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Benefits Of Improved Rice Husk Combustion, Bangladesh

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Executive Summary

Introduction: This project is funded by the Knowledge and Research Programme of the Department for International Development, UK. The project duration was from September 2000 to December 2003. The project goal is to achieve more efficient supply, conversion and use of energy. The project purpose is improved conversion efficiency of rice husk utilisation, with particular focus on small rural mills in Bangladesh. Rice husk is a biomass fuel used widely in South and South-East Asia.

Importance of biomass fuel: Two billion of the worlds poor do not have access to a clean and efficient supply of energy (UNDP, 2003). These communities are reliant on biomass fuel. They use primitive and inefficient technology. This combined with poor work practices at home and in the small, agro-processing units can lead to waste of resources, pollution of air, contamination of soil and water. These factors have direct and indirect negative impacts on health.

In Bangladesh, 64% of the total energy supply is derived from biomass. This energy is obtained from various biomass sources of which rice husk is the largest (22%) single category. Hence, dedicated efforts to promote the optimal use of rice husk seemed appropriate in Bangladesh.

Use of rice husk in Bangladesh: Relevant to this research are (i) the different ways paddy is processed and the types of husk produced; (ii) uses of husk as a by-product; and (iii) the disposal of rice husk ash.
(i) Bangladesh produces on an average 28 million tonnes of paddy per year, giving approximately 6 million tonnes of rice husk. Paddy processing in Bangladesh takes two forms. 10% of the rice produced is dry hulled, while the 90% is parboiled and then hulled predominantly in small rice mills. The rice husk and bran mixture, a by-product of rice hulling, is used as a fuel to generate steam to parboil the paddy. All regions in Bangladesh, except in the eastern districts, parboil the paddy. **The focus of this research is on rice-husk from parboiled paddy processed in small scale mills**. The parboiling in small mills is done with primitive equipment and a majority of furnaces operate at low levels of efficiency (around 20%). This leads to considerable wastage of the bran and husk mixture. The husk and bran, separately and together, constitute essential inputs in animal and poultry feed. Supported by government, poultry rearing and livestock husbandry are expanding rural activities, particularly for the poor. However, the prices of the bran and husk inputs to animal and poultry feed have been rising.

(ii) In Sylhet and Chittagong, where the rice is dry processed, husk is made into briquettes, which is a cheap, clean fuel. Poor households and small food retailing units in these districts have shifted to using briquettes from firewood. These briquettes are made by a screw extrusion process, where the screw has a life of eight hours. Only a small amount of husk from parboiled rice is used for briquetting. The husk from parboiled paddy is more abrasive than husk from dry processed paddy. Consequently, the wear and tear of the screw used in the extrusion process is higher, giving a screw life of about three hours, which is not cost effective.

(iii) As most of the husk is used for parboiling paddy, disposal of husk ash rather than husk itself is a problem in Bangladesh. Parboiling rice mills throughout Bangladesh dump the ash from the furnace on the surrounding agricultural land and in water bodies. However, there is evidence that rice husk ash (RHA) has alternative value-added uses.

Project Objectives

The project objectives are to:

1 improve furnace design and increase combustion efficiency by at least 15% to save the husk and bran mixture used in small-scale operations for rice processing for increased provision of poultry and animal feeds;

2 identify ways to enhance the use of husk from parboiled rice in briquetting;

3 assess alternative utilisation of rice husk ash; and

4 assess the socio-economic impacts of improved utilisation of husk and create a dissemination plan for the findings of the project.

Methodology

Clearly, each objective/component has its own specific methodology. Here is a brief overview of project activities. The overall approach to research was to gather detailed baseline information for all components and then build on it. This meant that there were roughly three phases of project activities. The first phase undertook in-depth baseline studies in the areas defined by the four objectives. These studies were conducted in nine districts which were identified to have major clusters of rice mills. These studies informed the second phase that involved more in-depth field investigations, design improvements and the assessment of appropriate research strategies to achieve project objectives. The third phase undertook trials and tests of the improved technologies; assessed the alternative use of rice husk ash in India, where it is extensively used as construction material; and disseminated project findings in Bangladesh and a third country, Vietnam.

Findings and Outcomes

Improving Rice Husk Combustion Efficiency

Findings: Though there are some variations in furnace-boiler production capacity, there are three basic boiler configurations found in this sector. The configurations are: (a) Semi-cylindrical with flat bottom; (b) Cylindrical; and (c) Rectangular boxes.

However, a common characteristic is fabrication in small, local workshops from low-grade scrap sheet metal. The materials used are of variable quality. The designs of boilers are dependent on the preferences of the local technicians, or *mistris* as they are called. The rectangular box boilers are being increasingly phased out by their owners. This study focuses on configurations (a) and (b).

The main observations of the traditional furnace-boiler system are:

- Much of the heat loss from the furnace is from the large fuel inlet port; several openings on the side walls, and a large port for removing ash.
- High levels of flue gas exit from all ports and openings that carry away a large amount of heat. This also results in high temperature at working level.
- The design of the furnace is such that the required amount of air for complete combustion of husk is not available.

- This insufficient supply of air and consequent build up of carbon monoxide pressure in the furnace cause it to back fire from the fuel inlet port. This makes for hazardous working conditions for the person feeding the furnace manually;
- The thick black smoke of the flue gas indicates the inadequate air supply to the furnace;
- No O_2 was detected when analyzing the flue gas using "FEM" instrument;
- Rice bran is added with rice husk to enhance and sustain the fire;
- A large level of CO (> 10,000ppm) is present in the flue gas, which is much higher than the norms given in the required air quality measure;
- There is no instrumentation in the system to monitor the pressure/temperature/water levels etc.;
- There is no safety valve to avoid any untoward accidents;
- As there is no water level indicator the water is filled randomly, generally more than what is required. This also results in inefficient utilization of the rice husk;
- Rice husk consumption varies with furnace efficiency and the parboiling process used -partial or full parboiling of paddy;
- While the furnace is in operation, ash is removed at an interval of every two hours. The ash contains a substantial amount of heat and un-burnt rice husk;
- Steam is drawn at a low pressure about $0.5kg/cm^2$, which leads to a long processing time. The consumption of rice husk is positively correlated to the time required for parboiling;
- The heat absorption area provided is not adequate. Major portion of the vessel is exposed to atmosphere;
- The steam consumption rate shows a wide range - 150kg/hr to 650kg/hr. However, two distinct user group clusters are found at the lower and upper ends of the range; and
- The current cost of constructing a furnace-boiler unit falls between Taka (Tk) 96,000 to Tk 100,000.

Outcomes: The improved furnace design has increased the furnace efficiency by 22% as against the project objective of 15%. This brings the average efficiency of the new furnace to 44% as against the average efficiency of 20% found in furnaces being operated in rice mills. According to the Specific Fuel Consumption rate the rice husk savings are in the range of 44% to 54%, giving an average savings of 49%. The boiler has been made safe and emissions brought down to acceptable levels. The cost of the improved furnace-boiler unit is Taka 64,000 compared to the current cost of TK 96,000.

A model designated Mark 0 was built and used for trial runs and field testing. Feedback from the owner and technician where the demonstration unit is based was used to fine-tune the design. As two distinct user groups, in terms of production capacity and steam demand were identified, two models (Mark 1 and Mark 2) have been developed to cater to these two groups. Drawings have been provided as a basis for constructing the furnace with or without the grate. Additionally, information has also been made available for the construction of the chimney at the ground level, as per user demand.

Steam, used at the higher pressure of $1.0kg/cm^2$, reduces the processing time. However, this could lead to lower demand for labour unless the owner increases the daily production. The new furnace is designed to be constructed with material traditionally used. The local technicians can be easily trained to operate the new system as the field trials have demonstrated.

Improvements for Briquetting Rice Husk from Parboiled Rice

Findings: The conversion of biomass materials into a densified, solid product is not a new technology, though it appeared in Bangladesh only about 10 years ago. However, only a marginal amount of husk of parboiled rice is made into briquettes. The baseline survey made by this project showed that briquette making is technically sound and economically feasible. This study therefore, made no attempt to alter the overall production processes.

The main focus of this component was to improve the screw life for making briquettes with husk of parboiled rice; and to reduce the energy loss during the production process.

Outcomes: The new improved screw for this project was made with hot die steel with a tungsten carbide tip. The traditional screw is made with mild steel and hard-faced with hard craft arc rod. The length of the traditional screw is 496 mm, shaft diameter at top end is 35 mm and falls to 21 mm at the narrower end, the number of threads is seven. These dimensions were used to make the new screw.

The improved screw was used to run trials. A local factory producing briquettes was identified and performance comparison was made. It reveals that briquette production with the new screw is significantly more consistent than with the traditional screw.

Briquettes were successfully produced for 16 hours with the new screw. They were of good quality for up to 16 hours, after which the briquettes were more fragile and broke into small pieces. In comparison, production of briquette (using husk from dry processed paddy) with traditional screw is limited to 8.5 hours. The quality assessment showed that the crushing load of briquettes produced with the new screw is consistently higher, even though there is a slightly higher variation in density than for briquettes produced in commercial units.

The energy consumption was reduced by 26% by maintaining the die-barrel temperature at the optimum range of 280^0C to 290^0C, instead of at 350^0C-400^0C as is generally the practice in commercial units.

The prototype cost of the new screw is about 3.5 times the cost of the screw currently used. Commercial production is expected to reduce its price. However, there will be an increased profitability of Tk 3 per hour if only the new screw is used. Additional savings from electricity would raise the profit rate to Tk 7.57 per hour.

It is pertinent to note that these cost comparisons are with units processing husk from dry processed rice and operating with a screw life of eight hours. This traditional screw can only be used for three hours if using husk from parboiled rice. The operating costs of briquetting husk from parboiled paddy with the improved screw not only compare favourably with current units; it could open up a new area of enterprise even more profitable than the latter.

Alternative uses of Rice Husk Ash

Findings: In Bangladesh, 1.2 million tonnes of rice husk ash is produced annually. Although many alternative uses of RHA have been developed in the last few decades; such as use of RHA as a component of clay brick, firebrick, hollow brick, sandcrete and concrete etc., these applications have not yet been tried in Bangladesh. This study examined some of these applications, given that RHA is known to be a pozzolana and to contain over 95% of silica, a major constituent of Ordinary Portland Cement (OPC). The use of RHA as a component of construction material would considerably reduce the environmental impact.

However, before any applications can be recommended the pozzolanic characteristics of the ash in Bangladesh had to be determined. If the ash did possess pozzolanic properties, then the load bearing capacities of RHA-OPC blocks had to be determined. These tests constituted the main activities of this component.

Outcomes: The first set of tests indicated that the RHA possesses a spectrum of suitable physico-chemical properties such as: high surface area, good purity, and low crystallinity, hence, easy to pulverise. Additionally, it is a low cost raw material. These properties suggested that it could be used as a blending component in cement to replace the OPC by a certain percentage and in clay-RHA bricks.

Compressive strength tests of OPC-RHA blocks of 90% OPC and 10% with pulverised RHA obtained from new furnace indicate satisfactory compressive strength; thus permitting its use in medium load construction.

Potential Socio-Economic Benefits of this Project

Clearly considerable economic benefits will accrue to the owners if they adopt the new furnace design and follow the operating instructions. However, it is unlikely that the owners will share the increased profit with the workers. Improvements in the working conditions, a safer and less hazardous work environment, will be a considerable improvement for these lowly paid, vulnerable workers with no bargaining power. The situation of women workers, who make up 50% of employees in this sector, is particularly harsh. These improvements in working conditions would be particularly significant to the women workers who are tied by derisory wage relations.

The indirect beneficiaries, among others, will be small scale poultry units and households involved in poultry rearing. With the release of considerable amount of rice husk and bran in the market, it is expected to increase their local availability.

Briquettes where available, are popular among poor households and small food retailing units. Mills parboiling rice is widespread in Bangladesh. Even if half the amount of husk released by improved technology is used for making briquettes using the improved screw, the availability of a cheap, clean fuel would have substantial geographical spread. The production of briquettes would also generate new job opportunities for low income workers and give a boost to this sector of rural enterprise.

Alternative use of rice husk ash will go towards addressing the environmental problems in the rural areas.

Dissemination Activities Undertaken

Two sets of dissemination activities have been undertaken. These are:

1 Two-day national workshop in Dhaka. The first day targeted the user groups and they were taken to see the demonstration unit in operation. Very positive technical feedback was received which has been incorporated in furnace design and in the dissemination plan outlined in Chapter 7. The participants for the second day covered a wider group of government officials, researchers and NGOs, among others. The main outcome was that, given the large potential benefits of uptake, dissemination of the project outcomes was essential.

2 The dissemination visit to Vietnam showed the highly inefficient use of rice husk in households and in small agro-processing units drying fruits and other produce. The husk is burnt loose which is inefficient and polluting. This is particularly harmful when undertaken in closed environment; i.e., in households. Briquetting of rice husk has not been introduced in Vietnam. Considerable gains can be achieved in term of improved combustion efficiency; reduced health impact; and the production of better quality fruits if the husk is made into briquettes. NRI would look for funding to follow up on these needs for applied research and subsequent dissemination for improving the conversion efficiency of rice husk.

Strategies to Promote Uptake

Issues that have to be addressed

There are policy issues at the national level and social-attitudinal aspects at the sectoral level that have to be addressed in the strategies to promote the uptake of project outcomes. These are:

At the National level, the small scale rice mill sector is in a legal vacuum.

- Because of its rural location it is not recognised as part of the Small Industries Sector. This excludes the mill owners from subsidised credit. This has implications for developing any participatory financing schemes to promote uptake of improved furnace.
- The Inspectorate of Boilers still operates under regulations passed in 1923. It has made little attempt to develop standards for boilers with lower capacities used in small rice mills. The absence of safety standards for this sector means that there are no technical benchmarks on which official recognition can be given to improved and/or new technology for this sector. Without official recognition, the improvements cannot be made obligatory. Perhaps, some resources need to be allocated for updating this organisation.
- Department of Environment has not set any specified environmental standards for small scale rice mills. Consequently, the Department of Food applies the standards set for the brick kiln industry, which is much more polluting as it uses more polluting fuels. The chimney stack of a rice mill must be at least 30 feet (appropriate for the brick kiln) for the mill to qualify as a supplier of grain to the government. This again has implications for promoting the new furnace; it is cleaner and requires a shorter stack. This also helps to keep the overall cost of construction down.

At the sectoral level

- Levels of educational achievements among owners and operators are very low. They have little technical knowledge and are totally reliant on their technicians. It would therefore, be important to involve the technicians from the start in running field tests and in any dissemination activity that may be undertaken.
- Demonstration effect among the user group is strong. This implies the need for further dissemination units in large clusters to maximise its impact.
- In promoting the uptake of the new screw design for briquettes, the main limitation is the higher cost of the screw. Hence, it will essential to convince the entrepreneurs (current and potential) of the overall profitability of the new, improved screw during dissemination.

Dissemination Strategies

This project has three sets of project outcomes to promote. These relate to

1. Improved design for furnace and boiler for small scale, parboiling rice mills.
2. Improved screw design for making briquettes from husk of parboiled rice.
3. Use of rice husk ash in low to medium strength construction.

There are two countries where these are to be disseminated, Bangladesh and Vietnam. (India is not targeted for dissemination activities. Small scale rice milling using Engleberg hullers has been banned for the last forty years as it damages the grain and produces a high percentage of broken rice. Rice milling in India is essentially large scale and produces bran and husk as separate streams, which are then sold for animal and poultry feed and/or for making briquettes).

The dissemination plan has therefore three components.

These are:

A. Strategies to promote the improved furnace-boiler system and improved screw design for briquette making in Bangladesh.

Given the implications for dissemination identified in this project, the strategy to promote the uptake of improved technologies in parboiling rice and in briquette making would be two pronged (Fig. 7.1). One would be *direct action*, jointly with other stakeholders, at cluster level to promote the technological improvements; and the other would be *activities to affect institutional changes* that are necessary to facilitate uptake. The two sets of action are interdependent. The success of the second activity will affect the overall success of the first set of activities

B. It is proposed that field tests of rice husk ash used in combination with clay and cement is carried out in Bangladesh so that specifications can be developed for the industry. The specifications have to be developed in collaboration with industry and with some of the major providers of rural infrastructure like the Local Government Engineering Division.

C. Strategy to disseminate the production of, and use of, rice husk briquettes in Vietnam.

This would involve setting up a pilot unit producing briquettes and helping a targeted number of small units to redesign their combustion and fruit drying systems. At the household level, it would mean identifying an existing design of stove that could use briquettes. The project has to work through, and with, the commune leaders. They are still very influential. It is believed that, if the commune leaders can be convinced of the benefits of the project, dissemination will be facilitated by them. Wider dissemination in-country can be based on the outcomes of the pilot phase.

Conclusions

A great number of people in South and South-East Asia rely on the use of rice husk as an important source of fuel. However, its use is inefficient, with detrimental effects on the health of users and workers involved. This wasteful use continues largely because they do not have access to relatively simple and cheap technology that has already been developed and that can increase the conversion efficiency of rice husk and make more productive use of husk. The focus of donor agencies should be on disseminating such technology for improved use of biomass. This becomes all the more important as national governments in this region increasingly recognise the difficulties of reaching all the rural poor through the national electricity grid system.

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Glossary

ACC	Average Coefficient Value
ASTM	American Society for Testing and Materials
BRRI	Bangladesh Rice Research Institute
BS	British Standards
CBRI	Central Building Research Institute, Roorkei, India
CHS	Calcium Hydrate Silicate
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CORIFA	A Profile of Country Rice Facts
DFID	Department for International Development, UK
FAO	Food and Agricultural Organisation
FEM	Flue Gas Emission Analyser
FT-IR	Fourier Transform-Infra Red
GDP	Gross Domestic Product
IS	Indian Standard
MS	Mild Steel
NO_X	Nitrous Oxide
NRI	Natural Resources Institute
O_2	Oxygen

OPC	Ordinary Portland Cement
RHA	Rice Husk Ash
RWED	Regional Wood Energy Development Programme
SEM	Scanning Electronic Microscope
SFC	Specific Fuel Consumption
TERI	The Energy and Resources Institute
TGA	Thermogravimetric Analysis
TK	Taka – Bangladeshi Currency
TSP	Total Suspended Particles
UKQAA	United Kingdom Quality Ash Association
UNDP	United Nations Development Programme
XRD	X-Ray Diffraction

Note

1 Maund= 37.5 Kg

£1= Taka 80 (2001)

£1= Taka 109 (2003)

1 Introduction

1.1 Introduction

This project is funded by the Knowledge and Research Programme of the Department for International Development, UK. The project duration was from September 2000 to December 2003. The project goal is to achieve more efficient supply, conversion and use of energy. The project purpose is improved conversion efficiency of rice husk utilisation, with particular focus on small rural mills in Bangladesh. Rice husk is a biomass fuel used widely in South and South-East Asia.

1.2 Context and Rationale

Importance of biomass fuel: Two billion of the worlds poor do not have access to clean and efficient supply of energy (UNDP, 2003). These communities are reliant on biomass fuel. They use primitive and inefficient technology. This combined with poor work practices at home and in the small, agro-processing units can lead to waste of resources, pollution of air, contamination of soil and water. These factors have direct and indirect negative impacts on health.

Equally important is the trend over the last decade where national governments have increasingly acknowledged that it is not cost effective to supply electricity to the more remote and inaccessible areas of the country. For example, the Government of Vietnam has noted that alternative sources of power would be promoted in such areas; these include micro-hydro power and more efficient use of biomass fuels.

In Bangladesh, with very limited supply of clean energy, biomass fuels are important in all regions and account for 64% of the total energy supply (Baqui: 1996). Agricultural biomass is derived from rice husk (22%); cow dung (20%); rice straw (16%); and lesser amounts of jute straw, bagasse, firewood, twigs, leaves and other materials (Bangladesh Bureau of Statistics: 1995). Research into enhancing the efficiency of use of rice husk and its by-products has been under-funded. As the largest single category amongst biomass fuels in Bangladesh, dedicated efforts to promote the optimal use of rice husk seemed appropriate.

Importance of rice husk in Bangladesh: Relevant to this research are (i) the different ways paddy is processed and the types of husk produced; (ii) uses of husk as a by-product; and (iii) the disposal of rice husk ash.

1. Bangladesh produces on an average 28 million tonnes of paddy per year, giving approximately 6 million tonnes of rice husk. Paddy processing in Bangladesh takes two forms. 10% of the rice produced is dry hulled, while the 90% is parboiled and then hulled predominantly in small rice mills. To note briefly, parboiling involves soaking the paddy in water and then, in this wet state, steam processing it in large bins. Paddy is then dried and hulled. The rice husk and bran mixture, a by-product of rice hulling, is used as a fuel to generate steam to parboil the paddy. All regions in Bangladesh, except in the eastern districts, parboil the paddy. **The focus of this research is on rice-husk from parboiled paddy processed in small scale mills**.

Parboiling is done at predominantly small mills with primitive equipment and poor combustion creating heavy smoke emissions. Majority of furnaces operate at low levels of efficiency (around 20%) leading to husk and bran mixture being wasted. Furthermore, manual fuel feed mechanisms cause hazardous flashbacks to the person feeding the fuel to the furnace. With simple modifications to the furnace design it is possible to improve the safety conditions and to generate savings in rice husk and bran currently used as fuel. Saved husk can be made into briquettes, which is a cheap clean fuel. Such saving is important, more so because at present a majority of the rice mills do not separate husk from bran (a highly nutritious element). The husk and bran, separately and together, constitute essential inputs in animal and poultry feed. Supported by government, poultry rearing and livestock husbandry are expanding rural activities, particularly for the poor. However, the prices of bran and husk as inputs to animal and poultry feed have been rising.

2. The paddy in the eastern districts of Sylhet and Chittagong is dry hulled and the husk made into briquettes, which is a clean and efficient fuel. Poor households and small food retailing units in these districts have shifted to using briquettes from firewood. These briquettes are made by a screw extrusion process, where the screw has a life of eight hours. Only a small amount of husk from parboiled rice is used for briquetting. The husk from parboiled paddy is more abrasive than husk from dry processed paddy. Consequently, the wear and tear of the screw used in the extrusion process is higher, giving a screw life of about three hours, which is not cost effective.

3. 100 million tonnes of rice husk are produced in the world annually and its disposal poses a major problem to most rice growing countries. However, in Bangladesh as most of it is used for parboiling paddy, disposal of rice husk ash rather than husk itself is a problem. Parboiling rice mills throughout Bangladesh dump the ash from the furnace on the surrounding agricultural land and in water bodies. On the other hand, there is evidence that it has alternative value-added uses. However, any such alternative usage would depend on the amorphous and crystalline qualities of the rice husk ash in Bangladesh. No study has been undertaken to establish these properties of rice husk ash in Bangladesh.

1.3 Project Objectives and Outputs

The project objectives are to:

1 improve furnace design and increase combustion efficiency by at least 15% to save the husk and bran mixture used in small scale operations for rice processing for increased provision of poultry and animal feeds;

2 identify ways to enhance the use of husk from parboiled rice in briquetting;

3 assess alternative utilisation of rice husk ash; and

4 assess the socio-economic impacts of improved utilisation of husk and create a dissemination plan for the findings of the project.

The project outputs are as follows:

1. Demonstrated ability to save husk in small scale rice processing operations for increased provision of animal and poultry feed and for making briquettes.

