken many varied paths. In each country that produces rice there is some utilization made of the residue; the degree of utilization varies from almost zero upwards. The value of the utilization is purely relative, depending entirely on the concept of beneficial utilization (137). Table 29 summarizes some technical commercial opportunities for rice-husk, ash and char utilization.

A.1. CHAR

Char is defined as the residue remaining from a burning or pyrolytic conversion of rice husk, with carbon content of over 1.5%. Its utilizations and their commercial feasibility are varied.

A.1.1. Organic uses. From a tonnage standpoint, the largest utilization of char practiced is as a nursery planting or potting component or for use in paddy seedling propagation. In Japan, where the mean cultivated rice-field area is about 1 hectare, approximately 10% of the country's 3.2 million tons of husk is produced in "rice centres" where there is sufficient husk available to establish a profitable conversion operation. Most of these centres produce annually from 200 to 600 tons of husk.

It is traditionally said that something yielded from the rice field should be brought back to the field. Chaff cinder is an inorganic material whose main ingredient is silicic acid. It has various characteristics that make it supperior to calcium silicate. At present, 15 micro-elements have been determined necessary for a rice field, and almost all these elements are contained in chaff cinder. It is highly recommended for raising soil/water temperature, watering and supplying air to roots of plants.

As in Japan, the Mekong riparian countries take advantage of chaff charcoal for planting paddy seedling and vegetable seedlings in truck gardening.

Chaff charcoal is advantageously used to improve the soil for planting seedlings, horticulture, pomiculture and truck gardening, as well as to mix in feedstuffs. Although it is not a fertilizer in nature, it helps stimulate speedy and vigorous growth. When it is properly adapted, it deoxidizes the ingredients of silicon for more tasty rice, and by helping to retain soil moisture it facilitates root division and active elongation for dense growth. Yield increases of over 20% have been obtained.

About 20 l/m^2 of chaff charcoal are scattered to cover the seed-rice planted. Seed-bed containing 20 to 30% chaff charcoal in bulk substantially increases the tensility of seedling cord in terms of mechanical transplanting of waterfield rice. It is also widely recommended that 10 to 20% chaff charcoal be added to the nursery soil for tobacco plantation.

In the Philippines the use of char from the Tacurong (W134) power plant was found by Golden (W182) to reduce drastically the amount of nursery seed necessary. It was found that normally several seeds were planted per hill, because the stalks were very thin and in pulling the seedlings had excessive breakage. Golden tripled the area of the nursery so that the seedlings could grow more vigorously, then added char to loosen the soil. Instead of 75 kg of seed per hectare, they can now plant 10 kg. Seed is very costly, and the new method produces as many and in some cases more plants than the old method, with 1/7th the seed.

Seed-beds using char are normally warmer than those not using it.

Table 29

Technical/commercial opportunities for rice-husk ash and char utilization

Category	Form	Technical Status			Commercial Status	
		Proved	Possible	Conceptual	Proved	Possible
ABSORBENT						
Marine spills	LC			+		
Oil absorbent (Greasweep)	LC	+			xo	
Sweeping & floor cleaning (Greasweep)	LC					
BUILDING MATERIAL COMPONENT						
Calcium heterolsilicate brick (Silicior)	LC	+				o
Cement (impingement process)	LC		+			o
Concrete (acid-resistant)	HC		+			o
Concrete blocks	LC	+				o
Lightweight concrete	LC	+				o
CARBON SOURCE						
Fine filter media (water purification)	HC		+			o
Activated carbon	HC	+				o
Decolorizing charcoal	HC	+				o
Adsorption media (water purification)	HC		+			
Coagulant aid (water purification)	HC		+			
CARRIER						
Catalyst	LC		+			
FERTILIZER						
Anti-caking agent	LC	+			xo	
Coating for prills	LC		+			o
FILTER MEDIA						
Liquid, gas or oil	LC	+				o
Solids removal	LC	+				o
FILLER MATERIAL						
Rubber compounding (as carbon silica)	HC		+			x
Silica aerogel insecticides	LC			+		
Grit toothpaste	LC	+			o	
Rubber compounding (as silica)	LC		+			x
HYDROPONIC MEDIA						
Ash media	LC	+				o
INSULATION USES						
Hot tops (steel plant)	LC	+			o	
Bridge undercoat, steel beams, etc.	LC	+				o
Ingot insulation (steel plant)	HC	+			xo	

Category	Form	Technical Status Proved	Possible	Conceptual	Commercial Status Proved	Possible
PIGMENT						
Varnish - shoe polish	HC			+		
Paint				+		
Porcelain enamel suspension agent	LC			+		
Carbon paper, ink extender	HC			+		
REFRACTORIES						
Heat-insulation brick from ash	LC	+			o	
Porous media (Ontario Research)	LC	+				o
Ceramics	LC	+			o	
Insulating brick (Medium Temperature)	LC	+			o	
SILICA SOURCE						
Silicon tetrachloride	LC		+			
Silicon carbide nitride	LC		+			
For production of sodium silicate	LC		+			o
Dehydrating agent	LC			+		
Thickening agent	LC			+		
Dessicant and deodorizer	LC			+		
Fumed silica				+		
Finely divided silica			+			o
Silica coating (welding electrode)	LC			+		
Silica rocks for landscaping effects	LC	+				o
Silica source for glass manufacture	LC		+			o
Sintered glass material				+		
SOAP MANUFACTURING						
Soap ingredient from ash	LC	+			o	
SOIL USE						
Silica regeneration in silica-deficient soils	LC		+			o
Mulch media for surface control	HC	+			xo	

LEGEND

FORM OF HUSK PRODUCT: LC = Low-Carbon Ash
HC = High-Carbon Ash

STATUS:
+ = Techincal feasibility
o = Commercial, small use
x = Commercial, extensive use

In southern India, it is common practice for the local farmers to buy 30-kg bags of char to use in their fields and nurseries. In the Birbhum district of West Bengal char has been used for many years in the soil of onion and potato fields.

In Italy, the brightest and most colourful flowers grown for sale throughout Europe, in the Genoa-San Remo areas, grow with char from the parboiling mills (with husk-fired boilers) in the Milan area.

Char is also most beneficial in the growing of young trees; it is an excellent substitute for sphagnum or peat moss.

A.1.2. Steel manufacturing. The utilization of pure husk, char or ash for insulation and anti-slagging in the iron and steel industry is much more widespread than has ever been realized. References and sightings have been made in countries all around the world: in the United States and Canada, the United Kingdom, the F.R.G., Spain, Romania, the U.S.S.R., India and Japan.

The superior heat-absorbing features and insulation characteristics of paddy-husk char promote its use as a solidifying material for steel ingots. The maintenance of uniformity of physical and chemical characteristics within molten steel during ingot molding is essential. Without effective preventive measures, carbon, silicon, manganese, phosphorus, sulphur, etc. tend to concentrate in the centre of the ingot because of the lower content of impurities during solidification, and produce air holes, deflection, cracking, etc. This tendency can be eliminated if gas production is prevented, either by adding a deoxidizer such as aluminium to the molten steel or making some arrangement to keep temperature uniform. This can be done effectively by covering the steel ingot with paddy-husk char. Lathrop (223) implies that as far back as 1944 this use was of long standing and of accepted practice.

Black char from Italy is also sold in France and the F.R.G. for ingot insulation.

In Valencia, Spain, char is produced on a specific basis (no use being made of the produced heat) by Bonora (W140) for shipment to the steel mills in Bilbao.

Thousands of tons are sold in Japan to steel mill users, including Yawata, Fuki, Nihon Koken and Kawasaki.

In general, the amounts are used in such small quantities, in relation to what is available, that not a great deal of development work has ever been done to extend the use of this material, and one large steel producer in Japan reports that they are looking for a replacement material because of the physical problems of acquisition and use of this char. A large user in England also reports problems in using ash. It would be desirable to carry out research in order to maintain this utilization at its current level, or even to expand it. Individual producers do not realize its importance, and it is not a large enough factor of these operations for them to be concerned. This is an industrial and worldwide problem.

There are several such uses, with a great world impact but a small individual one. This is a very difficult area of development, because the successes have to be looked at on an overall international basis.

A.1.3. Water purification. As far as is known, there is today no commercial use of rice-husk char for water purification purposes.

Staackman (228) claims that finely ground rice-hull char is comparable in performance to diatomaceous earth. This attributed largely to its "spiekular" particle configurationç i.e., the char particles are basket-like, and as a result, filter beds should be less likely to become clogged or block off the flow through one another. Finch (168) obtained a U.S. patent for making a carbonized product useful as a filter medium. The product had a skeletal silica with a lattice structure with carbon disposed therein. Rice-hull char, however, is not much in use for this purpose and faces competition with diatomaceous earth.

Rice-hull char could also be used as a coagulant aid in the treatment of contaminated fresh or waste water. Fly ash from coal-powered power plants currently enjoys widespread acceptance for this use in the United States. Rice-hull char can do the same job by acting as relatively large nucleation sites to which suspended colloidal impurities can become attached, being subsequently swept out of the suspension as the ash particles settle.

In the early 1970s considerable work was done in Thailand on the use of rice-husk char as a filter aid and filter medium. Kitsavadhi (269; 270; 271) found that a properly treated char (with the silica partly removed by a caustic-soda wash) could also be substituted for diatomite.

A.1.4. Concrete aggregate. The use of char as a concrete aggregate is distinct from the use of low-carbon ash as described in Section 7.3.1. The use of char is, as far as is known, exclusively involved in the work of Mehta (72) in developing acid-resistant concrete. Mehta states that the resistance to acid derives from the replacement of lime in the concrete, and not in the inclusion of char carbon as a cement.

The acid-resistant nature of concrete made from paddy-husk char with lime should be of great interest to the food-processing industries, in which an acidic condition exists in many products to be processed.

As a parallel utilization Mehta has suggested the use of char as a cement in architectural concrete because of its unique colouring capabilities. However, smear resistance in this type of product is low. It is very similar to Silicior (A.1.7) in its marking action.

A.1.5. Rubber reinforcement. An early reference to the use of rice husk in rubber compounding is found in Angladette (1). Later references include Bianchi (24), Rubber Age (26), Beagle (137).

The earliest commercial use known is that by Bianchi, starting in 1930. Pirelli used the product made by Bianchi to cover its carbon-black requirements during World War II, but returned to carbon black when it became available again, because of price differentials.

In 1968, renewed interest in this utilization was shown by Koppleman (43A), who contemplated producing a material that would be acceptable by the rubber compounders. However, the promotion was a failure.

Recently Pitt (151A) announced an extension of the Mehta (72) process to produce a satisfactory material.

As a filler for rubber compounding, experiments have shown that higher or equivalent mechanical properties of cured rubber were obtained from batches containing char in proportions as high as 60% by weight. Superior mechanical properties were claimed for natural rubber compounds loaded with rice-husk char.