2. Identified routes for production of briquettes from husk generated by milling of parboiled rice.
3. A study of socio-economic impact of improved utilisation of husk and creation of a dissemination plan for project findings.
4. Identified alternative value-added use of rice husk ash.

1.4 Principal Activities and Approach to Research

Clearly, each of the components has their own specific methodology. These will be detailed in the following chapters. Here is a brief overview of project activities. The overall approach to research was to gather detailed baseline information for all components and then build on it. This meant that there were roughly three phases of project activities. The first phase undertook in-depth baseline studies in the areas defined by the four objectives. These studies informed the second phase that involved more in-depth field investigations, design improvements and the assessments of appropriate research strategies to achieve project objectives. The third phase undertook trials and tests of the improved technologies; assessed the alternative use of rice husk ash in India, where it is extensively used as construction material; and disseminated project findings in Bangladesh and a third country, Vietnam. A brief description of each phase is provided here.

However, before these activities could be undertaken main rice processing areas and clusters of rice mills had to be identified. A scoping study identified large clusters of parboiling rice mill which were then visited by the team. These clusters were in the districts of Dhaka, Dinajpur, Gazipir, Jessore, Munshigang, Mymensingh, Pabna, Nawabgan and Naogaon (Map 2.1). The cluster around Dhaka was dominated by large mills, which have efficient modern production technology and hence not in the target group of this project. There was an equal share of large and small mills in the cluster at Dinajpur. The rest of the clusters contained only small scale mills. Nationally, there are nearly 6,500 small scale parboiling rice mills.

Mills dry processing rice are large-scale and found to be concentrated in the districts of Sylhet and Chittagong. The main areas of briquette production are coterminous. The predominance of dry hulled rice in the eastern region is attributed to local consumer preference.

Phase One : During November-December 2000, the project team from NRI visited Bangladesh to carry out the baseline studies in collaboration with Bangladesh Rice Research Institute (BRRI). The main activities were:

- Making arrangements for implementation of the project in Bangladesh through BRRI.
- Visiting all the clusters of small scale mills identified above and undertaking in-depth study of 35 small scale rice mills. The aims were to (i) collect socio-economic data on the small scale rice processing so as to assess the firm structure, profitability, financial capability to adopt new technology, and attitudinal or other constraints to change; and (ii) collect technical data to assess the design of current furnace-boiler systems, procedures employed and work practices.
- Visiting the Boiler Inspectorate in Dhaka to ascertain safety and legal issues relevant to the project.
- Determining procedures to be adopted for obtaining fuel-use data for the small scale parboiling operations, taking into account safety and legal requirements.

- Visiting Sylhet and Chittagong to make a technical assessment of the processes used in briquetting and to assess the profitability of these firms.
- Making arrangements for a BRRI scientist to visit the University of Greenwich to carry out chemical and crystallinity analyses on rice husk ash produced in the furnace of small scale rice processing mills in Bangladesh. This is fundamental to assessing the alternative uses of rice husk ash.
- In UK, undertaking a scoping study of major rice processing countries in South and South-East Asia to assess the potential for application of improved technology, as all projects funded by Knowledge and Research Programme are required to disseminate project findings in a third country. Vietnam was identified.

Phase Two: In this phase (2001 to end-2002) the work was broken down into the three components. Activities focused on:

- Assessment of the baseline studies to determine the areas where improvements were necessary;
- Undertaking a more detailed technical study of 17 rice mills.
- Visiting briquette producing units in different districts of Bangladesh to collect samples in order to assess quality and strength.
- Assessment of the ways by which improvements to furnace-boiler unit could be achieved while keeping in mind the factors of safety, working conditions and affordability.
- Undertaking design improvements to enhance rice husk combustion efficiency in rice mills.
- Determining the location for setting up an improved design furnace-boiler unit.
- Determining ways by which to make production of briquettes more cost effective.
- Carrying out tests in the University of Greenwich to determine the chemical and crystallinity characteristics of rice husk ash produced in Bangladesh. Tests were also conducted on these samples to determine the compressive strengths in different combination ratios with Portland cement.
- Setting out a plan for disseminating project findings in Bangladesh and Vietnam. This plan was informed by the constraints to uptake identified in Phase 1.
- Setting up contacts in Vietnam to arrange a dissemination visit.

Phase Three: In 2003 the project team focused on the following activities:

- Setting up an improved design furnace-boiler dissemination unit in a small scale rice processing mill.
- Running trials and testing the operation of this unit and addressing the teething problems.
- Testing the new design of the screw in the extrusion process for briquetting and discussing the scope of wider application with the owners of briquetting units.
- Following the completion of the tests on the characteristic of rice husk ash in Bangladesh, a visit was undertaken by a BRRI scientist to India to review the different applications of rice husk ash, with a view to identifying alternative uses in Bangladesh.
- Undertaking a dissemination visit to Hanoi, Vietnam in February 2003, where meetings and presentations by the project team had been set up with various institutions.

- Running a two-day national workshop in BRRI in June 2003. The first day targeted the mill owners and their technicians. They were invited from the clusters visited by the team in Phase I and taken to the demonstration unit to see it in operation. The second day focused on disseminating to the institutions, government officials, NGO, researchers and academics.
- Final activities involved developing a dissemination plan to identify further dissemination activities beyond the life of this project that could enhance uptake of project findings.

1.5 Plan of Report

The report is structured as follows.

Chapter 2 presents the background to this study. Based on secondary data, it first describes the rice milling sector to illustrate the characteristics of the sector and to establish the importance of small scale parboiling rice mills. No secondary data were available either on the socio-economic characteristics of the user group or on the attitudes to technological change among owners and operators of rice mills. This information was important to the design of the project methodology; for indicating the nature of technological improvements acceptable to user groups; for issues of affordability and for subsequent dissemination activities. Section 2.3, draws on the baseline survey carried out in Phase 1, to analyse these characteristics.

Chapter 3 first analyses the characteristics of the traditional furnace design and then demonstrates how the new design of furnace-boiler unit has increased combustion efficiency by more than the project objective; improved the working conditions of the workers and increased profitability of the owners. It also sets out the potentials and limitations for wider replications.

Chapter 4 focuses on enhancing the production of briquettes using husk from parboiled rice. It describes the current procedures used for briquette production, the difficulties of using husk of parboiled rice, and the improvements developed by this project to address these constraints.

Chapter 5 discusses the wider socio-economic benefits that could be generated by the rice husk and bran saved by improved combustion efficiency. It also shows that briquettes, where available, have become the poor man's fuel.

Chapter 6 initially set out the characteristics of the rice husk ash in Bangladesh. It then describes the current uses in other countries and identifies potential alternative uses in Bangladesh.

Chapter 7 describes the dissemination activities already undertaken and their outcomes and then outlines further dissemination activities that could potentially enhance uptake. Chapter 8 will conclude the report with recommendations and identify further research needs in biomass fuel use.

1.6 Research Team

This project is a collaborative effort between the Natural Resources Institute, UK, the Bangladesh Rice Research Institute and The Energy and Resources Institute (TERI), India. The project is lead by Dr

Nandini Dasgupta of NRI. BRRI is represented by Dr. Abdul Baqui, assisted by Mr Ahiduzzaman. Mr P. Raman, Mr Sunil Dhingra and Dr V.V. N. Kishore make up the team from TERI.

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2 Structure of the Rice Milling Sector and Socio-Economic Characteristics of Owners in Small Scale Mills

2.1 Introduction

Section 2.2 will describe the stages involved in rice milling and the structure of the sector in Bangladesh to establish the importance and predominance of the small scale rice mills. Section 2.3 will focus on analysing the characteristics of user groups and the implications for this study.

2.2 Rice Milling in Bangladesh

Rice production in Bangladesh has seen a steady growth (Fig 2.1) with 29.86 million tonnes of paddy being produced in 2000 (Department of Food, Government of Bangladesh: 2001). Innumerable varieties are grown in about one million small, scattered farms. The geographical distribution of rice production is extensive though rice milling tends to be concentrated in certain districts. The main districts have been highlighted in Map 2.1.

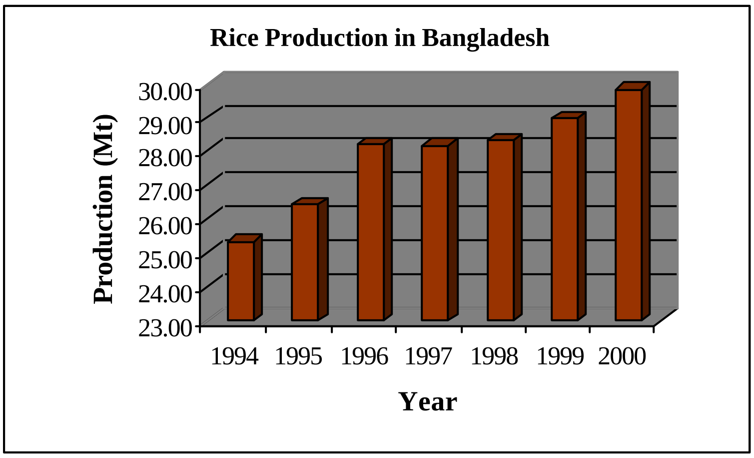


Fig 2.1 Growing Rice Production in Bangladesh

2.2.1 Description of Rice Milling

Rice milling is a generic term for various operations in the treatment of harvested, threshed and dried paddy in order to produce clean white or 'polished' rice kernels. Milling involves the following operations: removal of foreign matter from the harvested paddy, removal of the outer hulls, husk or shells from the dried paddy; and removal of the bran layer from the germ. A certain percentage of the grains are broken in the milling process.

Additional to these basic operations, in Bangladesh and some other countries, a parboiling step is included. Parboiling is a hydrothermal treatment of the paddy in which grain is soaked in water and steam treated in the wet state to gelatinise the grain starch. After this the grain is usually sun-dried, by spreading on drying floors, before proceeding with the basic milling operations of hulling and removal of bran as outlined above. Parboiling is claimed to have advantages over non-parboiled or dry processing in terms of yield and quality, as well as providing a product for which there is consumer preference.

Map No. 2.1 Indicating Districts with Main Clusters of Rice Mills

★ Districts with Main Clusters of Rice Mills and Areas of Field Study

Rice milling is carried out over a range of processing scales. Small rice mills can have a production of just a few tonnes or less per day. Some units hull and remove bran on the same machine, through which the grain may be passed several times. In contrast, a very large mill would produce 100 tonnes or more per day with multiple machines in line or in parallel at each stage of processing. However, in Bangladesh less than 20% of the rice is milled in large units. Overall milling is typified by a vast predominance of small mills (explained below). These small mills either process paddy for farmers and traders on a per-tonne cost basis or owners and mill operators buy the paddy and process it. This is then sold to the wholesalers.

There are different types of hulling machines: those that shear the hull between revolving rubber rollers; those that use compression-shear between rotating and stationary abrasive discs; and those which accelerate the grain to impact against a stationary target. The Engleberg huller is of the latter variety and is the most commonly used machine in Bangladesh, particularly in smaller mills. Maintenance of these machines can influence their performance in terms of hulling efficiency and level of broken grains. The maintenance is low in small units giving a substantial amount of broken rice which has then to be separated from the husk-bran mixture. Ironically, the market price for rice hulled by Engleberg hullers is at £ 0.77-0.92/20 Kg while those produced by rubber rolled hullers is £0.05- 0.75/20 Kg.

The hulling machines come in several capacities and are normally powered by electricity though they may be powered by other prime movers. For the smaller mills, the electricity consumption is in the region of 16 to 20 KWh per tonne of paddy (Rahman: 1988; Baqui: 1994). The power consumption in milling is primarily for hulling but it may include ancillary low powered items such as separators, cleaners or polishers.

Several variables in harvesting, processing and storage affect quality and yield of milled rice. In addition, certain constraints are imposed by the type of operating system and equipment utilised. Moisture content of the rice fed to the hulling machine is of great importance as it can affect the rate of breakage of rice grain. The recovery efficiency or yield of total rice (head and broken grain) from paddy varies from about 60% to 75%.Typical figures for the product yield from Engleberg hullers are: husk and bran 30%, head grain 46.5% and broken grain 16.9 % (Survey data).

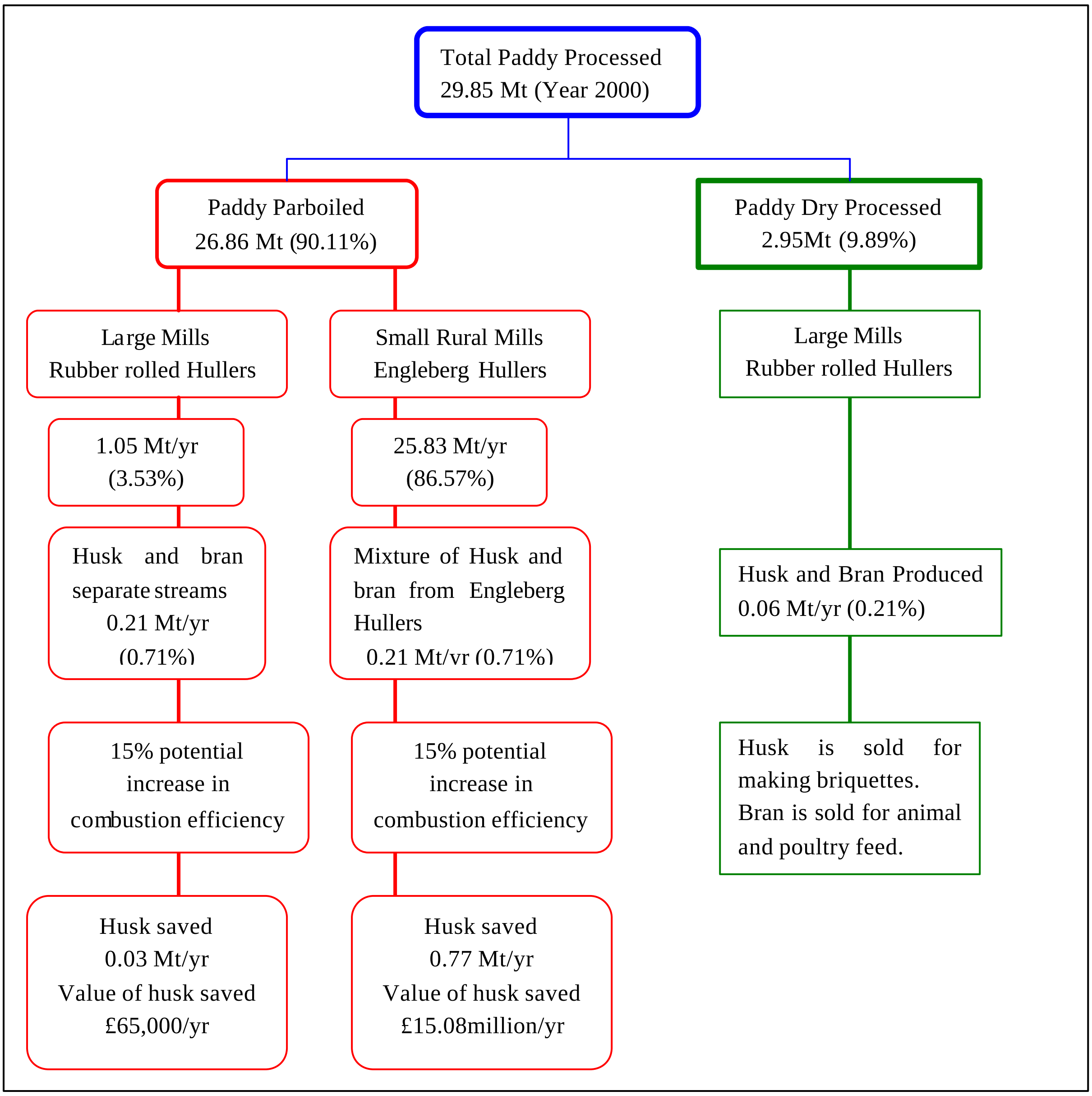
Uses of husk: The bulk of the husk-bran mixture from parboiling mills is used as fuel. Other uses of husk include feed for poultry and cattle, chicken litter, seedbed cover and briquettes.

2.2.2 The Structure of Rice Milling Sector

As Fig 2.2 shows, 90% of the paddy produced in Bangladesh is parboiled. About 10% of paddy is dry processed. The latter takes place in large mills using rubber-rolled hullers. These mills separate the husk from bran. The bran, which fetches a good price, is sold for animal and/or poultry feed and the husk for briquetting.

Less than 4% of the parboiling-hulling operations take place in large modern mills. In 2000, 25.83 million tonnes or nearly 87% of paddy produced was parboiled and hulled in small rural mills. This study estimates that there are nearly 6,5000 such mills in Bangladesh (Appendix 2A). These mills use Engleberg hullers that give a higher proportion of broken rice to total rice than rubber rolled hullers. The husk-bran mixture constitutes 30% of the total yield. Husk by itself constitutes 20% to 21% of the yield. As bran catches fire more easily, it is rarely separated from husk to be used as fuel. Thus, a valuable nutrient is burnt to compensate for poor technology and inefficient combustion systems. During the field visits it was observed that only a handful of mills in proximity to Dhaka separated the husk from bran as the latter fetched a price of TK 60 per bag of 25 Kegs. Large mills produce husk and bran as separate streams which they sell in the market.

Fig 2.2 Structure of Rice Milling Sector and the Role of Small scale Rice Mills in Bangladesh



As the figure above shows, small mills clearly dominate the sector in number and total production. They also have the more primitive and inefficient combustion systems. The targeted 15% increase in combustion efficiency in small mills will save about 0.77 m tonnes of husk per year. This provides the rational for one of main objectives of this project: i.e., to improve the efficiency of the furnace-boiler unit used in small mills.

2.2.3 Small Scale Rice Mills and Furnace-boiler Units

This section gives a brief description of the general characteristics of the small scale rice mills, before a detailed analysis is undertaken in the following chapter.

These small mills are located in rural areas. However, they tend to be clustered to maximise the benefits of agglomeration. This clustering may prove to be an advantage when disseminating improved technology. Within these clusters, many different scales of operation are found. On the basis of production capacity and steam requirement the mills can be grouped into two categories. (i) Those that process less than 6,000kg/day of paddy and have a steam requirement of 150 to 350kg/hr; and (ii) the user group at the higher end that process 6,000kg/hr to 10,000kg/hr. Their steam requirement is more than 350kg/hr. It will be important to cater to the needs of both these groups to enhance uptake of improved technology.

Though there are some variations in production capacity, there are three basic boiler configurations found in this sector and these are illustrated below (Plates 2.1 to 2.3). The configurations are:

a) Semi-cylindrical with flat bottom;
b) Cylindrical; and
c) Rectangular boxes.

However, a common characteristic is fabrication in small, local workshops from low-grade scrap sheet metal. The materials used are of variable quality. The designs of boilers are dependent on the preferences of the local technicians, or *mistris* as they are locally called. The rectangular box boilers are being increasingly phased out by their owners. This study focuses on configurations a) and b) and their technical characteristics are discussed in detail in Chapter 3.

Plate 2.1 Semi Cylindrical Boiler with an Open Furnace

Whatever the shape of the boiler, the husk is fed manually, directly underneath the boilers. No grates are employed. Some furnaces had chimneys (Plate 2.2), but these were of inadequate height and the furnace wall had several openings. The latter creates very hot and unsafe working conditions as hot flue gas e-+

`scapes from these openings. The inadequate draught and lack of oxygen creates flashbacks towards the stoker. Improving working conditions is therefore part of technological improvements envisaged by this project. Furthermore, none of boilers observed had any safety devices and explosions were common.

Plate 2.2 Cylindrical Boiler with Poorly Constructed Furnace

Plate 2.3 Rectangular Box Boiler

These small scale mills are in a legal vacuum. Firstly, they are not covered by safety regulations of the Inspectorate of Boiler; and secondly, they are not included in the Small Industries Sector.

The Inspectorate of Boilers still operates under the standards set out in the Boiler Act of 1923. This covers large industrial boilers and the Inspectorate has not developed norms for smaller boilers used by small industries like rice mills. Consequently these smaller boilers are regarded as illegal and dangerous. Furthermore, the Inspectorate is woefully understaffed and has no prosecuting authority.

They report any non-compliance to local authorities, who are expected to act on it. However, the latter are not known for their efficiency.

The Department of Industries in Bangladesh does not regard the small scale rice mills as part of the Small Scale Industries sector because of their rural location. This means that these rice mill owners are not entitled to cheap credit from banks like other small scale entrepreneurs in urban areas. This could have implications for technological change in this sector.

2.3 Socio-economic Characteristics of Small scale Rice Mill Owners

Experience and research show that factors affecting uptake of technological improvements in small firm sector are rooted in the ownership and organisational structure of the firm; in its socio-economic composition; and the target sector's perception of 'technological change'. More specifically, introducing technological change and improving work practices, however minimalist in nature, are not merely questions of availability of technology and resources. Several studies[1] have concluded that technological change could be inhibited by attitudinal, organisational and economic barriers.

This section therefore describes the following characteristics of the rice-mill sector and their implications for uptake of technological improvements. These are:

- ownership and the different operating arrangements found in the sector;
- the socio-economic composition of the sector; and
- the target group's attitude to change and their perception of what is technological change.

The analysis in this section draws on a detailed questionnaire-based survey of 35 rice mills in 8 different districts of Bangladesh (see Appendix 2-B for questionnaire). These districts were selected as they are considered important centres for paddy production and milling; hence representative of the wider situation. The questionnaire was designed to obtain information on all the abovementioned characteristics. The survey was undertaken in November-December 2000.

2.3.1 The Ownership and Organisational Structures Found in the Target Sector

Table 2.1 Showing the Growth in the Number of Rice Mills

Period in which the mills were set up	No. of mills	% of mills
Before 1970	2	6
1970- 1979	5	15
1980-1989	14	41
1990-1999	10	29
Year 2000	3	9

[1] Nairobi (Frijns *et al*, 1997); Calcutta and New Delhi (Dasgupta, 1997; 2000); in Hong Kong (Lei and Yang, 1993); in Africa (Scott, 1998).

As Table 2.1 shows, 70% of the mills were set up in the two decades of the 1980's and the 1990's; a period of steady increase in paddy production in Bangladesh. Nearly a third of the mills were established by the present owners while 12% inherited it from their father. Though ownership history seems quite straightforward the operating arrangements are more complex. Four types of operating arrangements were noted.

a) operated by the owner
b) operated by *beparis* (a group of traders)
c) operated by the owner jointly with the *beparis*; and
d) rice-mill leased to the *beparis*.

Each of these is discussed below.

(a) 55% of the mills are operated directly by the owners. They own the assets, which include the parboiling equipment, the boiler and furnace, the drying yard and the hulling mill. They employ and pay the workers directly. The paddy processed may be on a job-basis when brought in by the local farmer. Alternatively, the owner buys the paddy, processes it and sells the rice to the middleman at the local wholesale price. As observed in most small units, the owner is the main decision-maker but the 'supervisor' manages the day to day operations. In very small units, the owner is also the supervisor.

(b) 25% of the mills are operated by *beparis*. In this case the group of traders who operate the mill pay the owner a fixed and agreed sum of money on an annual basis. The assets (described in (a)) are still owned by the owner. The loss from damage to assets is picked up by the owner. The workers are employed and paid by the *beparis*. *Beparis* tend to buy the paddy and process it rather than enter into job-basis processing.