At times of high carbon-black prices, a blend of carbon black and rice-husk char is feasible; cost factors can determine the use of mixtures.

By analysis, rice-hull char contains 90% amorphous silica and 10% carbon (Industrail Materials Company analysis 10 Jan. 1975). Their published nitrogen surface area of 30 to 60 m^2/gram is indicative of some porosity considering the 0.1 to 2.0 micrometre particle size. The relatively high pH of 10.4 is usually an aid to sulphur vulcanization with organic accelerators. Rubber properties seen in the literature do indicate rice hull char does impart "many of the properties and characteristics of medium thermal blacks".

A.1.6. Antiskid additives. The high silica content and abrasive character of the char indicate potential value as excellent antiskid abrasive in tyres and shoe soles.

Mountain-climbing boots, work boots, and other special footwear are sometimes provided with antiskid soles. In both the tyre and footwear applications, the abrasive material must be tough enough to stand a shearing action equal to or greater than presently used materials.

A.1.7. Silicior. A building material utilizing char as the raw material was patented by Abdellatif (10) and was developed to be adapted to the housing problems of the lesser developed rice producing countries. The product is a light-weight brick or can be also produced as a lightweight aggregate. The brick can be sawn, riveted or nailed in a conventional fashion. It has excellent resistance to heat and cold, easy to mortar, with a crushing strength of 120 kg/cm^2. Recently a renewal of efforts on behalf of the silicior concept was announced by a company in southern France. The validity of the concept is without question and would doubly contribute if in some way utilization of the latent heat of the husk was realized during the carbonization process. With the residue then being utilized as a raw material for lightweight aggregate or building bricks or blocks.

A.1.8. Marine spills. In 1971 Kojima (166) in Japan showed that the clearing of oil from the surface of a lake or bay was successful using a char product. The use of a char product for this purpose is unique; the clearing of the spills was accomplished in a short time and with minimum effort.

A.1.9. Snow removal. Char is used in Japan to sprinkle on snow. Its superior heat-absorbing capacity proves effective for snow removal.

A.1.10. Landfill. Usually the last technique, because of its low (or possibly negative) relative cash return to the miller, is landfill. In every area of the world where husk is or has been burned, large areas have been filled in with the boiler residues. In Bangkok, where 40 years ago the municipal power plant was, and almost every rice mill is, husk fired, greater quantities of char have been used for fill. Saigon, in the years of husk-fired mills, saw large filled areas. This is however more a disposal than a utilization method.

A.2. ACTIVATED CARBON

Activated carbon can be made from paddy husk by two methods, depending on the quality required, and whether sodium silicate is required as a by-product for the soap industry. The chars obtained by a) incineration and b) destructive distillation should theoretically be essentially the same, i.e., carbon and silica in virtually the same ratios and physical state (although in practice differences occur). Hence, the term carbonization is used to refer to either process.

These chars can be rendered more useful by one or more of the procedures employed in the activation of carbon:

- Prior to carbonization, rice hulls are saturated with an aqueous solution of a suitable inorganic material (e.g., zinc chloride, potassium carbonate, potassium thiocyanate, etc.) and dried. After carbonization, the chars are washed to remove the chemicals, and then heated to activation temperature. A typical procedure is: 1) saturation with a 35% solution of potassium thiocyanate; 2) drying and heating to 300-350° C. It should be noted here that, to an unknown extent, the silica content of rice hulls appears to have an activating effect upon its char similar to that produced by added chemicals.
- Subsequent to carbonization, but without prior treatment, portions of the char are subjected to heat, with and without oxidizing gases (air, H_2O, CO_2, etc.). Typical procedures are roasting with steam at 750° C. or with carbon dioxide at 800-900°C.

If both sodium silicate and activated carbon are required, paddy-husk char from the rice mills can be used. The process involves removal of the silica with a sodium hydroxide solution, leaving activated carbon.

It appears that most processes for producing activated carbon from rice husk do not include a step for the sensible use of heat from the reaction.

Research in this field has been or is being carried out by W50 and W53. Two excellent literature reviews of activated carbon are Tucker (229) and Lathrop (223).

A.2.1. Use of furnace char. In the direct utilization of residue from a boiler or pyrolysis unit for the preparation of activated carbon, the ash level severely limits the char's usefulness as a raw material.

There is no agglomerating character inherent in the material, and the nitrogen surface area, 150 m^2/gm carbon, though low when taken on a per gram of carbon basis, is high for a raw char. If normalization is carried out, the rates for rice husk are significantly lower. The lower reactivity may be due not to a difference in the carbon substrate but rather to a blockage of the activating gas as a result of the high ash content.

Under microscopic study, rice-husk char is seen to contain three distinct fractions:

- semi-carbonized material consisting of large, flat thin particles;
- fully carbonized material, consisting of short fibres of intermediate particle size;
- very small carbonized particles of spherical shape, which are very friable.

The high surface area and suitable reactivity of carbon in raw rice-husk char indicate that it may be useful as a raw material for activated carbon if, by processing during or after char generation, the ash in the final product can be minimized or eliminated before activation.

A.2.2. RRL-Hyderabad. A recent announcement from this laboratory (W53) describes its process developed to produce a low-ash, high-adsorption activated carbon. The carbonized material is subjected to steam activation, then to treatment for silica removal by a caustic soda method. The sodium silicate can be marketed as well as the carbon.

A.2.3. Thailand. Research work by Kitsavadhi (42) showed the technical practicability of using a range of activating agents, but indicated that all the methods available are too expensive to produce a competitive product. There is therefore no commercial utilization of this concept in Thailand.

A:2.4. Anil Starch. The only known commercial producer of activated carbon from rice husk Anil Starch (W70), which produces commercial activated carbons, trademarked "Carbanil", in a range suitable for any refining or bleaching activity.

Their specification sheets show 2 to 5% ash content, with completely adequate characteristics as regards decolourization, colloidal separations, odour removal, etc. 2 tonnes per day of carbon are currently being produced from rice husk by their proprietary process, details of which are not available.

A statement by their management confirms that the market penetration capability of quality rice-husk carbon depends entirely on the acquisition cost of the raw husk. It is not clear whether any utilization is made of the silica removed.

A.3. CEMENT - CONCRETE (See also Section 4.6)

The use of low-carbon paddy-husk ash (as distinguished from char; see Section A.1.4.) as a cement or as a concrete aggregate has for many years been the subject of intense and widely ranging research and development. Early references are two German patents (67) of 1924. And yet today there appears to be no commercial utilization of rice-husk ash for cement or concrete purposes. Usually the products have higher insulating values than ordinary concrete but do not have adequate strength and stability. In order to obtain suitable strength the cement content must be so high that the product is not economical.

The report by Hough (11) covers very well the developments to date.

Mehta (private communication) reports that hydraulic cements with satisfactory properties can be made by intensive intergrinding of siliceous materials with 10 to 25% lime. The intensity of the mechanical activation treatment required for a particular siliceous material depends on the mineralogical character of the silica. Opaline materials do not require very intense mechanical action, so that by careful control of the calcination conditions, opaline silica should be formed from the rice-husk ash. In preliminary tests, the quality of cement made by mechanical interaction of a rice-hull ash lime mixture was excellent.

Yost (77) conducted research into the use of rice husk in cement. His definition of pozzolanic activity fills a sorely needed gap in the literature.

Staackman (228) discusses at length the utilization of rice husk in cement manufacture. His section on fuel utilization has today been proved quite valuable by the inception of a project at the Calaveras Cement Plant in Redding, California, U.S.A.

A.3.1. India. The Central Building Research Institute (W56) reports having studied the probable uses of rice husk and its ash as building materials. The pozzolanic properties of partially and fully decarbonized rice-husk ash were determined by lime-reactivity test. A high-quality pozzolanic material was obtained by burning a mixture of rice husk and clay with certain other admixtures. No additional fuel was required for firing, since the fuel value of rice husk itself was found to be sufficient. The product obtained was soft and easy to grind for use as a cementitious material or portland cement.

Lime produced by burning waste lime sludge with rice husk showed hydraulic properties and was used for soil stabilization. Maximum wet compressive strength up to 25 kg/cm^2 was obtained.

The Indian Institute of Technology (W62) reports that the rice-husk ash, when simply ground with hydrated lime, gives a cement-like material called ASHMOH. It was estimated that an ordinary steel 3 x 3 ft batch ball mill, with a 7.5 HP motor for the grinding operation, will convert a rice mill into a mini-cement plant as well, with an annual output of about 200 tons of cement.

ASHMOH cement has been tested on fairly extensive scale in the laboratory, but no large-scale construction has been carried out to date. Standard 1:3 sand mortar cubes made with ASHMOH attain compressive strengths of 100 to 150 kg/cm^2 in three days and 125 to 180 kg/cm^2 after 7 days. Compressive strength of 1:2:4 concrete blocks in 7 days has been as high as 180 kg/cm^2. The cement is very fine and plastic, like a clay ball, and it should have good waterproofing properties for plastering and lining of canals to prevent seepage.

Pingale (W60) reports a commercial operation in the Punjab utilizing rice-husk ash in a cement/lime combination.

IIT-Kharagpur (W63) is engaged in a project for manufacturing cement-mixed ingredients combined in an air-rice vertical kiln. Cement blocks using cement and husk ash in various ratios are being tested.

A.3.2. Other countries. Seng (W122) has shown considerable interest in the use of paddy-husk ash as a cement ingredient in concrete sections, both poured in place and precast. The NISIR laboratories have done considerable work on the burning of husk and the utilization of grey and white ash residues in concrete. Their results to date have had no commercial implications.

In Thailand, concrete blocks and concrete test specimens were produced around 1965 by the Department of Science. The experimental work was deemed to be of no value and was discontinued at that time.

A.4. CERAMICS - GLASS

There is very little information on this subject. The age and extent of the ceramic use of rice husk are not generally realized. The original glazing ash used on Celadon stoneware was derived from rice husks. The technique was brought from China to Thailand, but disappeared in the 14th century.

In Japan, husk is used to give a pinkish grey colour in firing earthenware crockery.

In the Philippines, OPIANA (79) wrote of glazing Philippine pottery ware.

Proctor (9) in 1882 wrote of the use of husk ash for polishing uses in the glass industry.

A.5. SILICA AND SILICATES

A.5.1. Sodium silicate. Sodium silicates have a great variety of uses in chemical and other industries. The principal applications are connected with their adhesive properties, their wetting powers, their usefulness as raw materials for a large number of industrial products and their binding and detergent properties. A new and very important use is as chief raw material for the production of colloidal silica, which is widely used in the petroleum industry. Finely divided silica is also much used in the refrigeration industry. Silicates in the form of water-glass find use as a mordant in the dyeing and printing industries. A major use of sodium silicate is as a bonding agent for raw rice husks as decorative architectural board.

Research conducted by the Paddy Processing Research Centre (245A) demonstrated that silica grey ash can be easily extracted from rice-husk with sodium hydroxide or sodium carbonate at relatively low temperatures to yield sodium silicate of high quality. Of the two extraction agents sodium carbonate is much cheaper and easier to handle.

In India, because of the large quantity of grey ash resulting from the burning of rice husks as fuel in small mills, it is felt that process development on pilot-plant and product scale is warranted. The high price of sodium silicate makes such development economically attractive. A pilot-stage processing plant exists at IIT-Kanpur (W62) in collaboration with the Food Corporation of India acting as an agent of Ministry of Food.

However, some of these contemplated methods of producing sodium silicate require the use of caustic soda, which is in short supply in India, and is relatively expensive. This constraint may account for the minimal commercial production, the only apparent sodium silicate production being as a by-product of carbon production (A.2.4.).

Thailand, too, has investigated the use of rice husk as a raw material in the manufacture of sodium silicate as an end product in the production of activated carbon (A.2.2.). The literature lists prior work on such utilization (243 to 246). In a report by Suyasinto (246), the by-product from carbon separation was discussed for use in detergent manufacture.

In the U.S.A., Staackman (228) reported on possible alternative recovery processes and on the economic feasibility of silicate production under varying conditions. He advocated the use of the husk to provide part of the sensible heat input as well as silica. However, there is no such plant using rice husk and no thorough economic study is being undertaken toward this concept.

A report by El Bouseily (245) indicates Egyptian interest in sodium silicate production.

A question that always arises when discussing sodium silicate production regards the purity of the finished product. If the approximately 5% of outside compounds present in normal rice-husk ash are of no consequence, then production is feasible. However, if the desired use requires a pure silica rice husk cannot be used.

A.5.2. Silicon tetrachloride. P.K. Basu (233-234) developed a laboratory process for the manufacture of silicon tetrachloride (used in the manufacture of electronic grade silicon, colloidal silica and silicone polymers) from rice husk. The process is a combination of chlorination and pyrolysis of rice husk, leading to a very intimate mixture of the silica and the carbon formed by the carbonization of the cellulosic matter in the hulls. It is possible that a pre-carbonized char could be used as the initial raw material for a similar process, using the subsequent procedure of Basu. Laboratory experiments indicate that chlorination of rice husk requires a considerably lower temperature than the mixture of sand and coke. The new process is claimed to have an economic advantage over the manufacturing processes now being used.

A.6. BUILDING MATERIAL

Char is used in various parts of the world for building material applications, as loose fil', bonded, or compressed; it is in all applications a sterile, weed-free and insect-resistant material. In some of the products the high pH (11) creates a definite insect barrier.

Compared with raw rice husk as a building material, charred husk offers some saving in the cost of the cement binder.

The use of char as a radiation barrier was discussed by Hough (14), but no utilization seems to have been made of this interesting property.

At one time it was reported that a process similar to the French Silicior development was at a considerably advanced stage of development in Iran. In this process, by Chittenden (W161), white ash was used in facings of a compression-moulded concrete.

In Thailand, sand/lime/ash brick production is reported by Suyasinto (20). It was found that a 10% lime content was most favourable and that shrinkage was high and the strength correspondingly less with higher lime percentages.

The use of ash in an adobe brick was discussed by Hough (11), describing development work in 1953.

In India, Iyengar (W78) produced samples of paddy-husk ash bricks of proprietary manufacture. Also at RRL, Jorhat (W54), development work has progressed on building bricks.

In Egypt considerable work has been done on a 20% carbon brick. This was reported by Maksoud (16), who also (15) evaluated building bricks prepared by five different methods of formation of the bonding material.

A.6.1. ME-HA . The most extensive commercial use of charred paddy husk in the building material field appears to be the loose-fill applications in the F.R.G. by ME-HA (W40). Extensive use is made of charred husk to provide an excellent insulation material sold there under the trademark "MEHABIT".

A.7. REFRACTORY USE - HEAT INSULATION

The use of rice-husk residue as a refractory material is widespread; in some uses, in a strict sense it should be called a heat-insulating material, but all such uses are included here under one heading.

There are three principal areas of use: pressure-formed brick; air-dried heat-insulating coatings; and fired refractories or heat-insulating uses.

Manufacture is carried out in several countries, primarily Egypt, the F.R.G. and Japan, and the products are sold in many countries.

There has been a great amount of development work toward refractory use. Some processes have enjoyed success for a number of years, including those of Jones (196, 197, 198, 200, 201, 202, 203) and Rowland (263, 264). The patents of Jones are said to cover all uses of rice-husk ash in a fired condition and those of Rowland to cover the uses as castable and facing, air-dried. Both of these developments had a number of years of commercial success (202), but such activity appears to have ceased. The work of Abdellatif (10) which resulted in the Silicior (A.1.7.) concept is in the building material field rather than as a refractory; however, the patent does mention use as a refractory.

A.7.1. Orylex. The best commercial refractory from rice-husk residue today is produced by Refratechnik Albert GmbH, Gottingen, F.R.G., (W43) and their licensee, Asahi Glass Company, Tokyo, Japan (W100).

This product is a light-weight refractory brick for the preheating zones of rotary cement kilns. The patents were issued in 1963 (208) and 1965 (205), and the brick went into production shortly afterward. The use of 65% rice-husk ash is known. The properties of the brick, both in abrasive-wear characteristics and in crack-resistance, added to its exceptional insulation properties, make it a worldwide success.

Some of its advantages are:

- The low loss of heat by radiation makes the kiln more economical to run;
- low shell temperatures and low weight of the refractory lining preserve the kiln structure and increase its service life;
- because of the low specific heat, the kiln can be put quickly into operation making for flexible working;
- the product binds and holds the alkalies at its surface. This reaction layer protects the brick from alkali attack and reduces mechanical wear. A crust formed by dust is frequently observed to develop on this layer and enhance the surface protection;
- the brick is of crystalline composition and has excellent volume stability. No fatigue phenomena have been found to occur.

The ash for this production has been imported from Italy, Pakistan and India. (See also Section 5.3.2.5.).

A. 7.2. Intermat. This company, based in Trino (Italy), is a subsidiary of Refratechnik Albert GmbH. It processes ash for shipment not only to its parent company but to other industrial users in Austria, France, F.R.G. and the U.K. It burns husk for its own account and also purchases a finished ash product from Po Valley rice mills for processing, packaging and shipping. Ash is produced in a density range from 200 kg/m^3 for a normal product to 700 kg/m^3 for a milled product. A maximum moisture of 5% is allowed.

A.7.3. Super-insulators (1948) Silex. These thermal super-insulator bricks were described in a technical bulletin (207) It is not known whether they are being marketed currently. A similar brick was mentioned in a series of reports (211) about four years later. Its use was in kilns, and a 50% increase in production was claimed.

A.7.4. Jones-Mount Royal Rice Mills. During the 1950s a considerable amount of work was done by Jones (195, 196, 197, 198, 200) and others (201, 202, 203) on fired refractory products utilizing rice-husk ash as the principal ingredient. Commercial production of some of the items continued for several years. The difficulty of obtaining a satisfactory raw material (grey ash) at a reasonable cost contributed to the discontinuance of this utilization.

A.7.5. Rowland. In 1967 Rowland (263, 264) obtained patents covering the manufacture of refractory materials from rice-husk ash (5 parts by volume), aluminous cement (1 part by volume), a filler (broken refractory bricks or pearlite - 2 parts by volume), and iron oxide (3% by weight). Considerable use of Rowland's product was made in the steel mills in Canada, both in linings and in "hot tops". His castable refractories were of particular benefit. Difficulties in procuring the necessary quality of ash at a reasonable cost made it hard to be competitive.

A.7.6. The Egyptian Company for Refractories (W11) produces high-quality refractory bricks in Alexandria using local rice-husk ash. Densities range from 0.72 to 1.10 gr/cm^3. These bricks have attained a solid reputation in the local refractory market owing to their unique properties and good behaviour in different industrial furnaces. They permit high temperatures of use (over 1200°C.) and have low bulk density. They have good thermal shock properties: the silica is amorphous and crystallization is slow. Their white colour helps reflection of heat in linings. As a result of their low iron content, there is no problem of iron migration in electric furnaces. Their conductivity is adequate for industrial furnaces. Their volume stability is high, owing to the absence of a crystalline phase. Table 30 shows details of the properties of certain of the ECR refractory bricks.

Table 30

Properties of ECR refractory bricks

Chemical and Physical Properties	Kafif 72	Kafif 85	Kafif 110
A. Chemical Analysis			
SiO_2 %	93.2	90.15	90.7
Al_2O_3 %	Nominal	3.15	Nominal
Fe_2O_3 %	Nominal	0.40	Nominal
Cao %	3.0	2.8	5.6
Alkalies Na_2O, K_2O %	3.8	3.5	3.7
B. Physical Properties			
Apparent bulk density gm/cm^3	0.72	0.85	1.1
Water absorption %	94.5	73.5	48
Apparent porosity %	68.0	62.5	53
Cold crushing strength kg/cm^2	15	40	170
Thermal shock resistance (0-1200°C)	Excellent	Excellent	Very good
Working temperature max.	1200°C	1180°C	1200°C
Thermal conductivity Kcal/m/h/°C	0.207	0.250	0.280
Volume stability	Very good	Very good	Very good
Pyrometric cone equivalent °C	1485	1400	1430

A.8. OIL ABSORBENT

Continuous commercial use of rice-husk ash since 1936 in the oil-absorbent field has been primarily due to the developments of Beagle (213). This largest utilization of low-carbon ash known is carried on in California and in Mexico. Pile burning, building burning and experimental machine burning have provided a supply of "GREASWEEP" for various oil-absorbent needs for over 40 years. As an absorbent material (sweeping compound), ash is used primarily to clean up oil spills and stains, and as an antiskid medium for concrete or asphalt paving in automobile service stations and repair facilities. No other product performs the unique function of "GREASWEEP".

A.9. OTHER COMMERCIAL USES

The Italian supplies of ash are channeled to uses of "hot tops", ingot insulation and other steel-mill insulation duties, as well as for refractory use.

Some other ceramic uses employing small quantities of ash are known in France.

In India and Sri Lanka, white ash is commercially used for tooth powder (Lever Bros.-Lamken) and as cleansing powder (Vim). It is also used non-commercially by the local people for the same purposes.

Ash furnished in quantity by Beagle in the 1940s and 1950s has been used as the filler body in hand soaps in the United States but this use has diminished since 1965. Similar uses are reported in West Africa, and exist in India. The use was mentioned by Lathrop (223) in his 1952 report.

Ash has in the past been used at times to coat ammonium nitrate fertilizer pills to facilitate their handling. This is not being done at the present time, so far as is known.

Ash has been used by Vaughn in West Virginia, U.S.A., as a component of fireproof insulation coatings for buildings, bridges and tanks. Davis, in Missouri, U.S.A., used ash in a sprayed-on material for insulation and fireproofing of steel structures.