(c) The owner and *beparis* jointly operate another 12% of mills. In Gazipur, the team found what turned out to be a typical arrangement. The *beparis* were responsible for the parboiling operations but the mill owner operated the hulling mill. The owner paid the cost of electricity used for running the water pump to fill the boiler. He received a return per maund[2] of rice parboiled. The owner also picked up the overhead costs. He had provided land for housing the workers and their families. The *beparis* admitted that their profit margins were higher than that of the owner. In other instances the *beparis* were in charge of operating and maintaining the parboiling equipment. They paid the owner for use of the drying yard. The owner kept control of the husking mill and charged the *beparis* for milling the paddy. The trader-operators paid the workers employed for parboiling and drying paddy, while the owner engaged the workers needed for milling the paddy.

(d) Rice mill leased to the *beparis*: This is a straightforward arrangement, whereby the *beparis* took over the mill for a payment of Tk 6000 per month to the owner. 13% of the owners had opted for this arrangement.

[2] One maund=37.5 kg

Implications for technology change: It has been widely acknowledged that most small firms have a preference for short-term profit maximisation. This in itself makes it difficult to sell technological improvements with long-term benefits. In this sector, in addition to this constraint, is the complex operating arrangements that could inhibit technological change. For example, the 13% of owners who have leased the mill or handed over the operations for a regular income will see little reason to invest in a new boiler and furnace system as they are unlikely to benefit from the enhanced combustion efficiency. However, the scope for higher profitability might encourage the *beparis* to work with the owner to improve combustion efficiency of the furnace. Hence, the dissemination activities should first focus on mills operated by owners.

2.3.2 Economic Characteristics of Small Rice Mills

One of the principal objectives was to understand the economic strengths and weaknesses of the sector and its implications for enhancing the combustion efficiency and of its uptake. The survey of 35 mills collected expenditure-income data at firm level to assess the economic health of the firms and their affordability for technological change. At the interviews the owners/operators noted that they all made a profit. The rapid expansion in the number of mills would appear to underscore this. However, the figures (see Appendix 2-C) provided do not add up to this picture. Hence, those values are not used in this analysis.

The questionnaire was designed to collect a breakdown of all expenditure and income streams, so that a profit and loss account could be developed. This would help to understand the issues of affordability. While the survey provided some very useful qualitative and quantitative information the expenditure-income data proved inconsistent and unreliable. On calculating the net income based on the figures provided, all but one mill were running at huge losses.

It is unlikely that all 35 interviewees (which included owners and *beparis*) randomly selected over a wide geographical area would intentionally give misleading answers. Most owners/operators in small units do not keep accounts and do not think of expenditure in separate streams. They have a general idea of their monthly outgoing against a tonne of paddy. It is believed that, consequently, when asked for a more detailed breakdown of costs, there has been double counting.

However, all interviewees were clear about the cost of building a furnace and a boiler. Given the wide geographical coverage, the cost ranged from Tk 95,000 to Tk 100,000.

Implication for the project: Issues of affordability is fundamental to this project. The cost of the improved design furnace and boiler should be the same as the current cost or lower to facilitate uptake.

2.3.3 Educational Achievements among User Group

Relevant to this project are levels of education and literacy among the owners. Generally, low levels of education are associated with limited access to knowledge, technical or otherwise, and limited ability to deal with new information. The owners tend to rely on family-based information, on intuition and/or on local contacts (Sethuraman, 1992).

As Table 2.2 shows the sector is dominated (87%) by relatively low levels of educational achievement. Of this, 42% did not get beyond middle school. This means that the ability to react to, and interpret new information, is likely to be limited. A related disadvantage is perhaps low levels of technical knowledge in this sector. This is reflected in its total reliance on the local mechanic.

Table 2.2 Levels of Education of User Group

Level of education	**Percentage of owners**
No schooling	10
Primary education	13
Middle school	19
Finished school	45
Graduate	13

Source: Survey data (November-December 2000)

In every district surveyed, the entire sector was dependent on the local *mistri* for any technical information, and for design and maintenance of the boiler. A *mistri* has no formal technical training. He has probably been apprenticed from a very young age and learnt on the job. Each locality had the fingerprint of its local *mistri.* Consequently there is variation in the boiler design from one area to the next.

Sethuraman (*ibid.)* notes that even if an entrepreneur has access to credit and capital and set up a small unit, the possibilities are that managerial and technic al ability may be generally low. The case in point is a rice-mill owner in Nawabgang, who sold the land he had inherited to set up the mill in 1998. The hulling mill remained idle for a year, as there was no high-tension power supply to the area. He noted that he was unawares that it was a requirement.

Implications for uptake: There are two important implications for technical information dissemination.

1. The present reliance on the local *mistri* means that he will play an important role in facilitating uptake. Additionally, the fact that there is so much local reliance for design and maintenance of boiler, the dissemination strategy will need to address the problem of regional variation in design. Even if the technological improvements offered is standard and applicable to all regions of Bangladesh, it will be necessary to highlight the drawbacks of many different bad practices found in the different regions of the country. Involvement of local *mistri(*s) from an early stage is likely to improve chance of uptake.

2. Demonstration of benefits will be a fundamental strategy given the limited ability of the sector to react to, and interpret new information; and its limited educational, technical and entrepreneurial skills.

2.3.4 Choice of Technology and Perceptions of Technological Change

The pertinent issues in this project are (a) the owner's approach to setting up a production unit; and (b) what is considered 'technological change/improvement'.

(a) Choice of technology and production process in a small industry is not a technical decision. Technology employed is adapted to availability of capital, space, raw materials and skills -locally and in the family. Furthermore, the technology used in the small industry is the cheapest with little attention to long term and financial viability. This combined with little subsequent investment, the processes used is soon outdated, inefficient, unsafe and inefficacious.

The quality of construction of the boiler and the furnace varied greatly often reflecting the financial ability of the owner and technical knowledge of the *mistri* employed. Inspection of boilers revealed that there was very little maintenance and upkeep. Some operations were considered highly dangerous with total disregard for safety of workers. Boilers were changed only when they were considered beyond repair.

(b) The owners were asked what technological improvements they would like to see in their mills. An analysis of their responses shows the target group is ambivalent of what technological change means. Some of the characteristics to emerge from this study are:

- There is confusion between technological change and expansion of operations using the same technology. When asked what kind of technological change they would like to undertake, some of the answers were: "add another hulling machine"; or "expand the drying yard".
- Most find it difficult to conceptualise/imagine anything other than what they use. This can be largely attributed to the fact that they accept/adopt, without questioning what the neighbouring mill owner is doing and/or what the *mistri* has to offer.
- None mentioned enhancement of furnace efficiency. This is primarily because they have not seen better, or can imagine it.
- Demonstration effect is very strong not because they want to see benefits before they invest, but because they are unable to envisage improvements. However, when asked if they would take up improved boilers at 'affordable' price that would be more efficient and safe, all the owners responded positively.

The implications for uptake: to facilitate uptake it will be important to exchange information, in addition to disseminating information on improvements. This is because concerns of the target group and issues of affordability have also to be addressed while the designs for the improved furnace-boiler are being developed.

2.4 Conclusions

Paddy production and rice milling are important activities in Bangladesh. Nearly 87% of the paddy produced is parboiled and hulled in small scale rural rice mills. Though there are some variations in the milling capacity among these small units, there is little to differentiate them in terms of low furnace efficiency. As bulk of the paddy in Bangladesh is processed in these small inefficient mills, the potential savings in husk that could be made by 15% increase in combustion efficiency are considerable.

Three types of boilers are found in this sector. The most commonly used are those which are semi-cylindrical and cylindrical in shape and the focus of this study. Improvements in technology and their uptake depend to some extent on the socio-economic composition of the sector; the nature of ownership and operating arrangements; and the owners' attitude to technological change. The low levels of educational attainments among the owners and their overwhelming reliance on the local technician mean that the later will play an important role in facilitating uptake. Demonstration effect will be important, not because the owners want to see benefits before they invest, but because they are unable to envisage improvements. However, when asked if they would take up improved boilers at 'affordable' price that would be more efficient and safe, they all responded positively.

3 Improved Furnace Design in Small Scale Rice Mills and Benefits Generated

3.1 Introduction

Section 3.2 will first analyse the different models of traditional furnaces, their characteristics; operating practices; and the reasons for their low operating efficiencies. It will also analyse the characteristics of boilers and the profiles for husk production and consumption in rice mills. All these features have implications for developing the improved design of furnace. Section 3.3 will give the design approach to developing the improved furnace model; the features of the improved design that address the constraints identified in section 3.2; and the results of the trial runs. Section 3.4 will set out the benefits of the improved furnace-boiler design. Section 3.5 discusses some of the social and policy limitations to uptake that have to be addressed through subsequent dissemination activities.

3.2 Designs of Furnaces and Boilers Currently in Use

There are several models of furnaces, but by and large they can be classified into two types. These are:

1 Rice husk fired furnaces with semi-cylindrical vessel; and

2 Rice husk fired furnaces with cylindrical vessel.

However, the type of conventional furnace and the parboiling practices are governed by the following factors:

1 Locality of the rice mill clusters;

2 Capacity of the rice mills; and

3 Demand of the rice market.

The new furnace design is proposed to replace the traditional designs of the rice husk fired furnaces with cylindrical and semi-cylindrical vessels. Review of studies of existing conventional furnaces, the field data collected and the observations made by the project team helped to derive the design factors. These are discussed below. Issues of affordability have already been discussed.

3.2.1 Rice Husk Fired Furnaces with Semi-cylindrical Vessel

The furnace walls are constructed with 9-inch bricks and clay. The clay used for construction is locally available and it is mixed with rice husk for better strength and to avoid shrinkage and/or cracking.

The furnaces with semi-cylindrical boilers are longer in comparison to the furnaces with cylindrical vessel. The base of the vessel is flat and made of 10-12 mm thick Mild Steel (MS) plate. The upper section of the boiler is hemispherical. The top, front and back sheets are made with a thinner gauge MS sheet of 2-3 mm. Figure 3.1 gives a conceptual view of the semi-cylindrical boiler used in the rice mill industries.

The underside of the vessel is thicker for two reasons: one, to take the load; and two, to reduce the rate of degradation as this section of the boiler is directly exposed to high temperature flame. Thus, increasing the thickness of the bottom sheet of the vessel increases its life. Since the top and side sheets are of thinner gauge, over a period of time they degrade faster than the bottom sheet and can cause the boiler to explode.

From the heat transfer point of view the different sheet thicknesses selected for the fabrication of the vessel has a contrary effect on energy efficiency. The bottom sheet should have higher conductivity rate to transfer the heat into the vessel; but being thicker it reduces the heat transfer. On the other hand, the non heat-receiving surfaces have thinner sheets and easily transfer the heat to the atmosphere. So the combination of sheets selected contributes to a large reduction in the overall efficiency of the furnace.

The furnace wall has three ports of size 11cm x 16cm on each side just below the vessel for exit of the flue gas (Fig 3.1). This is in addition to the chimney. Since the flue gas escapes from beneath the vessel it is at a high temperature and contributes substantially to reduction in efficiency. As the flue gas exits from these ports it catches fire and burns with a large flame. This flame is below the working height and can cause burn injuries to the workers.

An opening is provided in one of the sidewalls of the furnace to remove the ash from the furnace. The opening of this ash port is about 60 cm wide and 90 cm high. This large opening provides a path for considerable heat loss. The heat loss through this opening is in two forms:

(a) in the form of unutilized high temperature flue gas; and

(b) in the form of radiation heat from the high temperature flame of the furnace when ash is removed every two hours.

In the conventional furnaces, when the rice husk ash is removed from the ash port, it still contains a large quantity of unburnt char and partially burnt rice husk. This is because of insufficient supply of air in the furnace. This inadequate supply of air results in incomplete combustion of rice husk. The flame coming out of flue gas opening is another example of incomplete combustion. After the ash is removed, the partially burnt rice husk smoulders slowly, drawing in air from the atmosphere. This process of slow burning can go on for hours. This becomes one of the crucial factors in the rice husk ash analysis. The property/composition of the rice husk ash will vary with the time of collection (the time lag between the ash removal and sampling). So it could be one of the reasons for the variation of results obtained in the samples. This is discussed in Chapter 6.

The fuel inlet of the conventional furnace is provided with a very wide opening of the order of 75cm x 75cm. The severe heat loss from this port is similar to the losses described from the ash port. A large amount of heat radiation through the fuel inlet port makes for dangerous and uncomfortable working conditions for the person feeding the rice husk. Sometimes a backfire occurs from the inlet port causing burn injuries to workers.

In case of a furnace with semi-cylindrical vessel, a large brick masonry structure is constructed between the furnace and the chimney to carry the flue gas. The chimney is constructed with a wide base with the wall narrowing as the height increases. Construction of these structures consumes more materials than what is required for the construction of the furnace.

The boiler vessels have a provision of flange fitted manhole to clean it once in a while. Sealing occurs from inside as well as from outside the vessel. There are no safety measures adopted in the conventional furnaces. There is neither any indication of steam pressure or water level nor any safety valve. The nil/poor instrumentation leads to severe accidents when using the traditional furnaces.

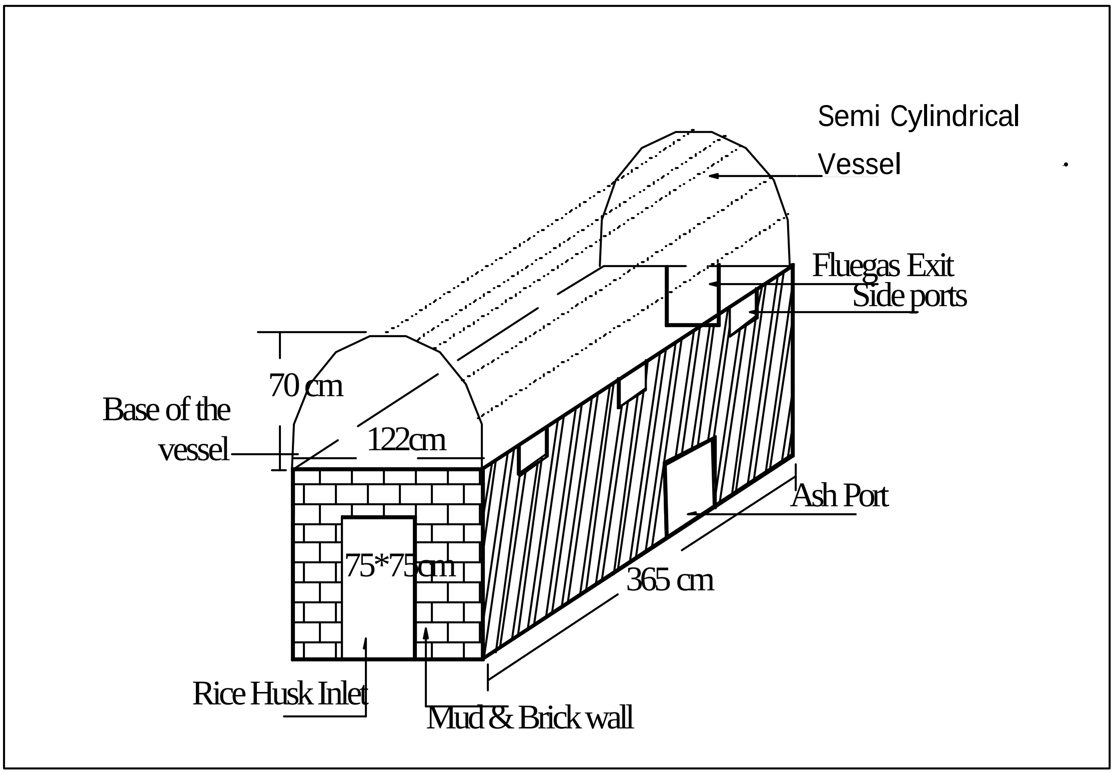


Fig 3.1 Conceptual View of the Semi-cylindrical Boiler

3.2.2 Rice Husk Fired Furnaces with Cylindrical Vessel

In Northern Bangladesh, the rice mill clusters have furnace with cylindrical vessel, which is used for steam generation. These furnace walls are 40.5cm (18”) thick at the bottom and taper to 9cm (4”) at the top. Similar to furnaces with semi-cylindrical vessel, brick and local clay mixed with paddy husk is used to construct the furnace. However, unlike furnaces with semi-cylindrical vessel boilers, furnaces with cylindrical vessels do not have flue gas exits on the side. The conceptual diagram of the cylindrical vessel used furnace is given in Figure 3.2.

In these furnaces the fuel inlet port is much larger, almost twice the area in comparison to furnaces with semi-cylindrical vessel. The efficiency loss is proportionately higher. However, like the furnace with semi-cylindrical boiler, this furnace also has a large port for removing ash and workers follow similar practices.

Flue gas exits for furnaces with cylindrical vessels are located just below the vessel, at the rear of the furnace. This means that the flue gas exits from the furnace at a very high temperature. This design also means that the heat of the flue gas is not utilized to heat the vessel. This is another factor that leads to poor efficiency of the furnace.

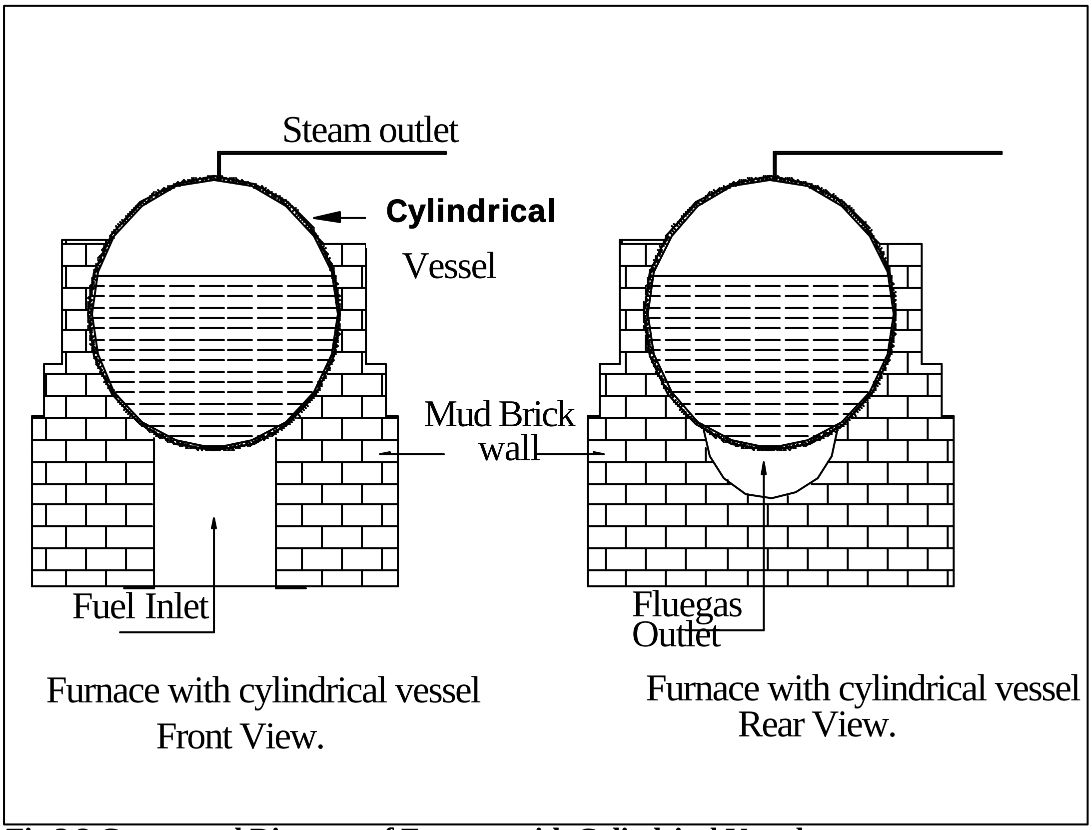


Fig 3.2 Conceptual Diagram of Furnace with Cylindrical Vessel

The cylindrical vessel is fabricated with 8 to10mm thick MS sheet. The underside, which is directly heated, degrades faster. To use the vessel for a longer duration, the rice mill owners reverse the vessel so that the upper section goes down to receive the flame and the degraded down section comes up. This reversal means that the degraded thinner portion of the vessel is now the steam forming area; i.e., the weaker portion of the vessel is used to collect the steam which is used at high pressure. This practice often leads to explosions and fatalities. Many working and operating practices, adopted in total technical ignorance, results into poor efficiency and dangerous working conditions.

Safety equipment or instrumentation is not installed in any of the furnaces, either in the case of cylindrical vessel or semi-cylindrical vessel. It must also be noted that furnace grates are not popular with owners, irrespective of boiler vessel model. It is considered an unnecessary expense and time consuming to clean.

Furthermore, these furnaces have a large masonry structure connecting it to the chimney. An analysis of the existing scenario of chimneys in the conventional furnaces shows that many of them do not even have a chimney. Those that do, very often the features are poorly maintained, with gaps in them. In the Mymensingh cluster, the flue gas exits directly from the rear wall of the furnace. In other instances, the flue gas exits just below the vessel from either side (e.g., in Kaliakor). Again these structures require more material than is required for the construction of the furnace.

3.2.3 Furnace Operating Practices

Two persons are continuously engaged in feeding the furnace with rice husk. One person transports the rice husk from the storage shed to the furnace fuel inlet. The second person sits at the inlet port and feeds the furnace continuously, irrespective of the steam demand. Two bins are used for parboiling of paddy. When one is being used to process the paddy the other bin is being filled with paddy. This means that each vessel is filled alternatively to parboil the paddy. The processing time varies from 6 to 13 seconds depending upon the process requirement (this is discussed in section 3.2.4). It takes longer to complete the steaming process of full parboiled paddy. In the case of half parboiling of paddy, process steam is used in limited measure. As soon as the paddy reaches the steam temperature the bin is emptied.

Steamed paddy is removed by opening a baffle at the base of the vessel. The paddy empties directly into a basket. The basket is transported to the paddy drying yard and spread out for sun-drying. The workers carry the basket of hot paddy on their head. The figures illustrating the process are in Appendix 3-A.

Since the husk is fed continuously at a very high rate, the pressure builds up inside the furnace. The furnace design does not allow the flow of air required to fire the amount of husk being fed. This leads to a partial combustion of rice husk and produces a high level of carbon monoxide (CO), which is a combustible gas and is hazardous for health (when it is not burnt). Furthermore, due to the build-up of pressure in the furnace these combustible gases escape from the inlet port as a fireball. When this occurs, the worker(s) feeding the husk has to move away quickly to avoid burn injuries. It is clear that adequate draft is not available in the traditional design of the furnaces. The flame escapes frequently, sometimes continuously, through the gaps left in the furnace walls. Figures illustrating the different aspects of the conventional furnaces are provided in Appendix 3-B.

There is no co-ordination between the person processing the paddy, who also controls the steam valve, and the person feeding the husk. The person at the processing end opens and closes the steam valve according to the processing requirement, while the husk is being fed continuously. In situations where the steam is not being utilized and the husk is still being fed, the steam pressure in the vessel builds up beyond the holding limit. Since the vessels are not made by professional welders and there is no safety valve installed the vessel explodes. Generally the normal operating pressure of these vessels is found to be 0.5 kg/cm^2.

3.2.4 Complexities of Parboiling and Energy Demand

The parboiling process of paddy varies from person to person and place to place. Generally, there are three types of parboiling processes. These are:

a) Partial parboiling of paddy;
b) Half parboiling of paddy; and
c) Full parboiling of paddy.

The 'level of parboiling of paddy' refers to size of the white bead formed in the rice kernel. In partially parboiled rice less than one-third of the rice grain is turned white. In the case of half parboiled paddy about half the rice grain is turned white. In the case of full parboiled processing the entire rice kernel is turned pale white. The process adopted can be easily determined by the colour of the rice. Thus, the level of parboiling is directly proportional to the size of the white bead in the kernel.

Relevant to this project is the fact that the energy demands vary according to the parboiling process adopted and the workers involved. So it becomes a complex process to arrive at a single parameter to compare in terms of Specific Fuel Consumption (SFC) required for paddy processing. The different parboiling processes will demand different steam consumption rates to parboil a given amount of paddy.

The majority of the mills use a mixture of rice bran and rice husk, but a few mills use a mixture which has maximum possible bran content. Bran is a valuable poultry and animal feed that is burnt in the furnace to sustain the flame of the rice husk. It is also found that the husk from partially parboiled paddy burns better than the husk from fully parboiled paddy.

In view of this complex situation this project focuses on furnace efficiency in terms of husk feeding rate and steam production rate. This approach provides an indication of SFC required for steam production in different furnaces. Though there are large variations in the SFC for steam production in different clusters, the average value of the data collected from various clusters can be taken as a base to quantify the furnace efficiency improvement and husk saving.

3.2.5 Flue Gas Analysis

The heat produced from the fired rice husk is distributed into various components, including into the water in the vessel for steam generation. Useful heat is that which has entered the vessel for steam generation, the rest is counted as heat loss. The following diagram (Figure 3.3) explains the possible directions of heat flow in a furnace.

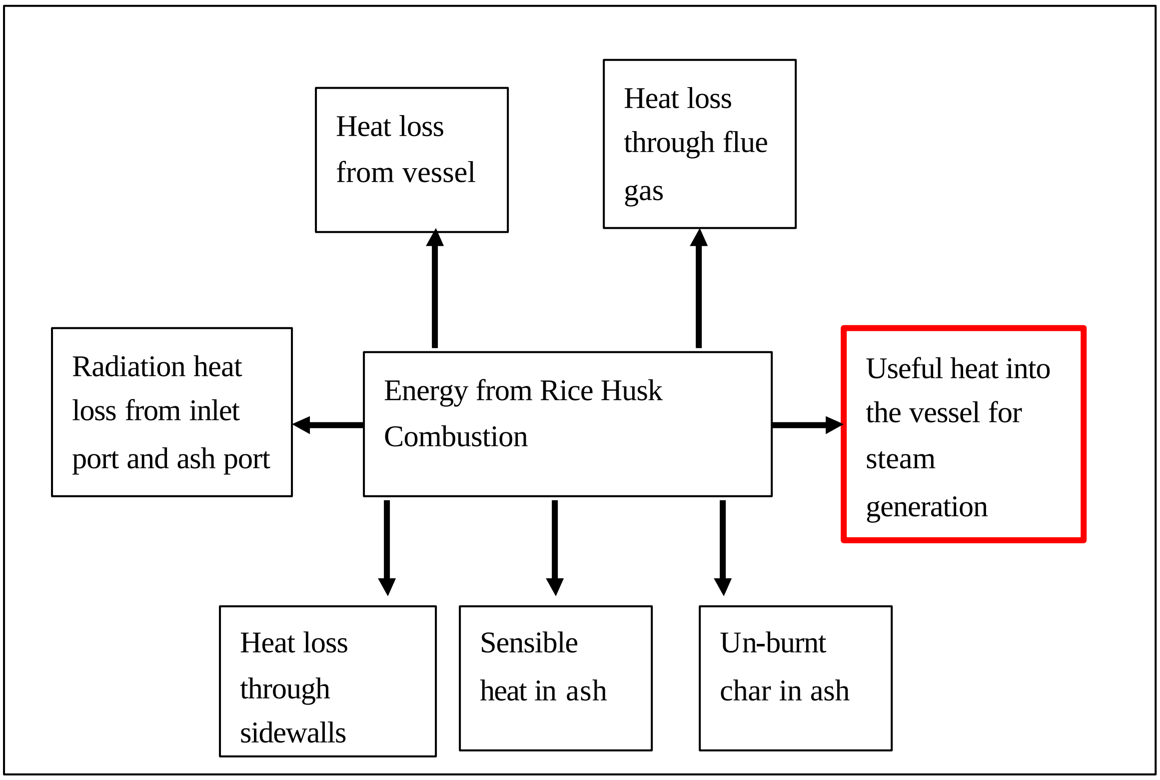


Fig 3.3 Energy Flows of Rice Husk Fired Furnace of Rice Mills

The heat loss through flue gas was determined with the help of a Flue gas Emission (FEM) Analyser. The flue gas analyser results of traditional furnace are given in Table 3.1.

Table 3.1: Results of the FEM Analysis of Traditional Furnace

Sl No	Component	Measures
1	Ambient temperature	27^{o}c
2	Flue gas temperature	720^{o}c
3	CO	> 10,000 ppm
4	O_2	Nil

From the above table the following conclusions can be drawn:

(i) The air supply for complete combustion of rice husk is not available;

(ii) The flue gas carries a large amount of CO, which is added to the environment;

(iii) The CO level around the furnace is quite high. FEM was unable to perform the self-calibration process, which indicates high a concentration of CO in the working environment;

(iv) The high level of CO in the flue gas ensures that adequate supply of O_2 is not available in the furnace;

(v) The filters in FEM get choked very frequently indicating that the presence of suspended particles is more than the normal level;

(vi) The flue gas temperature is also very high - of the order of 750 to 800°C, which indicates that a large amount of heat is carried away through the flue gas; and

(vii) The high level of CO and the absence of O_2 indicate that the draft created by the existing brick chimney is not adequate.

3.2.6 Efficiency of the Traditional Furnace

Conventional furnace efficiency was determined from field level data collected by BRRI, through FEM Analysis and observations made by TERI. The heat losses of all the components were determined to crosscheck the efficiency calculations. Different components of heat flow have been calculated and are illustrated by a Sankay diagram (Figure 3.4). The Sankay diagram indicates the percentage of heat flow in the different components and the percentage of useful heat, which is the efficiency of the furnace. The diagram highlights the areas on which this study should focus in order to increase the efficiency and also indicates the scope for reducing the heat loss.

From Fig 3.4 it can be seen that the maximum heat loss is through high temperature flue gas, which is almost 50% higher than the useful heat, used for steam generation. The next highest loss is the unaccounted heat loss, which is also higher than the useful heat. This includes (a) the heat that goes out in the form of large flame from the flue gas exits, ports of the sidewall and through the ash-removal port; and (b) the unburnt charcoal of the ash removed.

According to the Sankay diagram the main components to focus on, and to take into account for improvements, are: (i) to reduce the heat loss in the flue gas; and (ii) to reduce the unaccounted heat loss.

Tentatively, to achieve a minimum efficiency of 35%, another Sankay diagram (Fig 3.5) was developed to act as a base line from which to proceed with the improved furnace design. Figure 3.5 indicates the minimum required norms or the ratios of heat loss through different components to achieve an efficiency level of 35%, which is 15% more than the current average efficiency of 20% of the traditional furnaces; and also the project target. No significant change or improvement is planned for reduction in some of the components. The ash removal at the interval of every two hours is unavoidable, because rice husk is a fuel, which inherently has a high amount of ash content - of the order of 23% to 27%. The ash occupies a large volume of the combustion chamber and reduces the space available for the husk combustion. So it becomes important to remove the ash at a regular interval of two hours. The heat carried away with the ash is unavoidable. Similarly the heat loss though the wall surfaces is also not taken as a focus area because it is already at a minimum level because of the material used, i.e., a combination of clay and brick.

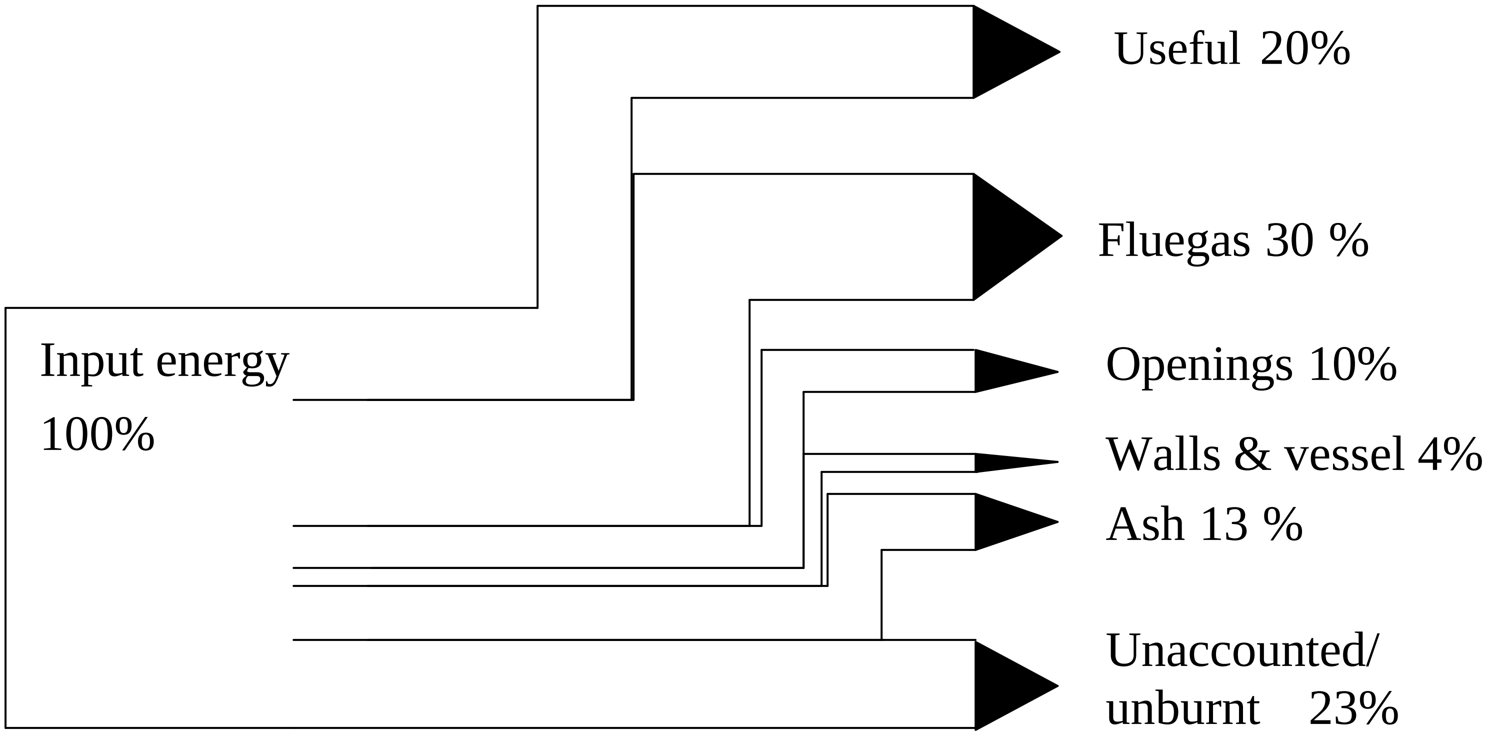


Fig 3.4 Energy Flows of the Traditional Furnace

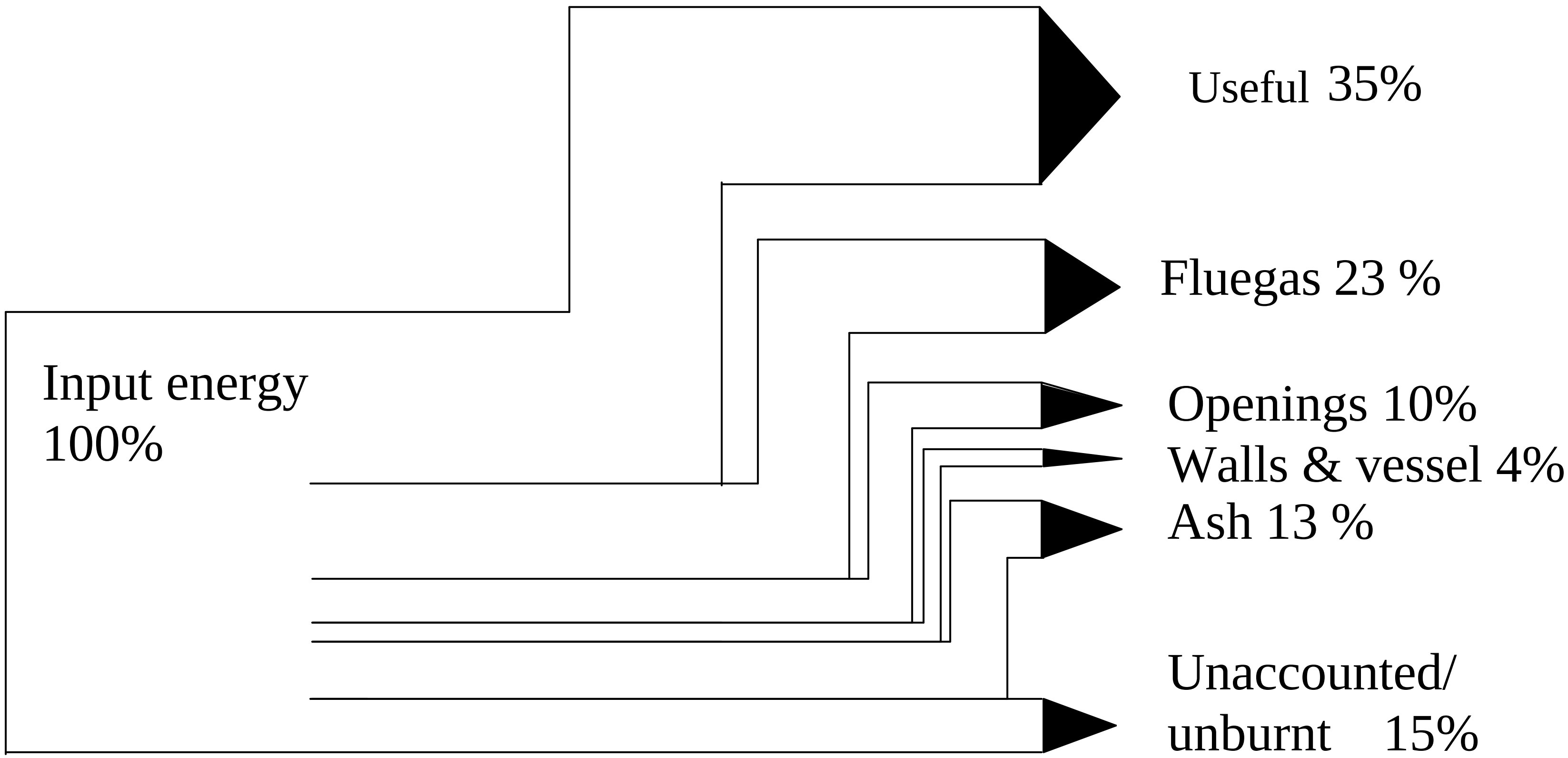


Fig 3.5 Energy Flows of the Proposed Furnace

3.2.7 Heat Absorption by Boilers and Overall Efficiency

The vessel used for steam generation in the furnace needs to follow several design criteria to maximise heat absorption. In the traditional furnace the vessel is placed in such a way that the steam generation is at a low efficiency. A typical semi-cylindrical vessel used for steam generation has a total area of about 15m^2 out of which only about 5m^2 is used to receive the heat. So the heat receiving area works out to 33% of the total vessel area, rest of the 67% of the vessel area is exposed to atmosphere and contributes to the heat loss factor. In case of the cylindrical vessels used for steam generation they have a total area of about 11m^2 out of which 40% of the area is used for heat absorption.

In both types of the conventional furnaces the vessel area used for absorbing heat is much less than required. This is one of the reasons for the exit of high temperature flue gas. In general it was found that in the conventional furnace only 62% of the required boiler area is available for heat absorption, a major factor in the poor efficiency of traditional furnaces. To achieve a higher efficiency level, maximum vessel area should be used to absorb heat and a minimum area should be exposed to the atmosphere.

3.2.8 Safety Issues

Some of the safety issues have already been discussed. This section summarises all the technical aspects that will be targeted by the improved design and the poor work practices that will be targeted by subsequent dissemination activities.

(i) Flame exits from the side walls below the vessel and can cause burn injuries.

(ii) The flue gas exits with a high level of CO, which can cause health-related problems.

(iii) Frequent vessel explosion occurs, that leads to regular fatalities among workers in the mill. Since the explosion occurs due to high-pressure steam, the vessel is carried a long distance and sweeps away anyone who comes in the path. There are several reasons for these explosions. These are:

- ♦ No safety valves are used to avoid explosion;
- ♦ Uneven and thin gauge sheets used for fabrication of vessel;
- ♦ Poor quality MS sheet used for fabricating the vessel;
- ♦ Poor welding and manufacturing of the vessel by untrained local *mistris*;
- ♦ Reuse of the old vessel by reversing its position or doing patch work repair of the worn out sections of the vessel;
- ♦ Absence of co-ordination between the untrained worker feeding the furnace and the person who is processing the paddy and operating the steam valve;
- ♦ Poor instrumentation: temperature gauge, pressure gauge, level gauge etc., are not used to assess the performance of the furnace.

3.2.9 Initial Ignition, Fuel Feeding and Use of Rice Bran

The furnace is initially ignited using a waste gunny bag. The gunny bag is lit using a small amount of kerosene varying between 250ml to 500ml. The ignited gunny bag is kept inside the furnace just near the mouth of the fuel inlet. Then a mixture of rice bran and husk is fed into the furnace through the flame of the gunny bag. Since the bran is in a fine powdery form it catches fire quickly and passes on to the rice husk in the surrounding. In the beginning (about 10 to 20 minutes) this mixture of rice husk and bran is fed at a very high feeding rate, which is double the normal feeding rate. During this period the inner section of the furnace becomes sufficiently hot to sustain the flame. The rice to bran ratio is reduced depending upon the furnace temperature. Most of the furnaces with semi-cylindrical vessels, and all furnaces with cylindrical vessels, use rice bran along with rice husk, throughout the processing period. This is burnt just to sustain the fire of the rice husk, which is a poor way of utilizing a highly valuable substance. The improved furnace is designed in such a way that in addition to improvements in efficiency it also tries to eliminate the need for rice bran firing.

3.2.10 Rice Husk Production

The ratio of rice husk to rice grain of the paddy is governed by the following factors:

(i) The fertility level of the soil.
(ii) The variety of the paddy.
(iii) The parboiling process.
(iv) Milling process of the paddy.
(v) Collection efficiency of the rice husk and bran.

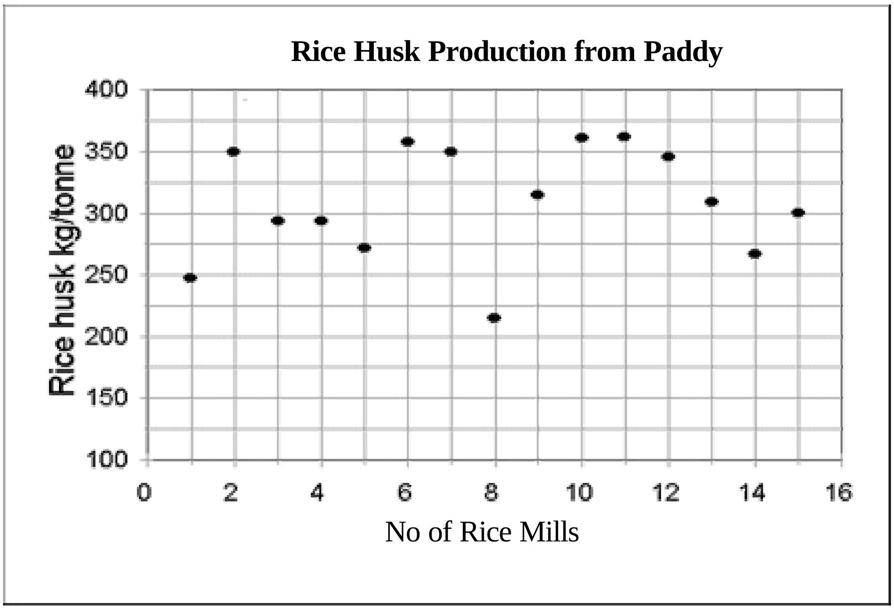


Fig 3.6 Profile of Rice Husk Production

Since there are several factors influencing the rice husk to paddy ratio, there is a large variation of husk production from the paddy. It varies from 250kg/ton to 350kg/ton. Average rice husk production works out as 309kg/ton of paddy processed. Profiles of rice husk production in different rice mills are given in Figure 3.6.

3.2.11 Rice Husk Consumption and Implications for Design Improvement

The processing capacity of rice mills in Bangladesh range from 6000kg/day to 16,000kg/day. The capacity of the mill depends on the cluster and the market demand in the locality. There is a large variation in the process of parboiling with the husk requirement varying accordingly. A large scatter is observed in the rice husk consumption level per ton of paddy processed (Fig 3.7). The fuel consumption varies from 75kg/ton to 200kg/ton.

The profile of rice husk consumption is governed by two factors (i) the level of steam consumption for parboiling the paddy; and (ii) the efficiency of the furnace to produce the steam. Since the specific fuel consumption (SFC) of the paddy processed is governed by two independent parameters it cannot be used as a designing tool for improved furnace. A profile of rice husk consumption in terms of kg/ton of paddy processed in different rice mills is shown in Figure 3.7.

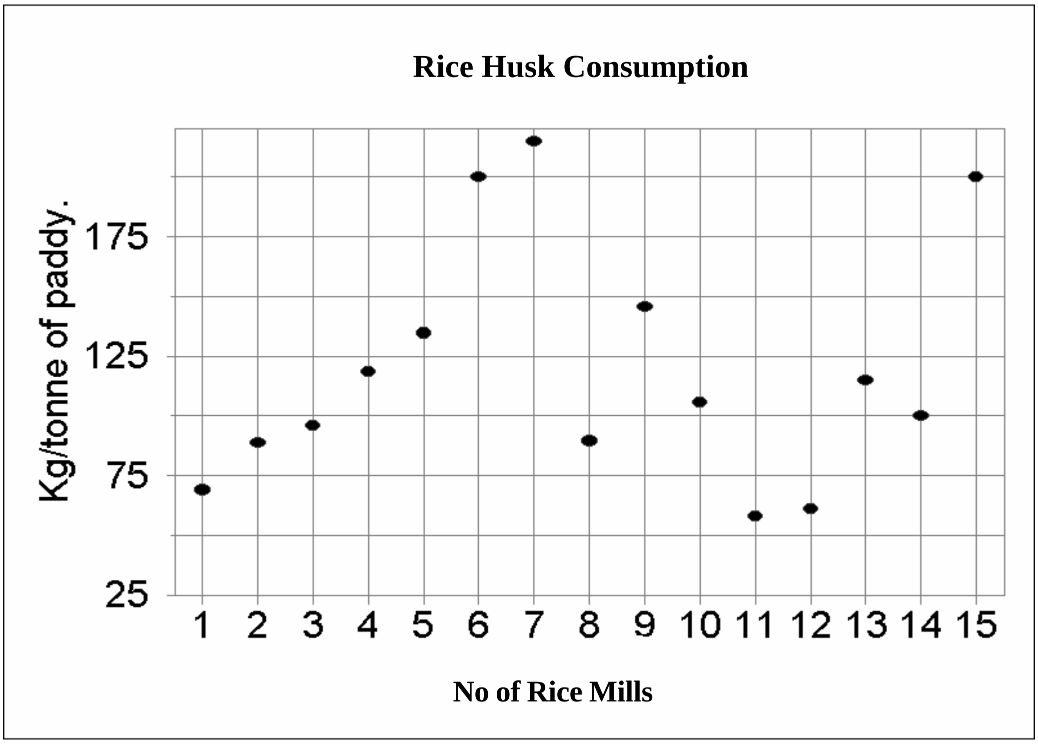


Fig 3.7 Showing the Wide Variations in Rice Husk Consumption in Small Mills

3.2.12 Steam Consumption and Steam Output Rates

Steam Consumption: In comparison to the variation of rice husk consumption for processing the paddy, the steam consumption rate for processing the paddy falls in a narrower range. It is in the range of 115 to 165 kg of steam per tonne of paddy processed.