A.10. CONCEPTUAL OR DEVELOPMENTAL USES

It has been suggested in the U.S.A. (159, 160) in India (162) and in Japan (163) to utilize a rice-husk ash product as an insect prevention and control method. The mechanism of action is that the silica acts as an abrasive on the waxy coating of the thorax of the insect, thereby upsetting the normal metabolism, and the insect dies. As far as is known, this approach has had no further development.

Yost (77) has investigated the properties of rice-husk ash/lime/soil mixtures for the stabilization of soils for roadbeds. He concluded that for certain soils the use of rice-hull ash increases the compressive strength over "natural" strength and uses "5% lime" strength and that, if economically feasible, the product was suitable for commercial use as a soil stabilizer.

DEFINITIONS

Ash - The residue remaining from a burning or pyrolytic conversion of rice husk, having a carbon content of less than 1.5%.

Baked air chaffs - A Japanese name for char.

Bioconversion - A general term describing the conversion of one form of substance into another by animals, plants or micro-organisms, accompanied by the absorption or release of energy.

Biomass - Any biodegradable material produced from a living source.

British thermal unit (BTU) - (generally used in engineering work in the UK and the USA). 1/180 of the heat required to raise the temperature of 1 lb of water from 32° to 212°F. (Formerly defined as the quantity of heat required to raise 1 lb of water from 62° to 63°F).

Burn - To undergo rapid combustion or consume fuel in such a way as to give off heat, gases and, usually, light. To consume with fire, to reduce to ashes. A rapid, self-perpetuating form of oxidation.

By-Product - An unavoidable secondary or incidental product.

Carbonization - Pyrolysis. Not normally used when discussing any reforming or when the residuals are other than char and flue gas.

Chaff cinder - A Japanese name for char.

Char - The residue remaining from a burning or pyrolytic conversion of rice husk having a carbon content of over 1.5%.

Conversion - The chemical or biochemical transformation of a waste material into a useful product.

Destructive distillation - A process in which coal, wood or other cellulous compounds are heated in the absence of air or oxygen so that thermal decomposition occurs, gases and vapours of decomposition products being passed to a collating and condensing system, leaving a solid non-volatile residue; carbonization; pyrolysis.

Distillation - By evaporation and condensation. The driving off of gas or vapour from materials (e.g. by heat) and condensing some or all the products.

Dispersant - The utilization of rice husk, char or ash to disperse other materials with which they are mixed.

Dry distillation - The reduction of a material to its components by decomposition in a controlled atmosphere.

Drying efficiency - $\frac{\text{moisture to be evaporated}}{\text{heat input}} \times 100 = \text{percent}$

Dual fuel engine - An engine prime mover that can operate on two fuels, usually one liquid and one gaseous.

Efficiency - The attainable value of an energy converter based on the ratio of the useful energy delivered by the system to the energy supplied to it.

Energy - The capability of doing work. Forms of energy include kinetic, potential, thermal, nuclear, rotational and electromagnetic. One form of energy may be converted to another, as when rice husk is burnt to produce steam to drive a turbine which produces electricity.

The energy content of a system can be measured in many ways, e.g. by measuring the temperature increase produced in water, or by measuring the current, voltage, and period of flow of electricity.

Energy efficiency - The amount of useful work or product divided by the fuel or energy input (e.g., in the generation of electricity, the amount of electricity produced per unit of fuel consumed).

Energy resources - All materials potentially usable by man as an energy source. Includes estimates based on geological evidence for quantities still undiscovered or whose exploitation will require more favourable economic conditions or better technology than now exists.

Enthalpy - The heat content per unit mass, expressed in BTU/pound.

Fuel - A material that develops usable energy during oxidation, or during a nuclear chain reaction.

Fuel cell - A device for directly converting the energy released in a chemical reaction into electrical energy.

Fuel gas - Gas from the combustion of fuel, the heating value of which has been substantially spent and which is therefore released to the flue or stack.

Fluidized bed - The result of the flow of a fluid, usually a gas, upward through a bed of suitably sized solid particles at a velocity high enough to buoy the particles, to overcome the influence of gravity, and to impart to them an appearance of great turbulence. Used in the petroleum and food industries.

Fluidized bed boilers - A means of generating power by moving powdered fuel (coal), in a liquid-like stream by use of air or other gases, into a combustion chamber.

Fossil fuel - a naturally occurring organic fuel (e.g. coal, crude oil, natural gas).

Fractional distillation - A method of separating the constituants of a substance by distillation and collecting the distillate in several portions (fractions) as the temperature rises.

Furnace - That part of the boiler designed for burning the fuel.

Gasification - The conversion of a solid or liquid to a gas. In the thermal processing of rice husk, a fraction of the stoichiometric oxygen required by the rice husk is admitted directly into the fuel bed to liberate the heat required for endothermic gasification reactions. The volatile portion of rice husks are pyrolized by the heat of the fuel gases, and the outlet gas composition reflects both processes.

Gas producer - A furnace designed especially for the gasification process to make a combustible, gaseous fuel from a variety of carbonaceous materials, such as rice husks, coal, charcoal, and coke, by reaction with steam and steam/air mixtures.

Gross (heat) value - See High heat value.

High heat value (also called "gross value") - Term generally used in the United States for combustion calculations, in which it is assumed that all water vapour formed by the burning of the hydrogen constituent is condensed and cooled to the initial temperature in the calorimeter at the start of the test. The heat of vaporization is therefore present in the reported values.

Isomerism - A condition in which substances having the same chemical formula differ in certain physical characteristics.

Hydrocarbons - Gaseous, liquid or solid compounds containing only carbon and hydrogen. There are a very large number of these compounds, which form the basis of petroleum products.

Hydrogasification - The treatment of an organic material at high temperatures and pressures to produce methane.

Low heat value (also called "net value") - Term generally used in Europe for combustion calculations, in which it is assumed that none of the water vapour condenses and that all of the product of combustion remains in a gaseous state.

Net (heat) value - See Low heat value.

Particulate matter - Solid particles, such as ash, which are released from a combustion process in the exhaust gases.

Pollutant - Any contaminant whose presence in a substance (generally air or water) detracts from or interferes with the latter's desired usage.

Polymerization - A method of combining smaller molecules to make larger ones, developed during the late 1930s to utilize refinery gases which were often wasted or burned as fuel. The opposite of cracking.

Power - The rate at which energy is used or at which work is done.

Power gas (also called "producer gas") - A low-energy gaseous fuel, sometimes produced from coal or rice husk, whose principal combustible components (carbon monoxide and hydrogen) are greatly diluted by air. Because of its low energy content, power gas cannot be transported economically, and is generally burned at the production site.

Producer gas - See Power gas.

Pyrolysis - The transformation of a substance into another compound or compounds by the application of heat in the absence of oxygen. In the context of energy, pyrolysis is the heating of organic materials (e.g. coal, wood, petroleum, solid wastes and agricultural crop residues) in the absence of oxygen with provision for recovery of the desired combustible products. If heat is applied slowly, the initial products are water vapour and volatile organic compounds. Increased heat leads to recombination of the organic materials into complex hydrocarbons and water. The principal products of pyrolysis are gases, oils, and char. It is possible to produce great variations in the relative proportions of these products by varying the pyrolysis conditions.

Reforming - Recombination of pyrolysis products into complex hydrocarbons and water.

Thermal decomposition - An irreversible chemical change brought about by the action of heat in an atmosphere devoid of oxygen; pyrolysis.

Thermal efficiency - A ratio indicating the available heat input that is converted to useful purposes. It is applied, generally, to combustion equipment. $E = \frac{\text{heat output}}{\text{heat input}} \times 100$

Utilization - Turning to profitable account.

Waste heat - The heat released to the environment from a heat source.

Waste - Any material not being put to useful function. Usually used in the USA to describe urban refuse or municipal solid waste.

CONVERSION TABLE

One acre = 43,560 ft^2, 4046.86 m^2, 0.4047 ha
One acre = 100 m^2, 1076.387 ft^2
One hectare (ha) = 100 are, 2,47 acres
One centalweight (cwt) = 100 lbs
One pikul = 133 1/3 lbs
One catty = 1 1/3 lb
One cavan = 44 lbs
One kilogram (kg) = 2.2046 kbs
One quintal = 100 kilograms - 220.45 lbs
One metric ton (MT) = 1000 kilograms - 0.9842 long ton
- 1.1023 short ton
One kg/ha = 0.89 lb/acre
One lb/acre = 1.121 kg/ha
One barrel (rice) U.S.A. = 162 lb paddy
One bushel (U.S. or Imp.) = 8 gal (U.S. or Imp.)
One ft^3 = 0.0283 m^3
One barrel (oil) = 42 U.S. gal - 306 lbs
One U.S. gallon = 3.785 litres
One atmosphere (atm) = 14.7 lbs/in^2 (Eng)
One metric atmosphere = 1 kg/cm^2
One kg/cm^2 = 14.2234 lb/in^2
One lb/in^2 = 0.0703= kg/cm^2
One BTU = 0.252 Kcal
One Kcal = 3.968 BTU

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LIST OF WORKERS, SUPPLIERS AND INSTITUTIONS

Number	Name/Address	Contact	Scope of Interest
		ARGENTINA	
W1	Frugone & Preve Lda. S.A. H. Yrigoyen 1628 BUENOS AIRES	Mr. Jorge A. Balerdi	Rice miller user of rice husk power plants steam for motive power to drive rice mill.
W2	Avda. Belgrano 355 BUENOS AIRES	Mr. J. Agrest	Combustion consultant.
		AUSTRALIA	
W3	Rice Growers Cooperative Mills Limited P.O. Box 406 GRIFFITH, N.S.W. 2680	Dr. R.P. Coulter Grp Mgr, By-Products	Rice milling, research & development on rice husk utilization.
W4	Applied Energy Pty, Ltd. 18/20 Clarice Road Box Hill South VICTORIA, 3128	Mr. Adolfo Cittadini Managing Director	Specialists in combustion applications.
W5	John W. Barret 85 Killeaton St. East ST. IVES, N.S.W. 2075		Consulting engineer.
		AUSTRIA	
W6	Light Industries Section UNIDO P.O. Box 707 VIENNA	Mr. Andras Miklovicz-Chf Mr. E.D. Manning Mr. Horst Koenig	UNIDO is concerned with the whole spectrum of rice husk utilization from the industrial point of view.
		BRAZIL	
W7	Mernak, S.A. Rua Otto Mernak 276-Caixa Postal 23 Cachoeira Do Sul RIO GRANDE DO SUL	Mr. Eloi	Builds two series of Lokomoveis (Lokomobile) similar to Buckau R. Wolf and Esterer engines.
		CANADA	
W8	Ontario Research Foundation SHERIDAN PARK, Ontario	Mr. James D. Jones Dir., Dept. of Proj. Devp.	Pioneer worker patent holder in the use of rice husk ash in refractories and ceramics.