This is because the ratio of steam consumption to the paddy processed eliminates the factor of the furnace efficiency. **So, the Specific Fuel Consumption for steam generation can be a better parameter for comparing furnace efficiency as it can indicate the level of fuel saving, in the process of paddy parboiling**. Figure 3.8 gives a profile of steam consumption for parboiling of paddy.

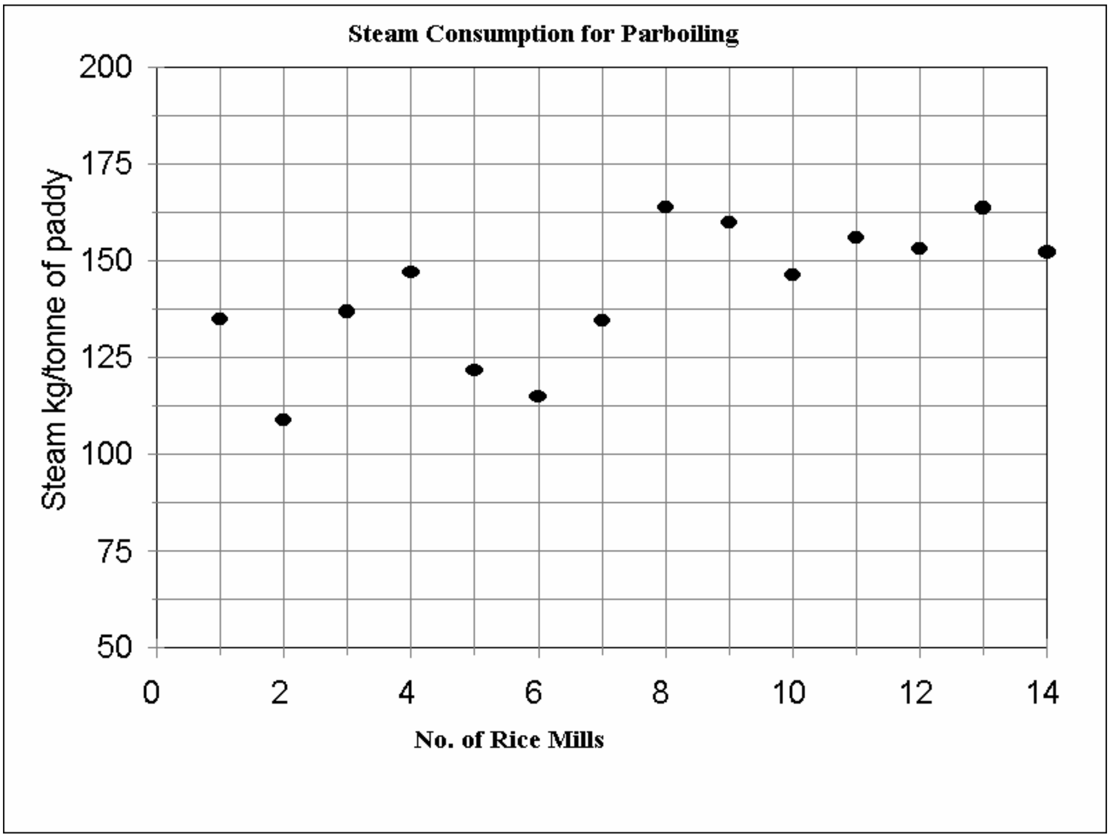


Fig 3.8 Profile of Steam Consumption for Parboiling Paddy

Steam output rate: Though the steam consumption rate per ton of paddy processed falls in a narrow range of 120 to 165 kg/t of paddy processed, a large variation is found in the steam output rate. This is because the paddy-processing rate varies with the location of the cluster where the mill is based, and the practice of the mill owner. The steam output rate varies from 150 kg/h to 550 kg/h. **These numbers clearly indicate that there is a need to go for different capacity furnaces.** Figure 3.9 gives profile of the steam consumption rate of the different rice mill surveyed. The large scatter of the steam flow rates can be seen from the graph provided.

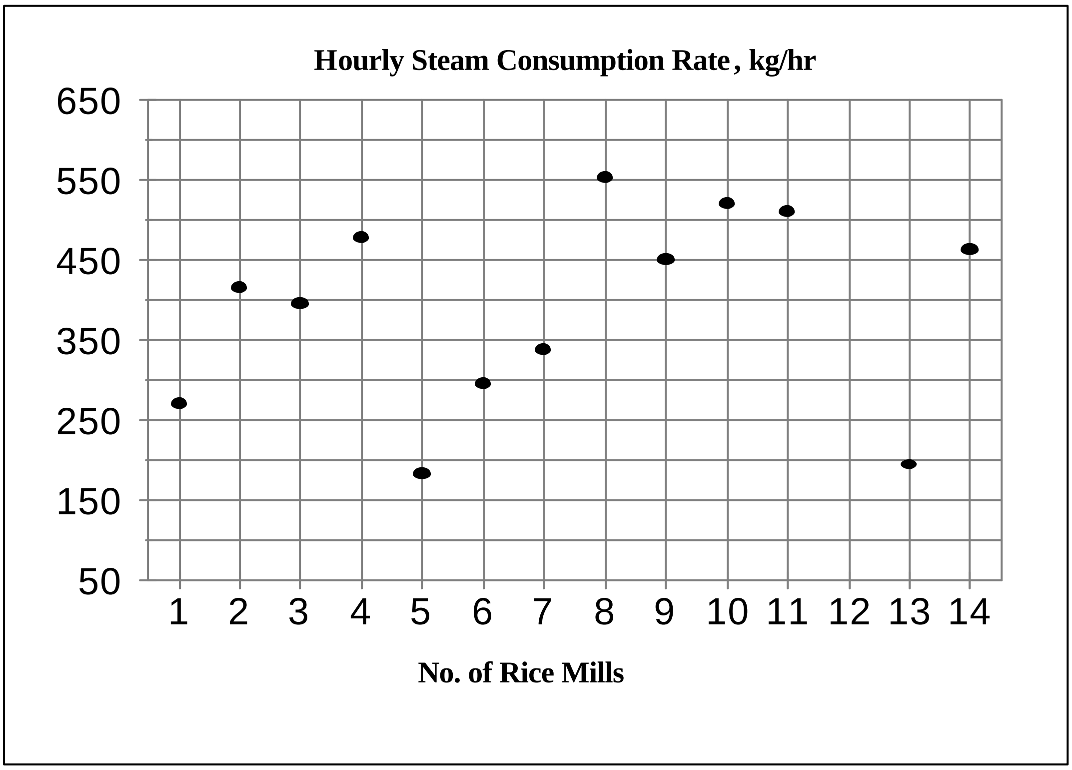


Fig 3.9 Hourly Steam Rate Consumption in Small Rice Mills

It was observed that, with a steam consumption rate of 250kg/h, a mill processes about 1660kg of paddy. In general, in the conventional boilers, the steam is delivered at a pressure in the range of 0.5 to 1kg/cm^2. **If the pressure is increased to 1.5kg/cm^{2,} there is considerable scope to reduce the processing time, which will ultimately reduce the operating time/duration and this will subsequently lead to reduction in fuel consumption.**

The details of paddy processing in the rice mills of Bangladesh are given below in Table 3.2. Details of steam consumption for processing paddy in the different rice mills are provided in Table 3.3.

Table 3.2 Details of Paddy Processing in the Rice Mills of Bangladesh

Sl.No	Paddy Kg/day	Husk produced kg/day	Husk produced kg/ton	Husk consumed kg/day	Husk consumed kg/ton	Surplus kg/day	Surplus kg/ton
1	10050	2483	247	695	69	1788	178
2	7500	2625	350	667	89	1958	261
3	6000	1761	294	575	96	1186	198
4	6000	1760	293	711	119	1049	175
5	6750	1835	272	908	135	927	137
6	4500	1610	358	900	200	710	158
7	4500	1572	349	966	215	606	135
8	11250	2418	215	1007	90	1411	125
9	7500	2362	315	1093	146	1269	169
10	11250	4060	361	1188	106	2872	255
11	16875	6110	362	980	58	5130	304
12	15000	5187	346	920	61	4267	284
13	11250	3475	309	1295	115	2180	194
14	7500	2000	267	750	100	1250	167
15	9000	2700	300	1800	200	900	100
16	8995	2797	309	964	120	1834	189

Source: Field Survey

Table 3.3 Details of Steam Consumption in the Rice Mills of Bangladesh

Sl.No	Paddy kg/day	Steam kg/day	Steam kg/ton	Steam kg/hr
1	10050	1357	135	271
2	7500	818	109	415
3	6000	822	137	395
4	6000	883	147	477
5	6750	821	122	184
6	4500	517	115	295
7	11250	1516	135	337
8	7500	1229	164	554
9	11250	1799	160	450
10	16875	2473	147	521
11	15000	2340	156	511
12	11250	1723	153	787
13	5250	860	164	194
14	7500	1142	1525	462

Source: Field Survey

3.2.13 Summary of the Observations of Traditional Furnaces

- For most furnaces the fuel is fed manually;
- There are many small and big openings on the side walls that contribute to high heat loss factor;
- In all furnaces the flue gas outlet is provided below the base level of the vessel, which leads to high temperature flue gas exit at working level;
- The flue gas carries away a large amount of heat;
- The required air supply for complete combustion of rice husk is not provided, which indicates that the draft from the brick chimney is not sufficient. This is due to the leak of gas on the "long flue gas path";
- Due to insufficient air supply the flame gets out of the furnace through the feeding port in the form of backfire, which affects the person feeding the furnace;
- Rice bran is added with rice husk to enhance and sustain the fire;
- The level of CO (> 10,000ppm) present in the flue gas is much higher than the acceptable standards;
- There is no instrumentation in the system to monitor the pressure/temperature/water levels etc.;
- There is no safety valve to avoid any untoward accidents;
- There is no co-ordination between the person feeding the furnace and the person processing paddy. Hence there is no control of the feeding rate of husk;
- Rice husk consumption varies with furnace efficiency and the parboiling process used, i.e., partial or full parboiling of paddy;
- Ash is removed at an interval of every two hours, while the furnace is in operation. The ash contains a lot of heat and unburnt rice husk;
- As there is no water level indicator the water is filled randomly; generally more than what is required, which also results in inefficient utilization of the rice husk;
- Steam is drawn at a low pressure of about 0.5kg/cm^2, which leads to a processing time of 12-13 minutes. The consumption of rice husk increases with the time required for parboiling;
- The thick black smoke of the flue gas indicates the inadequate air supply to the furnace;
- No O_2 was detected when analyzing the flue gas using "FEM" instrument;
- The heat absorption area provided was not adequate. Major portion of the vessel is exposed to atmosphere;
- The steam consumption rate varies in a large range from 150kg/hr to 650kg/hr; and
- The current cost of constructing a furnace-boiler unit is between Tk 96,000 to Tk 100,000.

3.3 Design Approach and Trial Run with Improved Furnace Mark '0'

3.3.1 Approach Adopted to Design the Improved Furnace

Based on the intensive analysis of the traditional furnace performance, the method of processing and the working conditions, the following points were considered to design the improved furnace:

- Primarily to improve the furnace efficiency by 15% from the current average efficiency of 20%. This means aiming at a minimum of 35% furnace efficiency.
- To improve the furnace efficiency and to reduce the rice husk consumption. Thus, the saved husk can be used for other application like briquetting and poultry feed.
- To design the improved furnace with higher efficiency and at the same time to keep the capital cost affordable and economic.
- The furnace should be able to provide the steam at higher pressure of 2.0kg/cm^2. This will accelerate the processing of paddy. The conventional furnaces deliver steam at 0.5kg/cm^2, which means a longer period for steaming. This in turn affects the quality of rice.
- To create sufficient draft through the chimney so that better combustion of rice husk will be achieved, and go towards improving the efficiency of the furnace.
- Flue gas path is provided around the vessel and the flue gas exit locations are designed to minimise presence of the suspended particle in the flue gas;
- It is proposed to make the vessel with boiler grade MS to reduce the rate of degradation;
- The fuel inlet, the ash removal port, chimney etc., are designed to provide a better working environment;
- The improved design is aimed to enhance the combustion process in the furnace by providing sufficient room and air for rice husk combustion;
- Since CO is present at levels much above the limit of the instrument's measuring capacity, the project aims to bring it down to an acceptable level;
- Safety aspects are addressed and care taken to avoid any situation that could lead to explosion or accidents, affecting the workers;
- It is planned to introduce minimum essential instruments like safety valve, water gauge and pressure gauge, temperature gauge etc.;
- The new improved furnace will be constructed using the same materials that are used in the construction of conventional furnaces;
- The technicians/*mistris* who construct the traditional furnaces can be easily trained to fabricate the new improved furnace. So the construction method of the new furnace would not complicate the process of uptake;
- To increase the area of heat absorption and to reduce the heat loss through the flue gas; and
- The improved furnace will be proposed in two capacities to meet the steam requirement of different users.

3.3.2 Design of the New Improved Furnace

After a detailed and thorough analysis of both conventional furnaces -with cylindrical vessel and semi-cylindrical vessel performance, the factors required to draw the new furnace design were derived. These are

(i) the scenario of husk production; and (ii) consumption for parboiling and the furnace efficiency. The new improved furnace designing has the following five stages:

Stage 1: Design of furnace 'Mark 0' based on the analysis of data and observations made of the conventional furnaces.

Stage 2: Fabrication and installation of the demonstration unit at a selected user's mill.

Stage 3: Operation and modifications of 'Mark 0' following observations and user feedback to develop Mark 1.

Stage 4: Based on user feedback, arriving at a fine tuned version of 'Mark 1' (from Mark 0), adapted to field conditions.

Stage 5: Arriving at final replicable designs of improved furnaces - Mark 1 and Mark 2. Mark 1 is designed to cater for lower capacity end-users, and Mark 2 is for higher capacity end users of the small scale rice mill sector.

3.3.3 Concept of the Improved Furnace

Based on the analysis above the model for the new furnace was developed to provide improved combustion efficiency and a clean working environment. Figures 3.10 and 3.11 illustrate the concept of the improve furnace.

The components of the improved furnaces were derived from field observations and the need to meet the requirements outlined above.

(i) *Rice husk feeding port*: As discussed earlier the fuel inlet is large in a conventional furnace, which leads to heat loss through radiation. It also causes dangerous flashbacks. To avoid these scenarios, a smaller opening is provided to feed the furnace. The worker is placed more comfortably to feed the husk in accordance to demand for steam. The smaller opening will eliminate flash fires and improve working conditions. It will reduce radiation heat loss and contribute to efficiency improvement.

(ii) *Grate*: None of the furnaces in small-scale rice mills have a grate. In general there was a resistance among rice mill owners to install a grate. However, a grate is provided as an option for the rice mills in case the owner is interested in installing one in an improved furnace.

(iii) *Fire zone*: An appropriate fire zone is designed to overcome the constraints of the grate and to achieve a higher efficiency. When the furnace is cold the rice husk needs to be in the air for a longer duration. This is for the rice husk to attain the ignition temperature and to burn the husk. When the furnace is hot (above 750^0C), the rice husk catches fire immediately so it requires a shorter time to be in the air to achieve a complete combustion. Space/fire zone is designed to meet both these conditions of combustion. The fire zone is deeper when it is cold. As the duration of furnace operation increases, because of the high temperature ash accumulation in the fire zone, the furnace temperature increases and the depth is reduced. This combination ensures a maximum combustion of rice husk, to improve the efficiency.

(iv) *Air inlet*: The husk feeding port acts as the primary air inlet. Two more ports on the sidewalls are provided to supply secondary air. The air supplied through the ports is distributed in the combustion zone to achieve a better combustion of rice husk and contributes to increased furnace efficiency.

(v) *Chimney*: A chimney with 300 mm (13”) diameter and 10.67 cm (20’) height from the ground level is proposed for exit of flue gas and to create adequate draught that will supply the required amount of air for complete combustion of rice husk. In all the conventional furnaces it was observed that the oxygen supply was insufficient. The improved furnace with adequate air supply and complete combustion of the husk will improve the efficiency. Adequate supply of O_2 will reduce the presence of CO in the flue gas. Present CO level in the conventional furnace flue gas is above 10, 000 ppm, which is much higher than the air quality norms. The new chimney design will help in providing a clean environment, in addition to the improvement in efficiency. The chimney is proposed to be mounted on top of the furnace and anchored on 3 sides (at 120^o) to overcome the stress due to heavy winds of monsoon season.

(vi) *Ash port*: An ash port is provided on a sidewall of the furnace at the ground level. The size of the ash port is selected in such a way that it can also acts as a manhole for servicing the furnace whenever it is required. The ash port opening is made smaller to reduce the heat loss in comparison to the conventional furnaces. Ash port dimensions are 60cm wide and 60cm high. The height is enough to enable easy and comfortable removal of ash. The ash port is closed with a RCC slab of 60cm x 60cm. Two handles are provided for easy handling of the slab; to close and open the ash port.

(vii) *Brick wall*: The method of construction of the brick wall is similar to that of the conventional furnace. Locally available clay mixed with rice husk was used to construct the wall. Mixing of rice husk in the clay reduces the thermal mass in the wall. It also reduces the heat loss through the sidewalls of the furnace.

The foundation for the brick wall is prepared by (i) ramming of the soil and levelling with a sand layer; and (ii) laying plain cement concrete made out of brick ballast, sand and cement at a lean ratio of 1:3:6.

The external surface of the wall is plastered using 1:6 cement mortar to protect the wall from heavy rains during the monsoon season.

(viii) *Vessel*: The vessel dimensions were arrived at from the cylindrical vessel based furnaces used at Mymensingh clusters and in the northern parts of the country. Cylindrical vessels are ideal to use in the furnace as against the semi-cylindrical vessels. The pressure distribution is more uniform in the cylindrical vessel than in the semi-cylindrical vessel. Though there is a large variation in the thickness of the metal sheet used for fabricating the vessel, for new improved furnace it is proposed to use 5 mm thick MS boiler grade metal sheet for making the vessel. None of the vessel with conventional furnace is fabricated with boiler grade MS sheet. The use of low grade MS sheet results in faster degradation of vessel and increases the chances of vessel explosion and accident. A local boiler manufacturer was identified for fabricating the vessel of the improved furnace. The vessel is provided with saddle arrangement for better support.

(ix) *Water inlet and steam outlet*: A one inch socket (2.54 cm) for water inlet and steam outlet was provided at the top of the boiler.

(x) *Instrumentation*: It is proposed to incorporate adequate instrumentation in the design of the improved furnace. A level gauge is to be provided to monitor the water level inside the vessel. This will ensure that the vessel is filled with only the required quantity of water. Over filling the vessel results in wastage of heat; more water will need more time and energy for steam production. To save time and energy it is essential that the vessel is filled with only the required amount of water. The quantity required depends on the steam consumption level.

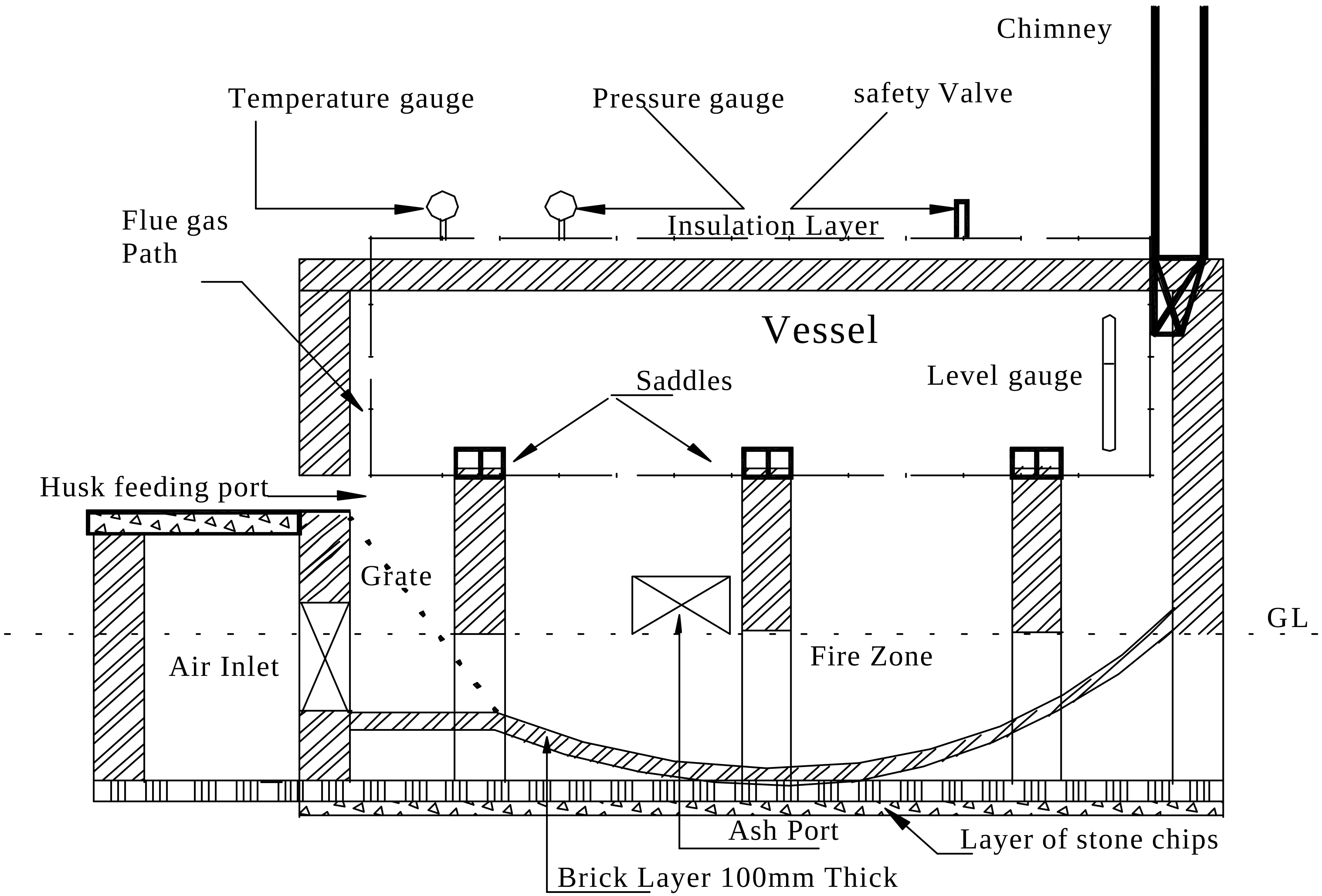


Figure 3.10 Concept and Components of the Improved Furnace with Grate Arrangement

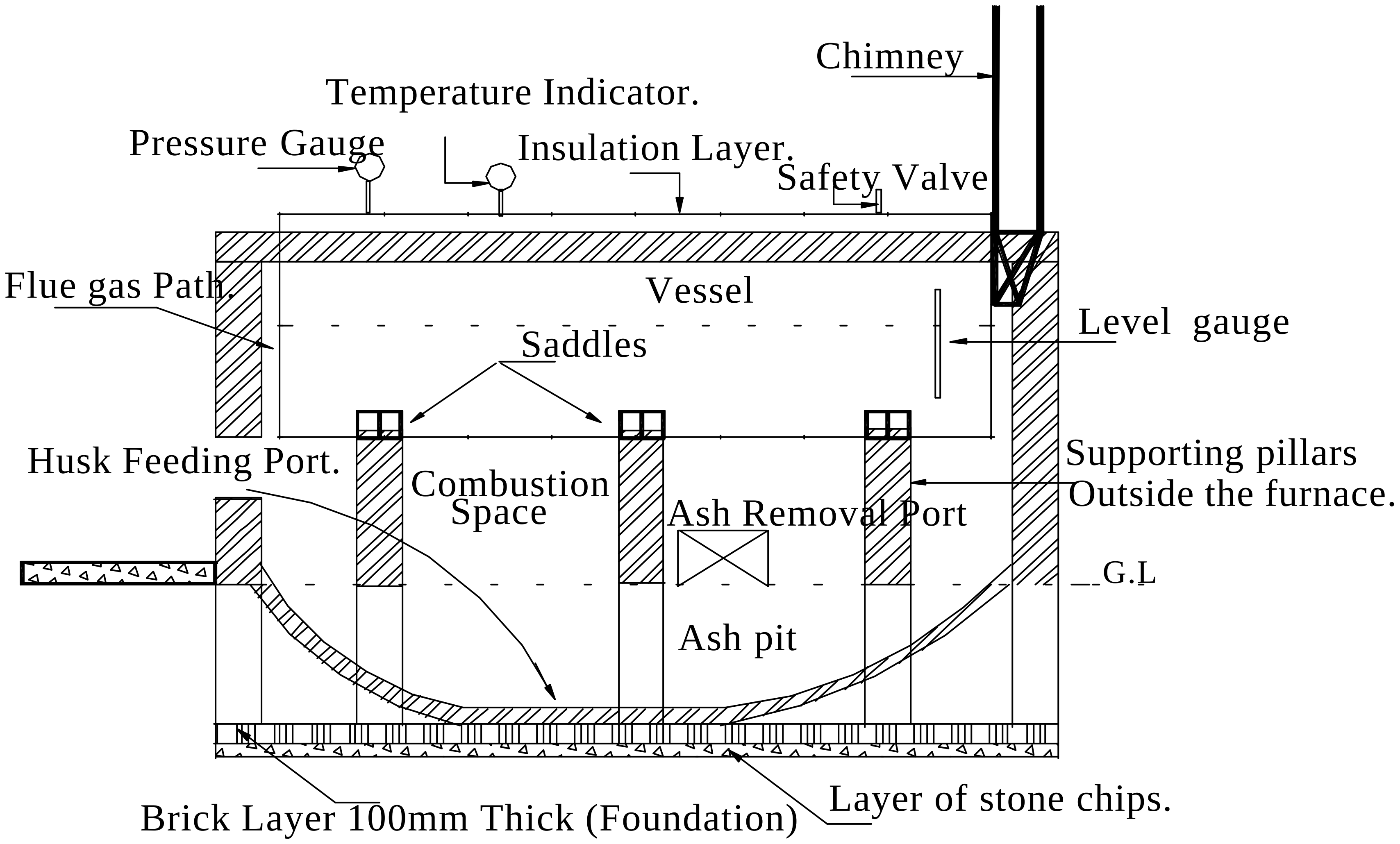


Figure 3.11: Concept and Components of the Improved Furnace without Grate

3.3.4 Vessel Fabrication

A local, government accredited boiler manufacturer was contracted to fabricate the vessel to ensure quality. The company was also contracted to provide all instrumentation for performance monitoring and to install safety measures such as safety valves etc. The vessel was tested for its pressure holding capacity through hydraulic pressure tests before being taken to the site. Hydraulic pressure test is necessary to confirm the working pressure of the vessel and to maintain a safe working atmosphere. The relevant diagram of the vessel, length and width sectional drawings, saddle arrangements for vessel support and list of equipment, were provided to the manufacturer.

3.3.5 Vessel Specifications

The paddy processing capacity of the rice mill varies from place to place and cluster to cluster but the vessel volume capacity is similar in all the rice mills. The vessel for the improved furnace is designed to hold the same capacity of the water as is the existing practice.

The specifications of the vessel are given in Table 3.4

Table 3.4 Showing Vessel Specifications

Size	1165 mm dia × 3660 mm L (approx.)
M.O.C	M.S. Sheet 5 mm thickness
Safety valve	2.54 cm (1") dia
Main steam valve	2.54 cm (1") dia
Water inlet valve	2.54 cm (1") dia
Pressure gauge	10.16 cm (4" dia) (0-70 psi)
Temperature gauge	2.54 cm (1") dia (0-150^{o} C)
Water level glass	1.27 cm (½") dia 20" L (approx.)
Blow down valve	3.81 cm (1½") dia
Manhole	45.72 cm (18") dia

3.3.6 Construction of Improved Furnace

Detailed furnace construction drawings along with dimensions are provided in the Appendices 3-C, 3-D, 3-E and 3-F for the different models and for the different components of the furnace.

(i) *Site selection*: Site selection for construction of a furnace plays a very important role in ensuring ease of operation and comfortable working conditions. Preferably the new improved furnace should be constructed where the conventional furnace is located. The next best location could be adjacent to the existing furnace or a place nearer to the processing platform. The shorter the distance of the furnace from the processing platform, lower the heat loss from steam pipes, helping in further reductions of rice husk used. The site proposed for the furnace construction should have a higher water table at the given location of the rice mill. A low water table will increase the duration of initial firing due to the high thermal conductivity of soil. The site should not be very close to drainage or canal, if any, and it should be at the same level as the water flowing into the drainage system. An appropriate available site should be selected for the furnace construction to achieve better efficiency and higher rice husk saving.

These factors were taken into account in selecting a site for the demonstration unit. The mill selected is in a cluster in Gazipur district, in proximity to BRRI. This was important for logistical reasons. The owner had to be kept informed as the project progressed; the construction and the subsequent trial runs required close monitoring and interaction.

(ii) *Landscaping and foundation*: The site selected for construction of the furnace has to be first levelled and cleared of any loose soil. The excavation for construction of the furnace section below ground level has to be undertaken as per specifications. The floor of the excavated portion is then well packed to give a solid foundation for the construction of furnace walls. The base level of the pit has to be levelled with 2.54cm (1") thick layer of sand and brick blast. Pre-cast concrete of 75mm thickness is laid on top of the sand layer. Now the pit is ready to lay the foundation.

(iii) *Preparing the Foundation*: Foundation is the main component of the furnace, since the load of the vessel and sidewall is distributed on it. The foundation layer must have a width of 450cm with a vertical brick wall rising to a height of 100 mm. Foundation layer is made with cement to mortar ratio of 1:5. Foundation layer marking is to be done very carefully as per the dimensions given in the foundation drawing. This is important to avoid any error and difficulty of loading the vessel on the furnace. The foundation should be made accurately to scale and levelled.

(iv) *Sidewalls*: Sidewalls are constructed using local clay and rice husk mixture. The "clay +husk" mixture has to be prepared at least a day in advance with the required proportion of clay, rice husk and water. Sidewalls have to be perfectly vertical and levelled. Maintaining plumb line and single levelled surface are essential for a strong structure. Sidewalls have to be constructed with a uniform thickness of 23cm. Three pillars are integrated along with the wall structure. The external side of the brick wall has to be plastered with cement to mortar ratio of 1:6 to protect it from the rain.

(v) *Combustion zone*: The combustion zone/fire zone of the furnace has to be lined with (1) a 25 mm thick layer of sand; (2) with a layer of vertical brick, having a thickness of 100 mm; and (3) a layer comprised of a mixture of Brick Ballast (20mm) sand and lime. The mortar ratio would be 1:2:4 (lime, sand, brick ballast). The floor of the combustion space is to be made with a slope as shown in Appendix 3-D. This is done by filling sand into the furnace as per requirement.

(vi) *Placing the Boiler Vessel*: The boiler vessel of the furnace should be placed when the integrated pillar level reaches the required height. The vessel should be placed at the centre of the furnace providing a uniform gap for flow of the flue gas around the vessel. After placing the vessel on the sidewalls, their construction can be continued as shown in Appendix 3-D. The wall thickness reduces along with the flue gas flow pattern. The opening for the flue gas exit is to be provided at the top of the furnace as shown in the Fig 3.11. A small portion on the top of the vessel should be left uncovered for installation of the instruments like water level indicator, pressure gauge and safety valve.

(vii) *Chimney Installation*: A foundation has to be made at ground level for installing the chimney. The foundation has to be made with a 1:2:4 mortar having a thickness of 150 mm. 4 bolts as per the template of the chimney base are to be embedded into the pre-cast cement foundation for the chimney. The chimney should have an opening to connect with the flue gas exit of the furnace as shown in Appendix 3-D. A detailed drawing of chimney installation at the ground level is given in Appendix 3-F.

(viii) *Curing of the furnace*: The furnace has to be cured by wetting the cement-plastered section of the wall for the duration of one week. The furnace is then left to dry naturally for a period of 3 to 4 weeks. After natural drying of the furnace walls the furnace is fired with low level heat for 3 to 4 days for 4 to 5 hours each day to remove the moisture trapped in the sidewalls of the furnace. Allow the furnace to rest for 2 to 3 days after pre-heating. The furnace is then ready for operation. The total process of curing, from curing the civil structure to the pre-heating stage, will take around 40 to 45 days. A systematic follow up of the curing process is essential to avoid any major crack in the civil structure. If the furnace is not properly pre-heated, it will take time to sustain the fire inside the furnace. To have a better drying and pre-heating of the furnace, it will be ideal to construct the furnace during dry months. One should avoid construction of the furnace in the monsoon season, as this will create problems in curing, drying and pre-heating of the furnace.

3.3.7 Material Requirements for the New Furnace (civil components)

The materials required to construct the new furnace are given in Table 3.5. These requirements are for a furnace designed to supply steam at a pressure of up to 2-kg/cm^2 and with an output rate of 500 kg/h.

Table 3.5 Civil Components Required for the New Furnace

Sr. no	Components	Quantity
1.	Sand	200 cft
2	Cement	400 kg
3	Stone chips	100 cft
4	Brick	4500 Nos.
5	Fire brick	300 Nos.
6	Acoset	300 kg
7	8 mm MS bar	80 m
8	C.I Bar 25 mm sq 600 mm length	20 Nos.
9	M S channel 50 mm width (2 pieces)	1.35 m

3.3.8 Features of the new Improved Furnace

The main features of the new improved furnace are summarised below. Views of the improved furnace are provided in Plates 3.1 and 3.2.

1. Designed to achieve a minimum of 15% improvement in the efficiency of the existing furnace.
2. Safety measures are taken into consideration while designing the furnace.
3. A water level gauge is included to the monitor water level in the vessel.
4. Fuel feeding and ash removal systems are modified to facilitate operation.
5. Factors of human comfort are taken into account while designing the furnace, in addition to the efficiency improvement.
6. The operator will not receive as much direct radiation heat as in case of the conventional furnace.
7. The operator can sit on a platform to feed the rice husk in to the furnace. The air flows below the platform, keeps it at atmospheric temperature and helps to improve working conditions.
8. The vessel is well supported with appropriately designed saddles for stability.
9. An inclined grate is provided to ensure supply of adequate air and enhance combustion of rice husk.
10. Pipe made of MS sheet will be used as the chimney, instead of massive brick construction. This keeps the cost low.
11. Combination of local clay and husk has been used to construct the sidewalls.
12. In case of the conventional furnace, the flame and smoke comes out from below the vessel and from around the furnace, and within the working height of one meter above the ground level. These problems were avoided in the improved furnace since

the flue gas exits only through the chimney. The will also provide an improved working environment and air quality.

13. The furnace is designed in such a way that the flue gas will carry lower amount of dust particles in comparison to the conventional furnace, because of its low velocity exit from around the vessel.
14. The husk saved can be briquetted. Rice husk briquettes have a good market value and can contribute to improved income of the rice mill operators. The bran saved is in much demand and could fetch a good price. These benefits are discussed in Chapter 5.
15. Flue gas heat can be used instead of diesel and electricity for briquetting units attached to rice mills.

Plate 3.1 View of the Furnace from the Side Showing the Ash Removal Port and Secondary Air Ports

Plate 3.2 View of the Furnace Showing the Fuel Inlet Port and Furnace in Operation

3.3.9 Trial Runs with Improved Furnace Mark '0'

A parallel steam outlet pipe was provided from the demonstration unit to the processing bins so that during the period of the trial runs and modifications to the improved furnace, the user was able to use the conventional furnace without upsetting the routine paddy processing.

Ignition during the trial run took longer than anticipated because of high moisture content in the sidewalls and floor of the furnace. This was because the furnace was constructed during monsoon season. As a result the clay mortar and bricks of the sidewalls did not reach the required level of dryness for igniting the furnace. For a period of 3 days the furnace was heated using firewood to dry the sidewalls. After removal of moisture from the sidewalls and floor of the furnace the initial firing time was reduced.

Initially a mixture of rice bran and rice husk was used till the furnace was heated and able to sustain the fire. Once the furnace was in continuous operation only rice husk was used as feed. No bran was necessary. At this stage one basket of husk-bran mixture was found to be sufficient to start and run the furnace when it was at cold condition.

During the trial runs of the improved furnace, the designated worker was trained to feed the husk at a lower rate. The differences in the feeding rates of the rice husk in the conventional furnace and in the improved furnace were made clear to the worker so that he did not feed more than what was required.

3.3.10 User Feedback

User feedback provided the main guidelines for the fine-tuning and modifications of the improved furnace to suit field conditions. User satisfaction is fundamental to achieving an acceptable and replicable design. Hence, trial runs and the process of improving furnace design and modifications were carried in the presence of the user/owner and the furnace operator. The major feedbacks received from them are:

- The operator at the mill where the dissemination unit had been installed was not comfortable with use of a grate in the furnace.
- The owner of the mill wanted to increase the chimney height from 12 feet to 20 feet even though it was not necessary.
- The operator and the owner both wanted the flame to reach the end of the furnace as in the case of the conventional furnace.
- Need to quicken the start-up time of the furnace.
- Vessel to be supported without using pillars inside the furnace as pillars created problems for removing ash.
- Larger diameter of the steam pipe to have higher steam flow and speedier processing of paddy.
- Ash port is needed only on the sidewall instead of on the rear wall as provided in some of the conventional furnace.
- A marking on the water level gauge is needed as a reference point to indicate the level to which the vessel should be filled during routine operations.

3.3.11 Furnace Modifications Based on User Feedback

The following modifications were made on receiving the feedback:

- The furnace was modified to fire the rice husk without using the grate, at the same time without affecting the combustion efficiency of the rice husk;
- The fire zone was modified to give a longer residence time for the husk during the initial firing period. This means that the rice husk will be in the air for a longer period to burn when the furnace is cold. The husk will be in the air for a shorter time when the furnace is hot. When the furnace is hot, at about 750^0C, the husk ignites more quickly. It takes longer time to ignite with a cold start. With these modifications to the furnace Mark ‘0’ the initial ignition time was reduced substantially;
- By increasing the combustion space, flame stability of the husk is enhanced and use of rice bran for initial ignition was reduced.
- The intermediate pillars used to support the vessel were removed;

- A 7.5 cm by 5 cm cast iron bar was used to replace the pillar. The load of the vessel is distributed on the sidewalls instead of the pillars in the furnace. The same saddles were used to support the vessel on the cast iron bar;
- Chimney height was extended by another seven feet as per the user feedback;
- An ash removal port was provided on the sidewall of the furnace; and
- The fuel inlet port was made smaller (30cm x 45cm) to avoid the radiation heat reaching the worker feeding the furnace.

3.3.12 Test Runs and Training

Test runs were conducted to parboil paddy using the improved furnace. Before and during the test runs, the firemen and operators were trained to use the instrumentation of the furnace-boiler system. They were taught:

- To use the water level gauge and how it indicates the water level in the vessel;
- To read the temperature gauge and to have an idea of the power input level, which will be useful in reducing start up duration;
- To read the pressure gauge and to know the processing time.
- To remove the ash at the required interval;
- To use the steam effectively without wastage; and
- How the safety valve functions. This was explained prior to its use in routine operations. This was done by actually demonstrating how the valve operates when the pressure increases beyond a safe limit.

3.3.13 Observation during Test Runs and Data Analysis

Several test runs were conducted in the presence of the team and the users of the rice mill. The rice husk feeding rates during all the test runs were in the range of 115 to 130 kg/hr. The steam consumption rate was 300 kg/h at 1.5 kg/cm^2 pressure of steam. The flue gas from the improved furnace was analysed to study the air supply for complete combustion and the reduction in the CO-level. The result of the flue gas analyses of the improved furnace and the conventional furnace are given in Table 3.6.

Table 3.6 Results of flue Gas Analysis of Mark 0 and Conventional Furnace

S No	Component	Measures for Mark 0	Conventional Furnace
1	Ambient temperature	26^{o}C	27^0 C
2	Flue gas temperature	440^{o}C	720^{0}C
3	CO	3300 ppm	>10,000 ppm
4	O_2	4.5	Nil

Steam production efficiency was calculated from the steam output rate and rice husk-feeding rate. The power of the furnace (i.e., thermal output) is calculated from the water temperature rise during the initial stage. The graph in Figure 3.14 shows the water quantity in the vessel.

The graph showing the rise in temperature during the initial period is given in Figure 3.15. Different sets of reading taken to calculate the furnace efficiency is given in Table 3.7. The heat flow details are given in Table 3.8.

Table 3.7 Details of Temperature Rise with Time

Sl.No.	Duration	Time	Temp In^{0}C	Pressure In Kg/cm^2	Water level In cm
1	0	11.15	45	0	70.5
2	15	11.30	60	0	70.7
3	15	11.45	85	0	70.9
4	15	12.00	100	0.2	71.2
5	15	12.15	110	0.5	71.5
6	15	12.30	120	0.9	71.8
7	15	12.45	130	1.2	72
8	5	12.50	140	1.5	72.3
9	7	12.57	145	1.8	72.3

Table 3.8 Results of Water Boiling Test

Sl No	Details	Test 1	Test 2
1	Water	2600.00lt	2600.00 lt
2	Temperature initial	45.00°C	45.00°C
3	Temperature final	85.00°C	60.00°C
4	Time	30.00 min	15.00 min
5	Fuel	130.00 kg/h	100.00 kg/h
6	Rise in temperature	40.00 °C	15.00 °C
7	Husk	65.00 kg	25.00 kg
8	Combustion Efficiency	47.06%	45.88%

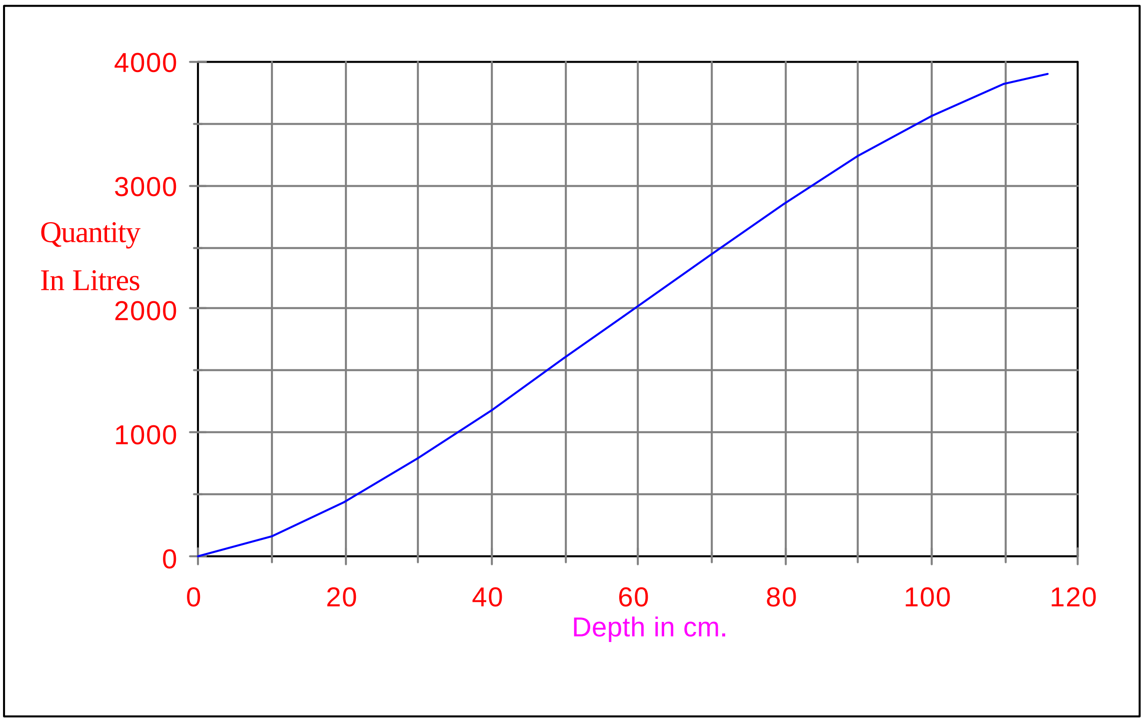


Figure 3.14 Water Quantity in the Vessel with Respect to Water

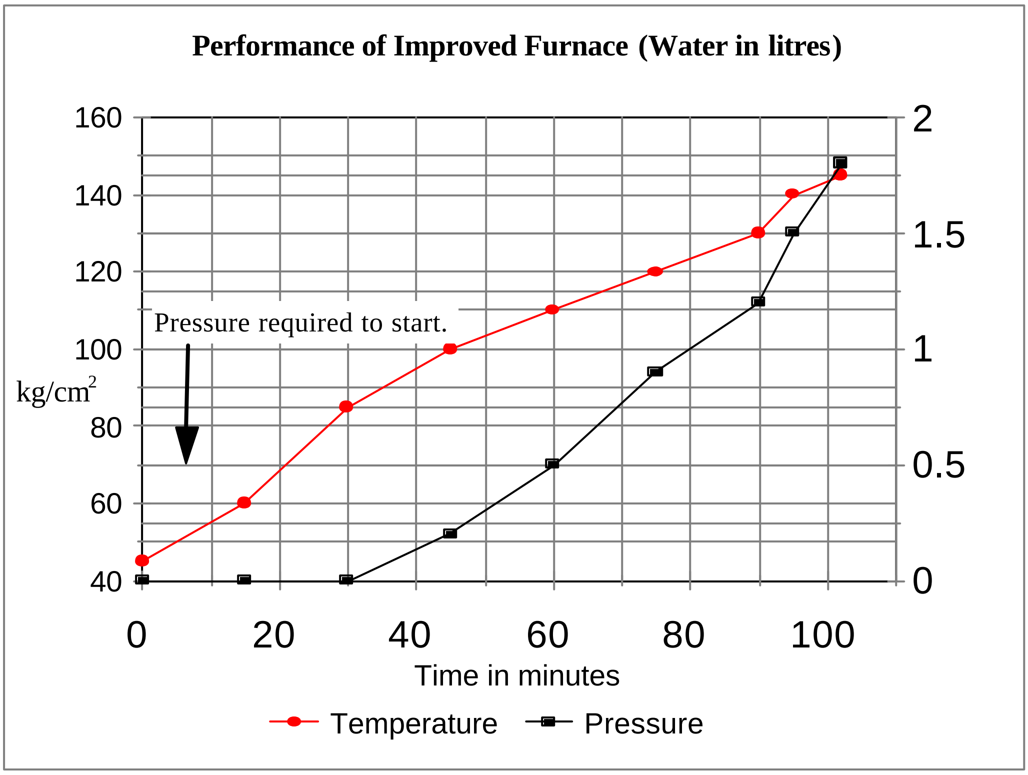


Figure 3.15 Performance of Improved Furnace

3.3.14 Heat Flow Analysis of Mark 0

A detailed heat flow analysis was done to assess the heat loss in different component. Figure 3.16 shows the details of heat flow/heat loss through different components. It can be seen that:

(i) the heat loss through the flue gas has been reduced;
(ii) the CO emission was brought down to the acceptable level;
(iii) the increase in O_2 level shows the adequate air supply for improving the combustion efficiency of the rice husk has been achieved;
(iv) the O_2 level indicates that the chimney is functioning to the level of expectation by creating adequate draft;
(v) smoke level is found to be lower than the conventional furnace; and
(vi) the ash removed from the furnace has less carbon content (white/grey in colour, instead of black). It also indicates better combustion of rice husk.