CHINA

W9	Joint Commission on Rural Reconstruction, 37 Nan Hai Rd. TAIPEI 107	Mr. Tien-song Peng Farm Machinery Specialist Mr. Jun-liang Liang Taichung Dist.Ag.Imp.Sta.	Machine for making rice husk charcoal

DENMARK

W10	Argus Fyr A/S Femagervej 39 2650 HVIDOVRE	Mr. S.E. Perning	Manufacturer of power stokers for rice husk as a fuel.

EGYPT

W11	The Egyptian Co. for Refractories P.O. Box 1211 ALEXANDRIA	M. Shams El Din El Sioufi Chairman	Producer of refractories, white silica from rice husk.
W12	The Egyptian General Organization for Rice Mills 6 Falaky Square CAIRO	Mr. A. Ezzat Said,Dr.Gen. Mr. A. Talaat Aziz, Chm. Mr. G. Kerdany, Dir.Gen. Agr. Eng.	National organization
W13	Ein-Shams University EIN-SHAMS	Dr.Eng. Ahmed El-Said Gad El-Mawla Asst.Prof.of Heat Engines Faculty of Engineering	Study of various prime movers used in rice milling.
W14	National Research Council CAIRO	Mohammed A. Arafah, Res. Mr. Abdel Maksoud, Res. Mr. A.A. Khalil, Res.	Studies of building bricks using black ash and lime by steam curing and chemical bonds under normal conditions.
W15	Rashid Rice Milling Co. P.O. Box 854 ALEXANDRAI	Moh. Sherif El-Herrawi Chm., Board of Directors	Experienced in utilization of rice husk.
W16	University of Tanta TANTA	Dr. Tayseir El Shamy	Sodium silicate awareness.
W17	University of Alexandria ALEXANDRIA	Dr. Ahmed El Bouseily Dr. Mohamed Hussien Abdel-Megid, Chem. Eng. Dept.	Sodium silicate studies.

FRANCE

W18	Conservatoire National des Arts-et-Metiers 27 bis, Quai Anatole-France 75007 PARIS	Prof. Dr. J. Girerd	Research and development of rice-husk residue utilization.

W19	Distibois Rans, 39700 ORCHAMPS (Jura)	Mr. A. de Lacotte	Designs and builds gas producers. Operator of dual fuel (pilot fuel) engines from producer gas.
W20	Duvant Moteurs Diesel Boite Postale 2 36 59308 VALENCIENNES	Dr. A. Dennetière Tech. Dir.	Manufacturer of dual fuel (pilot fuel) engines for producer-gas operation.
W21	Etablissements Parent NERAC (47)		Builder of rice-husk fired boiler at Gimeaux.
W22	Ferbeck et Vincent PARIS		Builder of rice-husk fired furnace at Gimeaux.
W23	Sica France Riz 13200 ARLES	Mr. J. Moureau	Rice processor husk-fired boiler for process steam.
W24	Société des Produits Chimiques Alumineux 13240 SEPTEMES-LES-VALLONS	Ing. Edgard Harari Dr. A. Abdellatif	Manufacture of bricks, blocks, slabs, "Silicior"
W25	SODETEG BP 15 92 PLESSIS ROBINSON	Prof. M. Girerd	Interested in rice husk utilization.
W26	Syndicat des Riziculteurs de France Rue Romain-Rolland 13200 ARLES	Mr. R. Metz, Dir.	Public organization. Interested in utilization of rice husk.
W27	SACM (Société Alsacienne de Constructions Mécaniques) 1 rue de la Fonderie 68054 MULHOUSE		

GERMAN DEMOCRATE REPUBLIC

W28	VEB Maschinen und Muhlenbau Wittenberg Betrieb des VEB Kombinat Fortschnitt 46 WITTENBERG, Lutherstadt	Mr. Hans Georg Kaiser	Rice milling machinery manufacturer.

GERMANY, FEDERAL REPUBLIC OF

W29	AEG-Kanis Turbinenfabrik GmbH 8500 NURNBERG 1 Frankenstrasse 70-80		Turbines of all types. 400 KW up - for all uses.
W30	Amandus Kahl Nachf. Hamburg Postfach 260343 Dieselstrasse 5-9 2057 Reinbek (HAMBURG)	Mr. Joachim Behrmann	Manufacturer of pelleting machinery.

W31	Buhler-MIAG GmbH D33 BRAUNSCHWEIG Postfach 3369	Mr. Karl-Heinz Kunde Mr. M. Wehmann	Rice milling machinery Constructor husk fired. Power plant builder.
W32	Cornelius Schmidt, Eisen und Stahlwerk Von Kettelenstrasse 1 509 LEVERKUSEN, Kuppersteg	Mr. Simon Mr. Paland	Manufacturer of rice husk burning furnaces and grates. Dedusting and scrubbing equipment.
W33	Eisenwerk Theodor Loos GmbH 8820 GUNZENHAUSEN Nurnbergerstrasse 71-75	Ing. H. Ernst	Boiler manufacturer.
W34	Gebrüder Wagner 7 STUTTGART-Bad Cannstatt Hofenerstrasse 118-126		Boiler manufacturer
W35	Gerbrüder Weiss KG 6343 FROHNHAUSEN (Dillkreis)		Specialize in boilers & combustion equipment for use on solid cellulosic fuels.
W36	Peter Hansen 2000 HAMBURG 60 Agnesstrasse 26	Peter Hansen, Director Mr. Wolfgang Schneede	Broker-rice husk and residues.
W37	Institut fur Landmaschinenforschung d. Forschungsanstalt für Landwirtschaft 3301 BRAUNSCHWEIG	Dr. W. Baader	Research on gas producers - equipment.
W38	Kuhnle, Koop & Kausch FRANKENTHAL (Pfalz)		Turbines
W39	A. Lambion Maschinenfabrik D3549 WETTERBURG (Waldeck)	Mr. Alfred Lambion	Furnaces, grates, boilers. Experience in furnaces for rice husk burning.
W40	ME HA Dammstoff-Fabrik GmbH D6707 SCHIFFERSTADT Postfach 102		User of rice husk char for insulation material "Mehabit"
W41	Turbinenfabrik J. Nadrowski GmbH 48 BIELEFELD Postfach 6104		Small and medium-sized turbines, direct and geared. 2 KW to 2,100 KW
W42	Naumann & Co. D2000 HAMBURG 74 Berzeliusstrasse 7-11		Hanseata rice mills and rice machinery. Husk fired dryers.
W43	Refratechnik Albert GmbH 34 GOTTINGEN Postfach 2	Dr. P. Bartha Dr. G. Hotz	Producer of refractories using rice-husk ash in manufacture. Research and development on rice husk and derivatives.

W44	F.H. Schule GmbH 2 HAMBURG 26 P.O. Box 260620	Mr. Hans G.W. Keesenberg Mr. H. Petersen Mr. R. Runte	Rice milling machinery complete rice mills, complexes, dryers, parboiling plants, steam power plants
W45	Siller & Jamart KG 56 WUPPERTAL-Barmen Horather Str. 20-24		Husk-fired boilers.
W46	Spillingwerk HAMBURG GmbH 2000 HAMBURG 11 Postfach 11 05 29	Mr. H. Spilling	Steam motor manufacturers. Complete husk-fired power plants. Contractors.
W47	Standardkessel Duisburg 4100 DUISBURG Wilhelmschoehe 3		Prefabricated boilers and steam boilers.
W48	Streckel & Schrader K.G. 2 HAMBURG 70 Hinschenfelderstrasse 35	Dipl. Ing.Karl Streckel	Rice milling equipment manufacturers. Complete rice mills.
W49	Terry GmbH 42 OBERHAUSEN 1 Postfach 10 16 29	Mr. V.P. Leupolz	Terry and Kuhnert turbines and generator sets among a full line of turbines. Generator sets 300 to 750

INDIA

W50	Council of Scientific and Industrial Research Central Food Technological Research Institute Cheluvamba Mansion MYSORE-570013	Dr. B.L. Amla, Director Dr. H.S.R. Desikachar Mr. L.K. Lakshmin Narayana Mr. K.R. Bhattacharya	Research projects concerning rice husk.
W51	Council of Scientific and Industrial Research Rafi Marg NEW DELHI-110001	Mr. Baldev Singh, Chief Technology Utilization Mr. K. Rajagopal, Scientist	Interested in spectrum of waste utilization including rice husk
W52	Council of Scientific and Industrial Research Structural Engineering Research Centre Adyar, MADRAS-6000020	Prof. G.S. Ramaswamy, Director	Research on fly ash for structural use in buildings. Parallels for rice husk.
W53	Council of Scientific and Industrial Research Regional Research Laboratory HYDERABAD-500009	Mr. G.S. Sidhu, Director Mr. Bharat Bushan, Dep.Dr. Mr. E.R. Saxena, Scien. Mr. S. Rajender Rao, Scien. Mr. S. Raghavendar Rao, Lib.	Research and development of processes. Fuel-related, carbons, activated carbons.
W54	Council of Scientific and Industrial Research Regional Research Laboratory JORHAT (Assam)		Has conducted rice-husk research and development, both heat-related and other.

W55	Council of Scientific and Industrial Research Regional Research Laboratory JAMMU (Tawi)		Research and development on heat- and energy-related use of husk as well as other facets of husk utilization.
W56	Central Building Research Institute ROORKEE, (U.P.)	Mr. A.C. Banerjee, Scientist	Working on the utilization of husk in cementitious materials.
W57	Cement Research Institute of India M-10, South Extension (II), Ring Road NEW DELHI 110049	Director	Use of ash as cementitious material.
W58	Central Rice Research Institute CUTTACK	Dr. S.Y. Padmanabhan, Director	
W59	Central Fuel Research Institute JEOLGORA (Dhanbad) Bihar	Mr. M.G. Krishna, Dir. Prof. S.K. Dasgupta, Deputy Director	Research, development and testing of husk-fired equipment.
W60	The Food Corporation of India Bara Khambolane Connaught Place NEW DELHI-110011	Dr. S.V. Pingale Dr. S.N. Sharma	Research and development and publication of husk-related processes and utilization particularly in reference to sodium silicate production.
W61	Indian Agriculture Research Institute Hillside Road NEW DELHI-110012		
W62	Indian Institute of Technology Kanpur IIT Post Office KANPUR-16 U.P.	Mr. P.C. Kapur	Have developed a hydraulic-setting cement called "Ashmoh", made from rice-husk ash. Ongoing programmes concern high-temperature silica thermal insulation refractory-lightweight concrete blocks, fillers, additives.
W63	Indian Institute of Technology Rice Process Engineering Centre KHARAGPUR, West Bengal	Dr. T.P. Ojha Mr. R.C. Maheshwari Mr. B.D. Shukla	Research and development - construction of husk-fired furnace-dryer. Gas producer. Air-suspended husk furnace.
W64	Indian National Scientific Documentation Centre Hillside Road NEW DELHI-110012	Dr. S. Parthasarathy Scientist-in-Charge	National centre.