Furthermore, the overall furnace efficiency has improved to an average of 44% in comparison to the conventional furnace which has an average efficiency of 20%, which means that the improved furnace is twice as efficient as the conventional furnace.

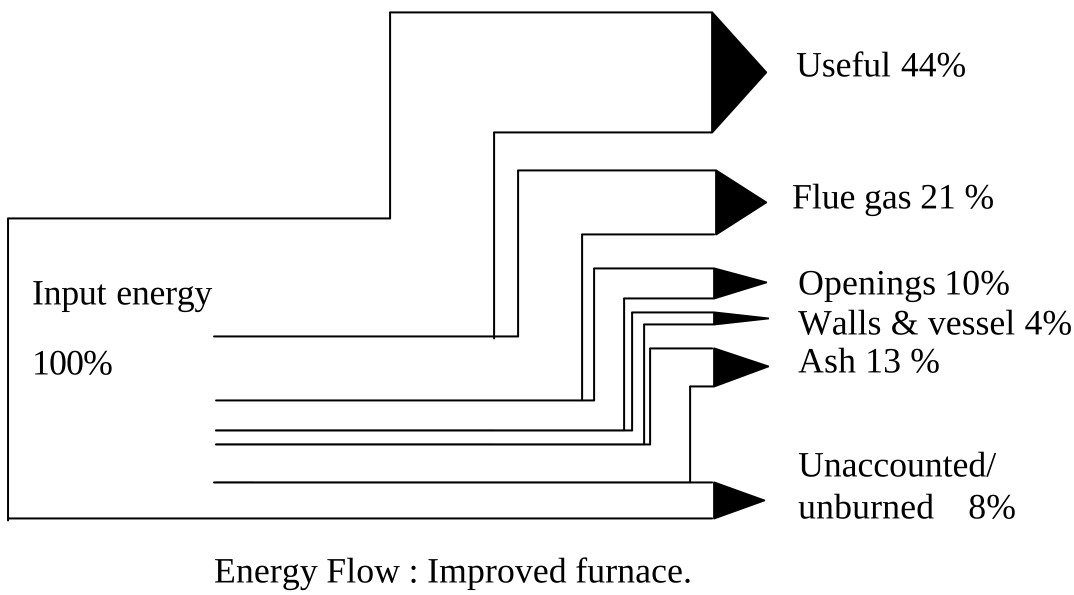


Figure 3.16 Heat Flows through Different Components for Improved Furnace

3.3.15 Field Tests

Field tests were conducted after the test runs. During the field tests the owner of the mill operated the furnace using trained workers and operator and without the presence of the project partners. The persons involved in collecting the field data of the conventional furnace were employed to collect the data during the field test of the improved furnace. The results of the field tests are given in Table 3.8. The field tests indicate that over a period of time, the operators learned to use the furnace more efficiently; to correct the rate feeding of rice husk; and to fill the vessel with the right amount of water by using the level gauge. The field results also indicate that the operators used the instrumentation provided in the system effectively. In Table 3.9 the comparison of the specific fuel consumption in the conventional furnace and in the improved furnace provides a clear picture of improvements in efficiency and fuel savings achieved.

Table 3.9 Comparative Test Runs for Conventional and Improved Furnaces

		Conventional furnace	**Improved Furnace**	
	Details	**Regular Operations**	**Under Controlled Condition ***	**Regular Operation ****
1	Husk feeding rate (kg/h)	320	130	110
2	Steam production rate (kg/h)	413	300	326
3	Specific fuel consumption(SFC) (kg husk/kg steam)	0.77	0.43	0.35
4	Efficiency (%)	24	43	53

* Test runs carried out in presence of project team – average of 4 test runs

** Test runs carried out by the mill operators – average of 2 test runs.

It can be seen from the above table that the enhancement in combustion efficiency is about 29% during regular operations. The Specific Fuel Consumption for steam generation was calculated; it shows an average fuel savings in the range of 44% to 55%.

Based on the results of the field tests, one can say with some confidence, that the existing furnace operators can be easily trained to operate the improved furnace. The user and the operator felt comfortable to operate the new furnace and realised the benefits of reduction of rice husk used. The workers appreciated the improved working conditions with lower ambient heat and greater safety standards.

3.3.16 Final Design – Mark 1 and Mark 2

As noted earlier, on the basis of production capacity and steam requirements the small scale rice mills can be grouped into two categories. These are (i) the users at the lower end who require steam at the order of 150 to 350kg/hr; and (ii) the users at the higher end who require steam at pressure of more than 350kg/hr. It is important to cater to the needs of both these groups to enhance uptake. Hence, following the modifications to Mark 0 made after trial runs and field tests, two designs- Mark 1 and Mark 2 were developed for replication and dissemination. This strategy provides furnaces with two different capacities to better match the technical requirements and the financial abilities of the different user groups within the sector.

Improved Rice husk fired furnace - Mark 1: The Mark 1 furnace is designed for use in rice mills with capacity to process up to 6000 kg/day. The size of the vessel is 2500mm in length and 1165 mm in width. The furnace is designed to have a steam delivery capacity of 150 to 350 kg/hr. Within Mark 1 design, two furnace types are proposed. These are (i) fire zone with grate arrangement; and (ii) fire zone without the grate arrangement. Based on the actual steam requirement on a day to day basis, the required amount of water can be filled in the vessel with the help of the water level gauge. Husk feeding can be controlled according to the steam flow and the pressure level.

Improved Rice husk fired furnace - Mark 2: Mark 2 furnace design parameters are similar to that of Mark 1. Width wise dimensions of the vessel and furnace are the same as those of Mark 1. This is to make the construction of furnace and vessel fabrication easier for the local *mistris* and manufacturers. The grate dimensions are such that it can be used in both the furnaces. Only the length of the furnace and the vessel were modified to increase the capacity of the furnace. Mark 2 can be installed in rice mills, which process paddy in the range of 6000 kg/day to 10000 kg/day. The water can be filled into the vessel according to the average daily steam consumption level. Depending upon the steam and the pressure level rice husk feeding rate can be controlled.

Detailed drawings for the construction of furnaces Mark 1 and Mark 2 are given in Appendix 3-D and 3-E, respectively. Appendix 3-F illustrates the installation of the chimney at the ground level as per user demand.

3.3.17 Comparison of Performance

The furnace performance was compared with different ambient conditions and with different levels of cold start. A substantial reduction in the flue gas temperature from 720°C to 440°C was achieved in the improved furnace. The CO level was brought down well below the acceptable norms of air quality standards. In general the conventional furnaces process the paddy at steam pressure 0.5 kg/cm^2. The improved furnace processes paddy with a steam pressure of 1 kg/cm^2. This brings down the processing duration to 6 to 7 seconds; the conventional furnaces take about 13 seconds to process a bin of paddy. The performance comparison is given in Table 3.10.

Table 3.10 Comparison of the Results Obtained from Conventional and Improved Furnaces

Sl No	Component	Unit	Conventional Furnace	Improved Furnace
1	Ambient	^oC	27	26
2	Flue gas temperature	^oC	720	440
3	O2 content	%	Nil	4.5
4	CO content	ppm	>10000	3300
5	Steam pressure	kg/cm^2	0.5	1.0
6	Efficiency	%	20	42
7	Processing duration	Min	13	6
8	Cost of making Furnace-boiler unit	Tk	95,000	64,000

It is pertinent to summarise the performance improvements:

- The improved furnace was operated using the rice husk alone. No bran was necessary for initial firing.
- Improved efficiency results in savings of rice husk.
- Importantly, the cost of constructing an improved furnace and boiler is less than the current cost.
- The operators learned to feed the rice husk according to the required rate.
- The operator learned to use the instrumentation. This indicates that the participatory approach to improvements in work practices used can be successful.
- The furnace was fired with different types of rice husk, i.e., husk from half parboiled and full parboiled paddy, without affecting its efficiency.
- The lower feed rate of husk makes work easier for the firemen.
- Low radiation through the feeding port makes for easier working conditions.
- Low CO content means a less polluted working environment.
- Reduced flue gas temperature results into reduction of ambient temperature in the working area.
- High-pressure steam reduces the processing time. However, this could lower the demand for labour unless the owner increases the daily production.
- Flame does not exit from the ports of the furnace allowing workers to move around freely.
- Water level gauge indicates the quantity to be filled and water available for processing etc.

- Pressure gauge/temperature gauge indicates the level of performance and required husk feeding rate.
- The safety valve ensures that there is no possibility of an explosion. Thus, it promotes a sense of safety among the workers.

3.4 Potential Benefits

The potential benefits generated by improved furnace-boiler design are discussed here. This section explains how lower costs were achieved; the levels of rice husk savings made and the increased profitability for owners; and the improvements in working and environmental conditions for the workers.

3.4.1 Material and Capital Costs

The improved furnace is designed to use the same material that is used for the construction of conventional furnace. Table 3.11 shows the savings been made in civil components used.

- Bricks of same quality but fewer in number are used in the improved furnace. This is because the metal chimney of the improved furnace largely eliminates the work and material involved in the construction of the massive masonry structure for flue gas path and chimney, used in conventional furnaces. Thus, there are reductions in material and manpower requirements and in cost.
- Building mortar is the same as used in the conventional furnace, which is a mixture of clay and rice husk.
- The local *mistris* constructing the conventional furnace can be easily trained to construct the improved furnace.
- The weight of the vessel is also reduced because of uniform thickness of the metal sheet selected for its fabrication. In conventional furnaces, the vessels are heavier as a thicker MS plate is used.
- Through an appropriate combination of materials the capital cost was brought down in such a way that the capital cost of the improved furnace is lower than that of the conventional furnace.
- Since the capital cost of the improved furnace is comparable or marginally lower than the cost of the conventional furnace the question of the duration of payback period does not arise.
- If the furnace is used with a grate, the rate of return will be increased even further due to increased combustion efficiency.

Table 3.11 Material and Cost Comparisons

	Components	Unit	Unit Cost (Tk)	Quantity		Cost (Tk)	
				Conventional Furnace	Improved Furnace	Convent-ional Furnace	Improved Furnace
1	Brick	Nos. (Thousand)	3500	14	5	49,000	17,500
2	Cement	Bags	220	2	3	440	660
3	Sand	M^3	150	5	2	750	300
4	Labour	Man Days	100	30	10	3000	1000
5	Vessel	Kg	-	725	450	30,000	35,000
6	Chimney	Kg	20	-	90	-	2700
7	Mason	Man days	160	20	8	3200	1280
8	Labour cost	Man days	90	35	16	3150	1440
9	Foundation	Man days	100	15	5	1500	500
10	Miscellaneous	5%	-	-	-	4500	3500
	Total					**95,540**	**63,880**

3.4.2 Husk Savings

Since there is an increase in the efficiency of the furnace, there is a proportionate increase in savings of rice husk. The rice husk feeding rate is relatively lower for improved furnace than for conventional furnace. According to the Specific Fuel Consumption rate the rice husk savings are in the range of 44% to 54% with an average rice husk savings of 49%.

In addition to the savings in husk due to the efficiency improvement, there is an additional reduction in rice husk consumption due to the reduction in the processing time. This can be seen in terms of reduction in steam consumption rate, while using the improved furnace. When the average steam consumption rate of 413 kg/h is reduced to 313 kg/h, as in case of the improved furnace, it can result in additional husk savings of 16%.

In view of the above two points, it is practically feasible to reduce the rice husk consumption by at least 50% from the existing level.

3.4.3 Environmental Benefits

In addition to the efficiency improvement and rice husk saving the improved furnace provides several benefits through environmental improvements:

- The person feeding the improved furnace is exposed to much lower levels of radiation heat because of smaller opening of the rice husk feeding port.
- Lower temperature around the furnace provides for more comfortable working environment. This is because (i) the vessel is not exposed to the atmosphere so there is

less radiation heat; and (ii) no flames exit through the sidewall ports as in the case of the conventional furnaces.

- The smoke level is reduced and it is more transparent in comparison to the thick black smoke of the conventional furnace. This is because of the adequate air supply available for combustion in the improved furnace.
- No O_2 was present in the flue gas of the conventional furnace. In the improved furnace it is at the optimum required level of about 4.5%.
- CO in general should not exceed 5000 ppm in the flue gas of an industrial furnace. In the conventional furnace flue gas contains more than 10,000 ppm of CO. The improved furnace brings down the CO content in the flue gas to the order of 3300 ppm, which is an acceptable level for such industrial applications.
- The ash removed from the conventional furnace contains a lot of char and unburnt husk. They start to burn after they have been removed from the furnace, which adds to the high temperature in the working environment. In the improved furnace the quantity of unburnt rice husk in the ash is reduced by lower husk consumption and better combustion in the furnace. This lowers the ambient temperature.

3.4.4 Safety Factor

Safety factors were given equal importance as efficiency improvement when designing the improved furnace. The main aspects of the safety improvements can be categorised under three factors:

(i) safer air quality;
(ii) eliminating flash fires; and
(iii) safety in terms of avoiding accidents due to vessel explosion at high pressure.

- Air quality is ensured by improving the combustion of rice husk and appropriate chimney design;
- Flash fires have been eliminated by the design of the combustion zone, feeding port, lowering flue gas temperature etc.; and
- To avoid any situation of vessel explosion as it frequently happens in the conventional furnace, a safety valve to open at a set pressure has been introduced.

3.4.5 Ease of Operation

Operation of the improved furnace is easier than the conventional furnace because of the following aspects:

- Smaller rice husk-feeding port;
- Low rice husk feeding rate;
- Easier working environment around the furnace;
- Husk feeding by one worker at a time is sufficient, whereas in the case of the conventional furnace two workers feed the husk simultaneously, and continuously;
- Easier removal of ash because of its reduced quantity as compared to the conventional furnace; and

- Instrumentation provides a clear indication of how the furnace is operating. In the conventional furnace the operator has no information on temperature, pressure, water level etc.

3.4.6 Summary of Salient Achievements

- The furnace operates on rice husk alone.
- It takes half an hour for a cold start and fifteen minutes during regular operation.
- Furnace starting time is comparable to that of the conventional furnace.
- The furnace operates at an average efficiency of 42%.
- Average steam consumption rate is 130 kg/h.
- Average husk consumption rate is 125 kg/h.
- Paddy parboiling time has been reduced by 50%.
- The pressure builds up to 0.5 kg/cm^2 within half an hour.
- During regular processing, the steam output rate is about 315 kg/h.
- It was found that the steam pressure of 1 kg/cm^2 is ideal for parboiling paddy.
- The safety valve opens when the pressure in the vessel exceeds 2 kg/cm^2.
- The CO level is down to an acceptable level.
- The smoke pollution has been reduced.
- Furnace operates with all the required instrumentation.
- The cost of improved furnace is less than that of the conventional furnace.
- The improved furnace is an economically viable model
- The two models developed ensure that the improved technology is available to users with different production capacities.
- Local *mistris* and operators can be easily trained.
- It is a readily adaptable improved design.
- Replicability and training can be reasonably straightforward.

3.5 Scope for Replication

This section sets out the three factors that could make replication of the improved design of furnace and boiler acceptable to user groups. These are the potential economic gains they can expect; the simplicity of construction and ease of training their operators; and the support of the workers as it creates a cleaner and safer environment. Given the acceptable levels of emissions of CO, NO_x and TSP, the improved model should also receive official support.

3.5.1 Potential for Economic Gains

The user group can benefit substantially from husk savings. As noted in Chapter 2, Bangladesh now produces about 30 million tonnes of paddy per year. This generates 10 million tonnes of rice husk and bran, annually. Out of these 10 million tonnes of rice husk and bran, about 40%-50% is consumed within the rice mill by the husk fired furnaces. By improving the efficiency of the furnace by 49%, about 50% of the rice husk and bran fired can be saved, which is about 2.5 million tonnes per year. An individual owner could make an additional profit of Tk 40,000 per annum.

From a more macro perspective, the saved bran could go to meet the demand of the growing poultry rearing at domestic and commercial scales. The saved husk could be used to make briquettes, a clean alternative fuel for the poor. This will inject at least Tk 5 million in increased income at the country level. Emphasising these economic benefits should be one of the strategies for dissemination. This would be in addition to sharing information on technical benefits.

3.5.2 Simplicity of Construction and Operation

The construction the improved furnace is kept simple and is similar to that of the conventional furnace. The *mistris* who build the conventional furnace can be used to construct the improved furnace, following a short training programme. The workers involved in the conventional furnace can be easily trained during the initial trial runs.

To facilitate uptake, simplicity of construction and operation was an important factor in the design of the new improved furnace.

3.5.3 Instrumentation, Safety and Support of Workers

The furnace is provided with the minimum required instrumentation. The rice mill owner and the workers prefer a clean and safer working environment. The experience of this project shows that the instrumentation and safety aspects of the improved furnace increase the positive attitude towards installation of the improved furnace. This is will provide additional value for replicating the furnace, apart from improved efficiency.

3.5.4 Lower Emissions

There are no norms available for air quality standards in the rice mill sector. Hence based on the general industrial air quality norms the following standards were arrived at:
The air quality norms are tabulated in the form of (a) fuel specific; and (b) sector specific processes. There are no fixed norms drawn for rice husk fired furnaces (Appendix 3-G).

From the pollution point of view the limits of CO, NO_x and TSP are given in Appendix 3-G. The emissions from conventional furnaces are higher on all counts. As already noted the CO levels have been brought down to a range of 2500 3500 mg/Nm3. This is within the limit of the norms given for CO level in industrial/commercial and mixed applications.

Also by observation, it was found that the intensity of smoke is lower in the improved furnace than in the conventional furnace. Furthermore, the thick black smoke high in TSP is replaced by transparent smoke. These advantages will add to the value, and support the dissemination program of the improved furnace.

3.6 Limitations

The recognition of technological improvement is influenced by its extent of compliance to specified safety, environmental and technical standards. In Bangladesh, there are no such standards for small rice mills. Hence, official recognition of these technical improvements will be constrained as there are no bases on which to judge the compliance of the improved technology.

3.6.1 Chimney Height

It was noted in Chapter 2 that this sector is in a legal vacuum. During the dissemination workshop held at BRRI Bangladesh in June 2003, this issue was highlighted. The group noted that the Inspectorate of Boiler may ask the mills to increase the height of the chimney. Furthermore, the discussions revealed that the user group was unclear as to who sets the standards for the height of the chimney for rice mills, and what the bases were for them. This is not surprising as there is no clear government policy on this.

As noted earlier the Inspectorate of Boilers has not developed any standards for boilers of rice mills. The published norms refer to larger industrial boilers and are not relevant to boiler size used in small mills. The norms for industrial boiler units are given in Appendix 3-G. As such there is no stipulated chimney height determined by boiler capacity in the rice mill sector.

However, the Department of Food make the chimney height of 30 feet as a condition for rice mills to qualify as a government supplier. The Department has adopted the standards set for the brick kiln industry. This industry uses a variety of heavy fuels. So based on these aspects a taller chimney seems justified. A chimney of 30' is not required for the rice husk fired furnaces.

Additionally, increasing the height of the chimney above the design and technical requirements will be detrimental to combustion efficiency. The draft increases with chimney height. The excess air will carry away more heat from the furnace. Also, a taller chimney will carry a higher level of dust because of the increased draft or increased flue gas exit velocity.

The chimney height for the improved furnace is based on two main parameters: (a) to create sufficient draft for supply of air into the furnace and to ensure the complete combustion of rice husk; and (b) to emit the flue gas at a height, which does not affect the workers. If the pollutants are at a higher level, whatever the height of the chimney, it will pollute the atmosphere and subsequently affect the health of the people around. So the aim is to maintain the required height to create sufficient draft and to reduce the pollutant level for a cleaner environment.

In the conventional furnace the flue gas is drawn at a higher velocity, at the order of 3m/sec. It also draws directly from the fire zone of the furnace. In the improved furnace a separate flue gas path is provided around the vessel. The flue gas is drawn at a lower velocity of about 0.74m/sec, which is almost 4 times lower than the flue gas velocity of the conventional furnace. So the dust carrying capacity of the flue gas in the improved furnace is much lower, which results into lower dust level. The smoke coming out of the chimney is also more transparent compared to the flue gas of the conventional furnace, which is typically a thick black smoke loaded with heavy dust content.

The workshop showed that some users prefer the chimney to be installed from the ground as in the case of the conventional furnaces. This will add to cost but it can be modified according to the user's preference. A diagram for installation of the chimney at the ground level is given in Appendix 3-F.

Since there are no fixed norms on the height of the chimney, it should not be a barrier in the dissemination process of the new furnace. However, clear-cut standards should be set and recommended height of chimney for the rice mill sector provided.

3.6.2 Standards for Air Pollution Control

It is important that the Department of Environment sets norms which are realistic for the rice mill sector. These norms need to take into account the sector-specific capacities. These can then be applied by the Department of Food.

3.6.3 Structure of Policy and Regulation

The rice mill sector requires proper approval to replicate the new improved furnace. It involves a complex structure of policy and regulation through several departments/players. Existing boilers related acts were formed in 1923 and have not since been modified, despite the improvement in technologies and new requirements and standards.

3.6.4 Attitudinal Barriers to Shift

As discussed in Chapter 2 there is a psychological barrier to shift from the conventional furnace to the improved furnace. Hence, the modifications have been made to keep/adapt the design to existing views and perceptions. For example, modifications were made to bring the chimney closer to the furnace to convince the users. A psychological perception/mindset of what the furnace should be may delay change. As noted earlier, the low levels of education and technical knowledge is an added factor.

There is a second area where users need better understanding of the improved technology. The users expect the flame in the furnace to reach the back of the furnace. In the improved furnace the hot flue gas at 750^0C is sufficient to transfer the heat energy to the vessel. There is no need for the flame to spread throughout the furnace. The conventional furnace has a smaller area of heat absorption; it needs the flame throughout to have better radiation heat. In the improved furnace the heat is gained equally by radiation as by convection. These facts need to be clarified to the user, and proved through more demonstration units. There are several clusters of rice mills across the country. Convincing the users of different clusters based on one demonstration unit becomes difficult.