W65	Faculty of Engineering and Tech. Dept. of Food Technology & Bio-Chemical Engineering Jadavpur University CALCUTTA-700032	Mr. Sunit Mukherjee, Professor	Studying effects of heating under controlled conditions to produce white ash - modification of husk-fired furnace.
W66	Ministry of Food & Agriculture Krishi Bhavan NEW DELHI-110011	Mr. P.K. Kymal, Ex.Dir. Food & Nut. Bd Mr. M. Kuppuswamy, Chief Engineer Mr. N.S. Gangadharan, Engineer	Research and development of all rice-husk related processes and equipment, particularly husk-fired furnaces and dryers.
W67	National Committee on Science and Technology Dept. of Science & Technology Technology Bhavan NEW DELHI-110029	Mr. P.K. Bhatnagar Dr. J.K. Sridhar Rao Coordinator-Waste Util.	
W68	Punjab Agricultural University College of Agricultural Engineering LUDHIANA, Punjab	Dr. Pathak, Head Dept. of Ag. Engineering Mr. A.P. Bhatnagar, Head Dept.Process. & Structures	Development of dryers, furnaces and domestic stoves utilizing rice husk
W69	Thanjavur Cooperative Marketing Federation Paddy Processing Research Centre Lab Modern Rice Mill P.O. Vijayapuram TIRUVARUR 610 108 (TAMIL NADU)	Dr. V. Subrahmanyan, Pro. Head	Sodium silicate experience and data on the use of paddy husk as fuel for parboiling and drying.
W70	The Anil Starch Products Ltd. Regd. Office Anil Road, P.B. No. 1062 AHMEDABAD-380002	Mr. Shripal Chinubhai Sheth, Managing Director	Producers of specification grades of activated carbon made from rice husk.
W71	Binny Limited P.O. Box 111 Meenam Bakkam MADRAS 6 00 061	Mr. B.S. Dass Mr. G.V. Rao Mr. S. Balasubrahmanyam	Rice milling machinery.
W72	Chemech Engineers Private Ltd. 16/3, Sterling Road Nungambakkam MADRAS-600034		Dryers, parboiling, construction.
W73	Damodar Enterprises Ltd. 1-A, Vansittart Road CALCUTTA-1		Rice milling equipment manufacturer.
W74	G.G. Dandekar Mach. Works Ltd Dandekarwadi Bhiwandi, (Thana) MAHARASHTRA	Mr. A.K. Goil	Rice milling machinery. Interested in husk-fired dryers.

W75	East India Rice Mills Assn 7A, Elgin Road CALCUTTA-20	Mr. V.S. Aggarwal, President	Development of husk-related processes.
W76	Engineering Services Corp. No. 2, R.S.V. Naidu St. Kilpauk, MADRAS-10		Developing hot-air generator fired by husk. Rice milling and handling equipment constructor-designer.
W77	Greaves Cotton & Co. Ltd. 1 Dr. V.B. Gandhi Marg P-B No. 91 BOMBAY 400023	Mr. I.P. Gopal-Ram Mr. R.V. Natu Mr. I.K. Kumar	Westerworks boilers, gas engines.
W78	M.S. Iyengar & Associates (P) Limited D-II/4, NPL Quarters Dr. K.S. Krishnan Road NEW DELHI-110060	Dr. M.S. Iyengar Managing Director	Consultant: background of research in husk utilization.
W79	Jaya and Company Boiler Engineers Post Box No. 1347, Trichy Rd. COIMBATORE-641018	Mr. J.S. Kamath Partner	Husk-fired boilers.
W80	Kirloskar Oil Engines Ltd. Corporate Office 11, Koregaon Road POONA-411001	Mr. S.K. Joshi	Rice milling equipment (Schule, Dandekar) - gas, oil and diesel engines.
W81	Modern Machineries Corp. 5 Clive Row CALCUTTA-1	Mr. Shrish Aggarwal	Rice mills, rice milling machinery. Concessionaire Dandekar, parboiling plants.
W82	Sarda Rice & Oil Mills P.O. Ahmadpur (Birbhum) 731201 (WEST BENGAL)	Mr. P.S. Sarda, Pres. Bengal Rice Mills Assn.	Rice miller, oil miller
W83	Scopa Chemicals 15, Mahendra Nagar, Canal Rd. JAMMU (Tawi) 180001	Mr. Ashok Thussu	User of rice husk as a raw fuel in boilers.
W84	Shaw Wallace & Co., Ltd. 7, Linghi Chetty St.-P.B. 14 MADRAS-1	Mr. L.R. Sharma, Div. Mgr.	Manufacturer of husk-fired dryers and parboiling equipment.
W85	Triveni Engineering Works Ltd NSIC Building P.O. Udyog Nagar NAINI-Allahabad		Single- and multi-stage turbines manufactured in collaboration with Peter Brotherhood, U.K.
W86	Wanson, India (P), Ltd. Chinchawad - (POONA) 19		Supplier of boilers to Dandekar

W87	Westerwork Engineers PVT.Ltd. 5-D Vulean Insurance Bldg. Veer Nariman Rd., Churchgate BOMBAY 400020		Husk-fired boilers and furnaces.

ITALY

W88	Ente Nazionale Riso Centro Ricerca MORTARA	Dr. Baldi, Director Dr. Francesco Ranghino	Library; research on rice husk.
W89	Ente Nazionale Riso Piazza Pio XI, 1 MILANO	Mr. Tino Morbello	National Board - publishes "Il Riso"
W90	Gariboldi S.N.C. Via Bertarini 72 20061 CARUGATE (Milano)		Manufacture of husk-fired steam plants, parboiling plants, boilers, furnaces.
W91	Intermat S.a.S. Casella Postale 13 13039 TRINO	Mr. Danilo Bertolotti	Producers of rice-husk ash for refractory, steel industries.
W92	Riseria di Monticello MONTICELLO		Producer-gas power system.
W93	Politecnico Instituto di Chimica Industriale Via Boccaccio, 26 MILANO	Dott. Ing. Pino Cucchetti	Consulting capability some facets of rice-husk utilization, furfural and residue utilization.
W94	Riseria Gariboldi 20 Via Pienza 20142 MILANO	Mr. Franco Gariboldi	Rice milling, user of husk-fired process steam for parboiling.
W95	Riseria Rosasco Bianchi ROSASCO (Pavia)	Mr. Antonio Bianchi	Rice millers, experience in husk-fired steam power, gas producers, residue production.
W96	S.A.P.R.I. Via C. Campari 68 27100, PAVIA	Dr. Carlo Grugni	User of husk-fired process steam for parboiling.
W97	Societa Italiana Furfurolo S.p.A. Via Gen. Albricci 8 20122 MILANO	Dr. Guido, Director	Furfural production, residue utilization.
W98	Stazione Sperimentale di Risicoltura VERCELLI	Dr. Russo, Director	Research station, formerly active on rice-husk developments. Library.
W99	STICED Via XX Settembre, 27 20123 MILANO	Dr. Riccardo Cucchetti	Consulting capability - some facets of rice utilization, furfural and residue utilization.

JAPAN

W100	Asahi Glass Company, Ltd 1-2, Marunouchi 2-chome, Chiyoda-ku, TOKYO	Mr. K. Mushakoji, Dir. Int'l Division	Producers of refractories using rice-husk ash.
W101	Chuo Boeki Goshi Kaisha (Central Commercial Co.) Ibaraki P.O. Box 8 IBARAKI CITY	Mr. T. Kagawa, Pres.	Builders and sellers of carbonizers, husk-fired dryers, husk-fired furnace.
W102	Kansai Sangro Co., Ltd. 1666, Minami Kawase-cho HIKONE CITY, Shiga-522-2	Mr. Masahiro Kojima President	Builder of carbonization, incineration and gasification equipment
W103	Inst. of Agric. Machinery 1-chome, Nissin-cho, Omiya-shi SAITAMA-ken	Mr. Toshizo Ban, Chief Processing & Storage	Involved in rice-husk utilization.
W104	Iwate University 3 Ueda MORIOKA CITY, Iwate	Mr. Hiroshi Shimizu	Studies on combustion furnaces, furnaces for drying, hot-water heater, domestic use.
W105	Kishida Publications Shin-Norin Building 7, 2-chome, Kanda Nishikicho Chiyoda-ku TOKYO, 101	Mr. Yoshisuke Kishida Chief Editor	Farming- processing- and milling-oriented trade magazines, "Farming Mechanization", trade catalogue.
W106	New Food Processing Techniques Assn. Post No. 162-Room 1002 Ichigaya Heights 28-4 Honmuracho-Shinjuku-ku TOKYO-162	Prof. J. Sakurai, Dir.	Interested in all facets of rice-husk energy utilization and residue utilization.
W107	Nichiyu Koki Co., Ltd. No. 11-5, Hacchobori Chuo-ku, TOKYO	Mr. Sakai	Builders of carbonizing furnaces.
W108	Okura Trading Co., Ltd. 3-6, Ginza 2-chome Chuo-ku, TOKYO 104	Mr. Kozo Susuki	Sellers of dryers and machinery.
W109	Pacific Projects Ltd. Int. P.O. Box 5361 TOKYO 100-31	Mr. Frank L. Turner	Consultant, agricultural economics.
W110	Satake Engineering Co., Ltd. Ueno Hirokoji Bldg. Ueno 1-19-10, Taito-ku TOKYO	Mr. Yoshiharu Satake, Managing Director Mr. Hisashi Ishida, Manager Overseas	Builders of rice milling machinery, dryers, carbonizers, etc.
W111	Takano Seisakusho Co. 470 Kamikumano TOYAMA		Builder of carbonizing furnace for dryers, water heaters, etc.

W112	Yamamoto Mfg. Co., Ltd. 813-17, Tendo-ko, Tendo-shi YAMAGATA-ken 994		Builder of carbonizing furnaces and husk-fired dryers.
W113	Yanmar Diesel Engine Co. Ltd 1-11-1 Marunouchi, Chiyoda-ku TOKYO	Mr. Yasuo Watanabe Mr. Seisuke Sakemi	Builders of rice milling machinery (Kyowa).
W114	Kaneko Agricultural Machinery Co., Ltd. HANYU CITY Saitama Prefecture	Mr. Y. Saito	Builders of husk-fired dryers. Gasification, combustion, carbonization and heat supply equipment.

KOREA

W115	Chemical Engineering Development Laboratory Korea Institute of Science and Technology P.O. Box 131, Dong Dae Mun SEOUL	Dr. Won Hee Park, Chief Dr. C.K. Yun	Utilization of low-grade anthracite fuels by mining carbonized rice husk 5-9%.
W116	Department of Chemical Eng. Seoul National University P.O. Box 105 Cheong Ryang SEOUL	Professor Shik Namkoong	Research papers cover use of carbonized rice husk as filtering aid catalyst in waste water treatment.

MALAYSIA

W117	National Paddy & Rice Board UNBC Building KUALA LUMPUR	Mr. Ismail bin Shamsuddin	Public agency.
W118	Industrial Boilers & Allied Equipment SDN. BHD. Shah Alam Works Selangor, G.P.O. Box 635 KUALA LUMPUR		Husk-fired boilers.
W119	The East Asiatic Co., Ltd. Denmark House 84 Jalan Ampang KUALA LUMPUR-04-05	Mr. Hans Malinowski	Rice milling machinery; construction and design of milling and drying complexes.
W120	Folin & Brothers SDN. BHD. Lot 16 Jalan 223 PETALING JAYA, Selangor	Mr. Wong Foh Ling Mr. Wong Boon Sun Mr. Teoh Geok Leong	Husk-fired boilers and furnaces.
W121	Federal Industrial Development Authority (FIDA) P.O. Box 618 KUALA LUMPUR 23-03	Mr. Liew Tet Seng (for the director)	Interested in the commercial development of rice husk and derivatives.

W122	National Institute for Scientific Industrial Research (NISIR) Lot 10-20 Peringkat III & IV Kawasan M.I.E.L. SHAH ALAM, Batu Tiga, Kelang, Selangor	Dr. Ong Kong Seng	Research and development on rice husk. Particularly working on cement manufacture from rice-husk ash and the use of cementitious materials.
W123	Malaysian Agricultural Research & Development Institute (MARDI) P.O. Box 208, Sungai Besi SERDANG, Selangor	Dr. T.K. Van, Dep.Dir. Dr. C. Devendra, Head-Animal Science	Research and development of utilization of rice husk.

NETHERLANDS

W124	B.V. Interutil Kommiezenlaan 32, Post box 3029 SCHIEDAM	Ir. H.R. Karstel	International consultants for utilities. Designed new husk-fired power plant installed in Surinam.
W125	Lindeteves-Jacoberg Export bv (Ex R.S. Stokvis de Zonen N.V.) P.O. Box 5014 WEERDESTEIN 17	Mr. J.A. Jetten Mr. J.J. Koster	Suppliers of rice milling machinery.
W126	S.M.L. Stichting voor de Ontwikkeling van Machinale Landbouw in Surinam Koninginnegracht 66 THE HAGUE	Mr. Schram	Netherlands headquarters of project in Surinam which has new, highly sophisticated rice-husk burning power plant.

PAKISTAN

W127	Industrial Development Bank of Pakistan P.O. Box 5082 KARACHI-2	Mr. Nazir Uddin Mahmood Director Mr. Khalid M. Nagra, Chief Off-Eng. Dept. Mr. M.J. Rahman, Mgr.-Eng.	Interestedin all facets of rice husk utilization.

PHILIPPINES

W128	Agri-Products, A Division of Bendana, Brown, Pizarro & Associates, Inc. 123 Pioneer Street MANDALUYONG, Rizal		Manufacture of husk-fired dryer, "Nation Dryer".
W129	Corwen, Inc. 708 Aurora Blvd. QUEZON CITY D 502	Mr. Manfred B. Fischer	Experience in construction of husk-fired power plants. Builder of rice mills.

W130	The International Rice Research Institute P.O. Box 933 MANILA	Dr. Nyle C. Brady Dr. Amir U. Khan Dr. Randolph Barker Dr. F.B. Duff	International organizaation. Research and development of rice-husk related equipment, particularly dryers and stoves.
W131	Kalayaan Engineering Co. Inc. 4255 Emilia Street P.O. Box 665 Makati Comm.Ctr. MAKATI, Rizal	Mr. Rafael A. Lahoz, Jr. President	Manufacture of husk-fired dryer.
W132	Kaunlaran Industries, Inc. Kaunlaran Bldg., Calamba LAGUNA, 3717	Mr. Arsenio E. Dungo, President	Manufacture of husk-fired dryer.
W133	Marinas Machinery Mfg.Co.Inc. Rizal Street, Pila, LAGUNA	Mr. Ernesto M. Marinas, Pres.-Gen. Mgr.	Building rice-husk fired dryer. UOP-IRRI Box type.
W134	Mindanao Progress Corp. 447 Del Monte Avenue QUEZON CITY	Mr. Roberto A. Tulio	Operator of rice-husk fired steam-power plant for mill operation.
W135	University of the Philippines at Los Baños Department of Agricultural Engineering LAGUNA	Mr. Dante De Padua, Dir. Mr. Anacleto Paras, Jr., Eng. Mr. Silvestre C. Andales, Asst. Prof.	Research and development work on rice-husk fired furnaces, dryers and all other facets of rice husk utilization.
W136	University of the Philippines College of Engineering QUEZON CITY	Dr. Ibarra Cruz	Worked on gas producers using cellulosic indigenous fuels.
W137	Kamalig Philippines, Inc. D & E Building QUEZON CITY	Mr. Casimiro R. Nadala	Operators of box-type dryers.

SINGAPORE

W138	International Development Research Centre Regional Office-Asia 30 Orange Grove Road SINGAPORE-10	Miss E.V. Araullo	International organization. Interest in rice husk utilization.

SPAIN

W139	Instituto de Agroquimica y Tecnologia de Alimentos Jaime Roig 11 VALENCIA-10	Dr. S. Barber Dr. E. Tortosa	Research and development concerning all by-products of rice; international coordinator.
W140	Jose/Cardona/Bonora Division Azul, 24 Benetuser, VALENCIA		Producer of "Cenicar", a char used in building materials and the steel industry.

SRI LANKA

W142	The International Rice Research Institute P.O. Box 205 COLOMBO 5	Mr. James E. Wimberly Project Leader	User of husk-fired boilers to generate process steam for parboiling.
W143	FAO Project SRL/71/531 964 Stage II, New Town ANURADHAPURA	Mr. J. Ramalingam Project Manager	User of husk-fired boilers to generate process steam for parboiling.

SURINAM

W144	S. M, L. Stichting voor de Ontwikkeling van Machinale Landbouw in Surinam WAGENINGEN, Dist. Nickerie	Ir. R. Shankar	Operator of sophisticated rice-husk fired power plant 1200 kw

SWITZERLAND

W145	Spilling Consul. Ag. Sonnenweg 4 CH-5610 WOHLEN	Dipl. Heinz Spilling	Power plant and utility consultants; built sophisticated rice-husk burning power plant.

THAILAND

W146	Amorn Chai Co., Ltd. 295/26 Suriwong Road BANGKOK	Mr. Kamchai Iamsuri	Rice miller-designer, user of husk-fired boilers for motive power, process steam.
W147	Department of Science Ministry of Industry Rama VI Street, Payathai BANGKOK 3	Mr. Vichien Sakornmonkol M.S., Dir. Res. Div. Mr. Anuchit Kijswasdi Chief, Res. Div Mr. Anuchitta Gisswadhi Res. Div. Miss Tweelak Boonkong Librarian	Research and development on rice-husk cement sodium silicate, activated carbon; National Library.
W148	Huay Nam Boiler Factory 164 Ma Kua Lane, Wat Phya Krai Yannava District BANGKOK 12	Mr. Kitti Thiranonda	Husk-fired boiler manufacture (Cornish type).
W149	Kwang Thai Seng Factory 216 Talad Lwang Bang-rak BANGKOK	Ms. Khun Pornphun Viri Yayonthr	Builder of steam engines. Complete rice mills.
W150	Lee Yung Cheing Factory Opposite of Wat Pratum Talad Noi BANGKOK		Builder of steam engines and boilers. Complete rice mills.

W151	C.A.E. Nana & Son 3 Sukumvit Soi 13 BANGKOK 11	Mr. M.C. Nana Mr. E.C. Nana	Millers and developers. Interested in rice husk utilization
W152	Sathorn Works Co. Ltd. 124/10 Soi Rewadi Tiwanond Road NONDTHABURI	Mr. Bamrung Sathorn Managing Director	Steam-heat exchanger dryers, rice milling machinery, pellet mills.
W153	Technological Research Inst. Applied Scientific Research Corporation of Thailand 196 Phaholyothin Road BANGKOK	Dr. Kasem Balajiva Research Director	Research organization. Experience in energy-related utilization of rice husk and residues.

UNITED KINGDOM

W154	Belliss & Morcom Manufacturing Limited Icknield Square BIRMINGHAM B16 OOL	Mr. C.S. Shephard Engineering Dept.	Manufacturer of V-type compound steam engines. 130 HP (100 kw) to 670 HP (500 kw).
W155	The British Library Science Reference Library 25 Southampton Buildings Chancery Lane LONDON WC2A 1AW		National Reference Library.
W156	A.J. Brockwell & Partners 21 Thornbury Rise DARLINGTON, DL3 9NE	Mr. A.J. Brockwell	Consultants - Producer-gas generator, design and construction
W157	Davy Powergas Ltd. 8 Baker Street LONDON W1M 1DA	Mr. Ian Nichols	Interested in gas producers.
W158	Lewis C. Grant Ltd. East Quality Street Dysart, Kirkcaldy Fife KY1 2UA SCOTLAND	Mr. R.M. Storie	Manufacturers of rice milling machinery, grain dryers.
W159	Ron Hawkey Partners P.O. Box 429, HOVE Sussex BN3 4PY	Mr. Ron Hawkey	Consultant, rice milling and construction of rice mills. Experience in husk-fired steam operations.
W160	Neil & Spencer Limited Station Road LEATHERHEAD, Surrey	Mr. J.P. Spencer Mr. J.J. Boex	Builder of producer-gas generators.
W161	Tropical Products Institute CULHAM, Abingdon, Berkshire	Dr. A.E. Chittenden Mr. A.R. Paddon	Research and development on cellulosic materials - producer-gas generators, steam production, all facets of rice husk utilizatior

UNITED STATES OF AMERICA

W162	Agnew Environmental Products P.O. Box 1168 GRANTS PASS, OR. 97526	Mr. Larry Sullivan	Manufacture and sales - furnaces, briquetter.
W163	Aerojet Energy Conversion Company P.O. Box 13222 SACRAMENTO, CA. 95813	Mr. Eugene M. Vanderwall Mr. Roy E. Jones, Jr. Project Manager Waste Mgmt Systems	Fluid-bed liquid waste dryer, chemical equilibrium work, advanced heat exchangers.
W164	Aerojet Liquid Rocket Co. P.O. Box 13222 SACRAMENTO, CA. 95813	Mr. Rudi Beichel Senior Scientist	Interested in advanced combustion-fluid bed incinerators-husk utilization.
W165	Babcock & Wilcox Company Power Generation Group One California Street SAN FRANCISCO, CA. 94111	Mr. Dennis E. Gregor Industrial Boilers Sls. Mr. L.A. Vais, Manager Gen. & Mech.Const.Ser.	Boiler manufacturers, power plant builders.
W166	Barbour Stockwell Company 300 Third Street CAMBRIDGE, MASS. 02142	Mr. Winthrop B. Coffin Vice President	Turbines - 1 1/2" to 20" dia. to 150,000 RPM, 1/4 HP to 550 HP.
W167	Battelle Columbus Laboratories 505 King Avenue COLUMBUS, OH 43201	Mr. C.N. Ifeadi	Research concerning energy from residuals.
W168	Copeland Process Corp. Oak Brook Prof. Building 120 Oak Brook Mall OAK BROOK, ILL. 60521		Fluid-bed furnaces.
W169	Carling Turbine Blower Co. 8 Nebraska Street WORCESTER, MASS. 01604	Mr. A.R. Carlson President	Steam turbines.
W170	Center for Housing, Building and Planning United Nations GCPO Box 20 NEW YORK, N.Y. 10017	Mr. E. Paul Mwaluko, Director	Interested in rice-husk ash as a building material - process to produce it.
W171	Combustion Power Co. MENLO PARK, CA.	Mr. R. Chapman	Developmental work - gas turbine power plant.
W172	Coppus Engineering Corp. WORCHESTER, MASS. 01613		40 to 700 HP, single-stage horizontal and vertical turbines.
W173	Deltak Corporation 6950 Wayzata Blvd. MINEAPOLIS, MINN. 55426	Mr. Dennis L. Swanda Vice President	Waste heat boilers of all types.

W174	Dow Chemical U.S.A. 2800 Mitchell Drive WALNUT CREEK, CA. 94598	Mr. Barrie H. Bieler Scientist	Rice-husk related research.
W175	Elliott Company General Offices HEANNETTE, PA. 15644		Small,medium and large turbines and turbo-generator, 1 to 10,000 HP
W176	The Flintkote Company Calaveras Cement Div. 8750 Wonderland Road REDDING, CA. 96001	Mr. Bill Siemering	User of rice husk as an energy and silica source in the manufacture of Portland cement.
W177	FMC Corporation 1450 Coleman Street P.O. Box 1178 SAN JOSE, CA. 95108	Mr. Frank Hickey	Parboiling specialists.
W178	Engineering Experiment Sta. Georgia Institute of Tech. ATLANTA, GA. 30332	Prof. W.H. Burrows, Head, Special Projects Dr. John W. Tatom, Principal Engineer Dr. Howard G. Dean Jr.	Research and development on pyrolysis.
W179	Garrett Research and Development Company, Inc. 1855 Carrion Road LA VERNE, CA. 91750	Mr. George M. Mallan Dir., Resource & Recovery Programs	Operates pilot plant - developed process for pyrolytic production of char and oil.
W180	General Electric Company Power Generation Division 55 Hawthorne St. P.O. Box 3736 SAN FRANCISCO, CA. 94119	Mr. D.E. Cecich Sales Engineer	Turbine generation systems. Large and super large turbo generation systems to 1,500,000 kw.
W181	Mr. Ward N. Harris RFD #2, Box 205 STUTTGART, ARK. 72160		Consultant - rice husk.
W182	Hawaiian Agronomics P.O. Box 3470 HONOLULU, HI. 96801	Mr. Wm. G. Golden Mr. Rayburn E. Parker	
W183	David F. Houston 223 Behrens Street EL CERRITO, CAL. 94530		Retired Western Regional Research Laboratory worker, author of Rice Chemistry and Technology.
W184	J.B. Hunt Company P.O. Box 9 STUTTGART, ARK. 72160	Mr. John B. Hunt President	Supplier of rice husk for all types of users.
W185	Industrial Materials Co. 2921 Leonis Blvd. LOS ANGELES, CA. 90058	Mr. Norman Pitt, Pres. Mr. Webb L. Nimick, Gen. Mgr.	Producers of finely ground chars usable for acid-resistant concrete and rubber reinforcing.

W186	Kansas State University Dept. of Grain Science & Industry MANHATTAN, KS. 66506	Mr. Ulysses A. Acasio	Research and development of husk-fired dryers.
W187	E. Keller Company 238 West Street WILLIAMSPORT, PA. 17701	Mr. Robert E. Lantz	Boiler manufacture - water and smoke tube.
W188	Kewanee Boiler Corp. 101 Franklin Street KEWANEE, ILL. 61443	Mr. G.L. Kasparian	Design information; supplier of boilers and stokers.
W189	League for International Food Education 1155 - 16th St. N.W. WASHINGTON, D.C. 20036	Dr. J. Ritchie Cowan President	A consortium of eight technical societies formed to help solve the world food and nutrition problems through education.
W190	James Leffel & Co. SPRINGFIELD, OH. 45501		Scotch boilers - underfeed stokers.
W191	The Library of Congress Reference Department Science & Tech. Div. WASHINGTON, D.C. 20540		Research Library.
W192	Liquid Processing Systems, Inc. 640 -143rd Avenue SAN LEANDRO, CA. 94578	Mr. Harvey Finch	Patent holder on char product process - interested in heat recovery and utilization, especially for water purification.
W193	The Department of Chemistry Louisiana State University BATON ROUGE, LA. 70803	Prof. Harlon O. Traylor Mr. Reid M. Grigsby	
W194	McBurney Stoker & Equipment Co., Inc. P.O. Drawer 47848 ATLANTA, GA. 30340	Mr. W.B. McBurney	Stokers and husk-fired power plants.
W195	Michigan State University Agricultural Engineering Dept. EAST LANSING, MI. 48823	Dr. B.A. Stout, Chmn.	Interested in energy implications of rice husk.
W196	M&M World Marketing Inc. Hispania Towers 7330 Northwest 12th Street MIAMI, FLA. 33126	Mr. G.E. Mustelier, Jr.	Rice-husk power complexes.
W197	Nathan Manufacturing Div. Wegner Machinery Corp. 35-41 Eleventh Street LONG ISLAND CITY 6, N.Y.	Mr. Jack N. Swendsen Manager	Series of very small and small turbines.

W198	The Quaker Oats Company Merchandise Mart Plaza CHICAGO, ILL. 60654	Mr. Leonard Stieger V. Pres.-Chemicals	Furfural production from rice-husk residue and production of steam.
W199	Resource Recovery Systems Barber Colman Co. IRVINE, CA.	Mr. T.H. Crane Sr. Prog. Engineer	Pyrolysis development, chemical recovery.
W200	Rice Growers Assn. of Ca. P.O. Box 958 SACRAMENTO, CA. 95803	Mr. Robert R. Mickus Research Director	Rice hull producer - research and development.
W201	Rice Journal Enterprises P.O. Box 14260 WASHINGTON, D.C. 20004	Mr. Carlisle B. Morrison Editor Mr. Gordon S. Carlson, Pub.	The Rice Journal magazine
W202	The Rice Millers Assoc. 1048 Pennsylvania Building WASHINGTON, D.C. 20004	Mr. J. Stephen Gabbert Executive V. Pres.	United States Millers' organization.
W203	Riviana Foods, Inc. P.O. Box 2636 HOUSTON, TX. 77001	Dr. John W. Hunnell	Rice milling and processing - fundamental interest in rice husk utilization.
W204	Stanford Research Institute 333 Ravenswood Avenue MENLO PARK, CA. 94025	Mr. F. Michael Lewis Sr. Mech. Eng.	Research on pyrolysis and gasification. Development work on char for rubber compounding.
W205	Skinner Engine Company ERIE, PA. 16512	Mr. R. Dennis Whiting	Steam turbines.
W206	Terry Corporation P.O. Box 1200 HARTFORD, CONN. 06101	Mr. Peter R. James	A complete line of turbines.
W207	Tillo Products Co. P.O. Box 34165 SAN FRANCISCO, CA. 94134	Mr. D.G. Westerbeke	Commercial utilization of husk as sewage sludge dispersant.
W208	Turbodyne Corporation Steam Turbine Division WELLSVILLE, N.Y. 14895	Mr. Gordon M. Grantier	Worthington turbines. A full line of turbines.
W209	Uncle Ben's Foods P.O. Box 1752 HOUSTON, TX. 77001	Mr. K.K. Keneaster Dir. Tech. Services	Rice milling and processing firm. Interested in all facets of husk utilization.
W210	Southern Regional Research Laboratory Agricultural Research Ser. United States Dept. of Ag. 1100 Robert E. Lee Blvd. NEW ORLEANS, LA. 70124	Mr. James J. Spadaro	National laboratory - research and development work on rice husk.

W211	Western Regional Research Laboratory Agricultural Research Ser. United States Dept. of Ag. 800 Buchanan Street ALBANY, CA. 94710	Dr. Arthur I. Morgan Jr. Director Mr. R.M. Saunders, Proj. Leader Mr. Robert L. Roberts, Technologist	National laboratory - research and development work on rice husk.
W212	National Agricultural Library U.S. Dept. of Agriculture BELTSVILLE, MD. 20705		National library.
W213	U.S. Dept. of Commerce National Technical Info. Ser. SPRINGFIELD, VA. 22151		National information service.
W214	U.S. Energy Research & Development Administration 1016 16th Street, N.W. WASHINGTON, D.C. 20545	Mr. John Tosh	Energy implications of rice husk for energy programs.
W215	Pacific Northwest Environmental Research Lab. U.S. Environmental Pro. Agency CORVALLIS, OR. 97330	Dr. H. Kirk Willard	Garrett pyrolysis project.
W216	Solid & Hazardous Waste Research Laboratory U.S. National Environmental Research Center CINCINNATI, OH. 45268	Mr. Robert L. Stenburg, Director	EPA function concerning rice husk.
W217	Dept. of Chemical Engineering University of California BERKELEY, CA. 94720	Prof. Scott Lynn	Development of production of silicon tetrachloride from rice husk.
W218	Dept. of Civil Engineering University of California 537 Davis Hall BERKELEY, CA. 94720	Dr. P.K. Mehta Assoc. Prof. Eng. Sci.	Inventor of process to produce cement from rice-husk ash and char.
W219	Dept. of Agricultural Eng. University of California DAVIS, CA. 95616	Dr. Brian Horsfield Asst. Prof.	Gas producers - designed and built a test suction gas-producer for use on renewable agricultural fuels - producer design - gasification theory - economic factors.
W220	College of Engineering The University of Utah SALT LAKE CITY, UT. 84112	Dr. Ivan B. Cutler, Prof.	Inventor of process to produce silicon carbide and silicon nitride from rice husk. Consultant on production of silicon nitride from rice husk.

W221	The University of Toledo 2801 W. Bancroft Street TOLEDO, OH. 43606	Dr. Wilhelm Eitel	Basic silica research.
W222	URS Research Company 155 Bovet Road SAN MATEO, CA. 94402	Mr. Milton Staackman Sr. Chem. Engr. Mr. Thomas C. Goodale	Research company - did 1970 USDA report on rice husk utilization.
W223	Wallace-Atkins Oil Corp. 2001 Kirby Dr., Suite 906 HOUSTON, TX. 77019		A holder of process for production of char and oil from rice husk.
W224	Eldon C. Beagle P.O. Box 874 WEST SACRAMENTO, CA. 95691		Consultant, rice husk utilization.

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