3.6.5 Loan Facility

As noted earlier, the rice mills do not come under the Small Industries category because of its rural location. This means that subsidised credit for capital investment, available to other small enterprises, is not available to rice mills owners. This can constrain uptake of new technology.

3.6.6 Ownership

The profit realised by the owners may not be shared with the firemen and furnace operators. So the interest to shift to a new technology at the worker level could be low. The benefits of husk saving needs to be shared with the workers involved in the furnace operation to overcome resistance at the worker level. This has to be sorted out at the user level by the policy makers.

3.7 Conclusions

One of the main project objectives was to improve the furnace design and increase combustion efficiency by at least 15% to save rice husk-bran mixture used in small scale operations for rice processing for increased provision of poultry and animal feed and for briquetting.

Following detailed analyses of the designs of furnaces in use and the heat flows through various components, this project developed an improved design that has increased furnace efficiency to 42%, i.e., an increase of 22%. This furnace model is called Mark 0. This model went through trial runs and field tests. Based on the analysis of these tests and user feedback modifications were made and the design was finalised.

According to specific fuel consumption rate, the rice husk savings is in the range of 44% to 54%, giving an average of 49%. The lower steam consumption rate of 313kg/hr in this furnace gives an additional husk saving of 16%. Given the above two points, it is feasible to reduce rice husk consumption by at least 50%.

A rice mill owner using 1000 kg of rice husk per day can save 500 kg per day. Operating the mill for 10 days a month for 8 months will give an additional profit of Tk 40,000 per year. At the macro level, 40% to 50% reduction in consumption of the rice husk-bran mixture means a saving of 2.5 million tonnes of the mixture. This would increase supply for the poultry feed market and for briquette production.

Our initial analysis showed that the production capacity and steam requirements of small-scale mills could be grouped into two categories: firstly, those users at the lower end who require steam at the pressure of 150 to 350 kg/hr; and secondly, the users at the higher end who require steam at more than 350kg/hr pressure. To cater to the needs of both these groups, models Mark 1 and Mark 2 were developed for replication and dissemination. This strategy provides two different capacities to better match the technical requirements and financial abilities of the different user groups.

Issues of affordability and attitudinal barriers were kept in mind while designing the improved furnace. The cost of the new furnace and boiler is marginally lower than the current cost. The construction methods are also kept simple and *mistris* would require only a short period of training before they can begin to construct these units. However, there is need for more technical information sharing with the user group and the *mistris* to enhance uptake.

The boiler comes with all the minimum required instrumentation. It has been made safe with a safety valve. A pressure gauge and water level gauge are also being used during operations. Flash fires from fuel inlet port and side ports have been eliminated. Radiation heat has also been reduced by insulating most of the boiler surface. This means considerable improvements in the working conditions of the employees.

A more complete combustion of the rice husk means lower emissions. The thick black smoke with high TSP has been replaced with more transparent smoke with little dust content. CO, present at level of more 10,000ppm, has been reduced to the acceptable standard of 3500ppm.

However, there are no environmental and safety standards or norms specified for the small scale rice mills. The Department of Food arbitrarily uses the standards set for the brick kiln industry. Such standards are inappropriate as criteria to select mills to supply rice to the government. Again, as rice mills are not included in the Small Industries category, because of their rural location, the mill owners are not entitled to any loans available to small entrepreneurs in urban areas. These issues will be addressed in the dissemination plan.

4 Improvements for Briquetting Rice Husk from Parboiled Rice

4.1 Introduction

The second objective of this project is to identify ways to enhance the use of rice husk from parboiled paddy for making briquettes. Currently, only a marginal amount is used for briquetting, generally mixed with husk from dry processed rice. As noted earlier 90% of the rice in Bangladesh is parboiled. Some of the husk is used for parboiling. However, with growing paddy production, disposal of husk is considered a problem, especially in large clusters of rice mills. Yet this biomass, once made into briquettes, is a cheap, clean fuel for small shops, and for poor and low income households.

The first activity of this project objective was to carry out a baseline survey of factories producing briquettes with husk from dry processed rice. The aim of this was to: understand the production and operation processes; establish the cost of production and the profitability of the units; and identify the difficulties of using husk from parboiled rice. Though these points will be discussed in detail below, it is pertinent to note the initial findings that defined the research directions for this component. *Firstly*, the survey showed that the screw-extrusion process used was technically sound and the operations were profitable. *Secondly*, the screw life in the extrusion process using husk from dry processed rice is eight hours. The husk from parboiled paddy is more abrasive than husk from dry processed paddy. Consequently, the wear and tear of the screw used in the extrusion process is higher, giving a screw life of about three hours, which is not cost effective. This was identified by the industry as main reason for limited use of husk from parboiled rice.

Given that briquette making is technically sound and economically feasible (though several bad practices were observed), no attempt is made to alter the overall production processes. This study focuses on:

- ♦ improving the screw life for making briquettes with husk of parboiled rice; and
- ♦ reducing the energy loss during the production process.

The plan of this chapter is as follows: section 4.2 will describe the generic process of briquetting; section 4.3, drawing on the baseline study, will analyse the production and operating processes, and the cost structure of briquetting units; and section 4.4 will describe the outcomes of activities aiming to reduce energy loss in briquette production and to improve screw life.

4.2 Briquetting of Rice Husk

The conversion of biomass materials into a densified, solid product is not a new technology, though it appeared in Bangladesh only about 10 years ago. Many biomass materials are suitable for briquetting, including sawdust, sugar-cane bagasse, groundnut shells and rice husk. The latter material has properties that make it very suitable for screw briquetting, including good flowability, normally low moisture content, moderate temperature release of lignin for binding, and the ability to produce strong briquettes with good combustion properties.

Screw briquetting of biomass is based on the action of a traditional food mincer/sausage machine, developed through screw extrusion for plastics, and modified to suit the properties of biomass materials. Basically, material is gravity fed from a storage hopper into a lower chamber, where it encounters a rotating, tapered screw feed mechanism. This forces the granular material into a tapered, heated barrel (or die) in which high compaction pressures are generated. Some agglomeration of the material occurs as a result of the pressure-induced intimate contact between particles, though the perceived wisdom is that lignin release from the biomass occurs, producing a natural binder. Lignin release is enhanced by heating the extrusion barrel to a temperature of perhaps 400°C, giving a surface temperature in the compacted material of a little over 300°C.

Also the screw is heated by frictional interaction with the extruded material and, as a result of contact with these high temperature metal surfaces, the visible surfaces of the tubular briquettes show signs of charring, i.e., their colour ranges from black to very dark brown. The charring process is accompanied by the release of volatile matter from the biomass material; this vapour release produces a very unpleasant working environment in the immediate vicinity of the machine and pollutes the atmosphere around the briquetting factory. The odour is distinctive and makes for ready identification of the location of briquetting factories, even in congested areas.

The briquette is released from the barrel in the form, usually, of a smooth surfaced, thick-walled tube, which is broken off manually when its length is about 60cm-90cm. The briquettes, ideally, are quite strong and have good transport properties.

Their outer skins are fairly waterproof, though the material inside which has not been charred (and is less bound by lignin) is susceptible to breakdown when in contact with water. If water contacts the inner material, swelling occurs, followed by lamination and total loss of strength.

4.3 Briquetting of Rice Husk in Bangladesh

Briquetting of rice husk was introduced in Bangladesh in around 1990. An entrepreneur in Sylhet imported a machine from Taiwan and set up a factory. The imported machine was complete with automatic loading facilities and a drum dryer. Problems of maintenance soon emerged and these facilities were abandoned. The technique has undergone further change in the hands of individual owners and manufacturer intuitions. Regionally, briquette production is coterminous with two main areas of dry processing of rice; these are Sylhet and Chittagong districts. The baseline study in Phase 1 focused on these two districts and carried out an in-depth study of 10 factories.

Sylhet still remains one of the main centres for briquette production, though over the decade its production and use has spread throughout the country. The main cluster of units in Sylhet is in the Sheghat area. It was reported that nearly 350 units operate in Sheghat. Nine units were randomly selected for in-depth analysis. A similarly large cluster is found in Chatkai area, Chittagong. Moral (1999) reported that briquettes were being produced in all districts of Bangladesh, albeit in small quantities.

4.3.1 Briquetting Machines in Bangladesh

Drawing on the baseline study, an analysis of production processes and practices are outlined here. Whilst the machine may have undergone change in the hands of individuals, most machines observed during the visit operated within a parameter range well within that shown in Table 4.1. However, the combinations of parameters used make almost every machine unique.

It is difficult to appraise precisely the overall efficiencies of all the machines seen because of uncertainties in the data provided by operators/owners, but power consumption for the production of 100kg of briquettes appeared to be in the range16 to 32kWh, with the double-sided machines having the lowest consumption. Taking an average figure of 25kWh for 100kg of product and comparing this with figures quoted for plastic extrusion machines of similar type (Perry's Chemical Engineers' Handbook, 6th Edition 1984), it is clear that power consumption per 100kg product is very similar for both types of material.

In certain circles in Bangladesh, a view is held that the viability of the briquetting industry depends on the illicit use of electricity through by-passing of meters or other means. Whilst one mill seen in Chittagong may have been doing this, no obvious examples of electricity theft was noticed. The team arrived at briquetting factories totally unannounced, so there was no opportunity to remove illegal wiring. Where owners were able to give us details of monthly electricity bills, these were entirely reasonable for the scale of the undertakings. Assertions of widespread electricity theft in the industry were not borne out by our observations. In Sylhet, the owners produced monthly electricity bills to back up the data provided.

Table 4.1 Ranges of Operating Parameters Used in Observed Briquetting Machines

Operating Parameter	Observed Range
Barrel heating method	Electricity, kerosene, diesel oil; No gas-fired heaters seen
Barrel heater power, kW	Normally 9-kW, though powers quoted were as low as 3-KW (probably incorrect)
Type of husk processed	Mainly from un-parboiled rice. Few observed machines were processing parboiled husk.
Particle size	All machines used un-ground husk
Husk throughput per machine, kgh^{-1}	60 - 120
Briquette output per machine, kgh^{-1}	55 - 105
Briquette diameter, cm	5.5 - 7.5
Barrel Surface temperature, ^{o}C	400 – 530
Briquette inside hole temperature, ^{o}C	100 – 210
Colour of surface layer	Usually black on both surfaces, occasionally dark brown. One mill produced briquettes with uncharred inside hole surface
Motor power/kW	11 – 19 (22 for double-sided machines)
Motor r.p.m	940 – 1800
Screw r.p.m	280 – 450
Screw life, hours	8 – 12
Barrel life, days	20 – 45
Barrel wall thickness, cm	1.0 – 1.3

Source: Field Survey (2000)

In spite of the fairly wide range of operating parameters (Table 4.1) used in the machines, all were producing briquettes of a satisfactory quality, though no obvious quality control procedures were in operation. When questioned about this, one owner informed us that if briquettes remained intact after being dropped from about 05m height they were acceptable. Much of the strength of the briquettes probably originates in the outer skins where the release of lignin binder is likely to be greatest.

It is perhaps worth commenting on the apparent regional variations in the machines seen during this visit. In particular, the diameters of briquettes produced in the Sylhet and Chittagong areas were mainly 6 cm and 7cm-7.5 cm, respectively. Larger diameter product appears to be associated with greater mass throughput rate, so the few machines seen in Chittagong had somewhat higher outputs than the majority of those seen in Sylhet. There appears to be no scientific rationale behind the choice of product diameter, though small diameter briquettes are likely to be more uniform in terms of density and strength.

Almost all of the machines seen were briquetting husk from un-parboiled rice. This has been the norm since the introduction of the technique to Bangladesh. In areas where processing of un-parboiled rice is carried out there is usually large surplus of husk, which can be converted into briquettes. Where parboiled rice is produced, husk is used as the energy source for water heating and a smaller proportion is available for briquetting.

The view in the industry is that parboiled husk is no more difficult to briquette than husk from dry processed rice. However, it is the more abrasive nature of husk from parboiled rice and its higher moisture content that increased screw wear. Hence, the main focus of this component was on improving screw life.

4.3.2 Good and Bad Practices

During the tours of briquetting factories, there were many instances of bad practice and only a few examples of good procedure. It was observed that most briquetting machines were installed in confined spaces, leading to very difficult and even hazardous conditions for the operators. Few of the machines had even rudimentary fume extraction systems, and atmospheric contamination by pyrolysis smoke made breathing difficult, even for short contact times.

Electric barrel heaters were connected to the electricity supply by bare wires, so typically 6 x 1.5 kW windings carried a current load in excess of 6 amps at a potential of 220 volts. Operators appeared to be aware of this danger and were reluctant to allow us to take temperature readings close to the barrel, but it would be very easy for a worker to accidentally brush against the unguarded connections.

None of the V-belt drives was guarded, so there was a danger of loose clothing being caught in the drives and the wearer dragged onto the rapidly-rotating machinery. Briquettes are manually removed from the barrel outlet by hand when they have reached a length of 60 cm-90 cm. The surface temperature of the briquette is at least 150^{o}C and minimal protection is provided for operators' hands.

It is unrealistic to expect that standards of industrialised countries will be applied in Bangladesh in the foreseeable future, but there is no justification for the current bad practices in the husk briquetting industry to continue. A little more space around the machines, properly guarded V-drives and electrical connections, and better ventilation would enormously improve working conditions and probably increase productivity. These issues could be targeted during dissemination activities.

One example of good practice observed was the use of a single motor to drive two briquetting machines, one on either side of a central pulley. This system was devised by the proprietor of Alec Engineering in Sylhet. It appears that the system gives considerable savings in power consumption and could be more widely used. Also, the cost of these machines (per barrel) is a lot lower than the alternative single barrel machines. However, a large floor space is required to install and operate such a machine.

4.3.3 Economics of Production

This section takes a snapshot view of how these briquette production units operate, their cost structure and profitability. Data for this analysis were obtained through in-depth firm level interviews with owners. The firms were randomly selected and owners were found willing to share information on their units. Ten units were studied, two in Chittagong (units 1 and 2) and eight in Sylhet (units 3-10). Time constraints prevented the team from covering more units in Chittagong.

Table 4.2 shows that it is clearly a profitable business. Units in Chittagong appear to be run more efficiently, giving higher per tonne profit. A break down of costs in Table 4.3 shows that for the same operational hours, Unit 2 achieves a much higher output of briquettes. Its advantage of zero husk transport cost is balanced out by briquette delivery cost, an expenditure most other firms do not incur- so it does not have any extra advantage. Both units in Chittagong achieve 6023 operational hours per annum. While briquette output for Unit 2 is 1590 tonnes per annum, it is 1265 for Unit 1. Unit 2 retails directly to the consumer at Tk 2.93 per kg instead of selling to middleman.

Table 4.2 Showing the Cost-income/Efficiency Status of Briquetting Units

No	Annual production Tonnes/annum	Annual costs Tk/annum	Gross income Tk/annum	Annual Profit Tk/annum (Rank)	Profit Tk/tonne (Rank)
1	1265	1,981,018	3,372,600	1,391,582 (2)	1100 (2)
2	1590	1,972,042	5,087,808	3,115,766 (1)	1960 (1)
3	855	1,878,960	2,622,598	743,638 (4)	870 (3)
4	891	1,984,762	2,162,961	178,198 (9)	200 (10)
5	452	966,247	1,059,960	93,713 (10)	207 (9)
6	1153	2,340,121	2,705,789	365,668 (6)	317 (7)
7	838	1,687,829	1,965,744	277,915 (8)	332 (6)
8	3373	7,078,910	8,094,240	1,015,330 (3)	301 (8)
9	891	1,699,892	2,020,348	320,456 (7)	360 5)
10	1120	1,929,330	2,539,086	609,756 (5)	544 (4)

Source: Survey data, November-December 2000.

Table 4.3 Showing Bre akdown of Costs in Briquetting Units

No	No of operational hours per year	Briquette output per year	Husk Tk per tonne output	Energy Tk per tonne output	Maintenance Tk per tonne output	Labour Tk per tonne output	Husk transport Tk per tonne output	Briquette delivery Tk per tonne output	Rent Tk per tonne output
1	6023	1265	686	317	24	149	297	93	0
2	6023	1590	682	208	131	87	0	133	0
3	6023	855	1127	601	224	147	98	0	0
4	6023	891	1149	638	138	135	100	0	67
5	4106	452	1021	531	285	209	93	0	0
6	4928	1153	1337	376	78	133	105	0	0
7	4654	838	1329	355	92	62	106	0	72
8	5353	3373	1356	538	39	57	108	0	0
9	6023	891	1175	309	111	151	94	0	67
10	6023	1120	1286	196	76	62	103	0	0

Table 4.4 Costs as a Percentage of the Total Operating Costs Based on One Tonne Output

No	Husk	Energy	Maintenance	Labour	Husk transport	Briquette transport	Rent
1	44	20	2	9	19	6	0
2	55	17	11	7	0	11	0
3	51	27	10	7	4	0	0
4	52	29	6	6	4	0	3
5	48	25	13	10	4	0	0
6	66	19	4	7	5	0	0
7	66	18	5	3	5	0	4
8	65	26	2	3	5	0	0
9	62	16	6	8	5	0	4
10	75	11	4	4	6	0	0

In Sylhet, there is more variation in production efficiency showing scope for improvement. It is pertinent to note that two units in Sylhet, Units 4 and 6, use kerosene instead of electrical coil heating to warm the barrel. This does not appear to give these firms any energy cost advantage (see Tables 4.3 and 4.4).

Units 5, 6 and 7 have much lower operational hours than most other units, because they cannot operate throughout the year. These units do not have any regular suppliers or enough storage space for husk. Those that operate throughout the year are either attached to a rice mill that provides a regular supply of husk, or that has large storage space. For example, Unit 3 has storage space for 7000 bags of husk. Such mills buy the husk soon after the harvesting season when the price is at its lowest.

The attitude to business among the owners was more professional than observed among rice mill owners. They appeared to keep accounts and most of the transactions were above board. This refutes the allegation made that these units made a profit because power supply was illegally sourced. This is important for this project. Information dissemination on improved production technique and exchange of views regarding the practicality of implementing any improvements is expected to be less difficult than for rice mills.

Section 4.3 has shown that the briquettes produced are of sound quality. It is also a profitable business. The main constraint identified by the industry to using husk from parboiled rice is high cost associated with short screw life and its cost of maintenance.

Section 4.4 Improving Screw Design and Saving Energy

It will be essential to demonstrate that the briquettes produced by using an improved screw design are of the same or higher strength and quality as the briquettes being produced commercially. It is therefore necessary to establish these parameters. To this end, a field visit in Phase 2 was organised to collect samples of briquettes from different regions of Bangladesh. These were then tested for strength and quality. This is discussed in section 4.4.1. It was noted above that high moisture content in husk from parboiled rice is a factor in increasing wear of the screw in the extrusion process. To address this problem it was decided to pre-heat the husk in the hopper using the heat of the briquettes produced. If successful, this would also lead to energy savings. This is reported in sections 4.4.2 and 4.4.3 Central to this component is improving the screw design to lengthen its life and then to assess the quality of briquettes produced by the improved screw. These issues are reported in sections 4.4.4 to 4.4.6.

4.4.1 Briquette Quality Assessment

Briquette samples were collected from five districts of Bangladesh e.g., Mymensingh, Sylhet, Chittagong, Gazipur (Kaliakor) and Dinajpur. Fifty samples were taken from each source. The briquettes were cut into standard pieces of 5cm length. The density of each sample was calculated by measuring the volume and weight (Table 4.5). The samples were then tested for their crushing strength. This was done by crushing the briquettes under a universal-testing machine. The briquette samples were put horizontally under the universal-testing machine and the failure modes were observed during the tests. The break-up of the briquettes followed a combination of these modes illustrated in Fig 4.1 and no pattern could be established. The tests were carried out at Bangladesh Institute of Technology (BIT) (now called Dhaka University of Engineering and Technology).

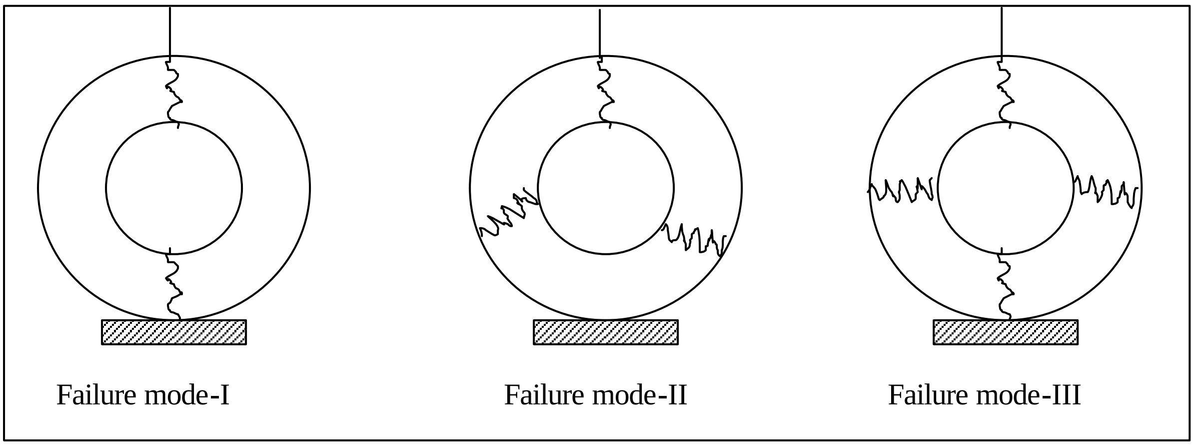


Fig 4.1 Showing Different Failure Modes Observed During Assessment of Crushing Strength

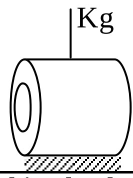


Table 4.5 Physical Properties of Rice Husk Briquettes Collected from Different Sources in Bangladesh

Source of briquette	Average outer diam.(cm)	Average inner diameter(cm)	Average density, (g/cc)	Crushing load, (kg/ cm length)	ACC** = Crushing load x density, g^2cm^{-4}	
					Range	Average
Mymensingh	5.87	1.97	1.24	57-109	68180-139088	98679
Sylhet	5.66	1.83	1.23	52-109	62873-138027	97474
Chittagong	6.51	2.46	1.20	36-124	43988-153481	95658
Kaliakoir*	6.43	2.43	1.23	28-81	34670-99793	67473
Dinajpur	5.12	1.71	1.13	18-80	20272-88828	52991

*Source of barrel heat was diesel burner

** Average crushing coefficient

The range of crushing strength varied widely. The failure was due to a combination of tensile and compression. The top and bottom halves of the sample behaved as an arc cantilever. Table 4.5 also shows that higher density gives higher Average Crushing Coefficient value (ACC), except in Kaliakor. The density of the briquette is 1.23g/cc both for Kaliakor and Sylhet but the average crushing load for briquette from Sylhet was higher than that of Kaliakor. This could be attributed to overheating of the barrel. According to Alam (2003), to produce good quality briquette, the optimal temperature range of the die barrel should 280°C -290°C for releasing lignin from husk. The owner of the briquette machine in Kaliakor had replaced the die barrel electric heater with a diesel burner. This raised the temperature well beyond the above range. As a result the outer layer of the briquette was burnt and the lignin had lost its binding property, leading to a loss in strength.

To establish the relationship between the size of the briquette and its crushing load, a Multiple Regression Model was developed. The relationship between the outer diameter, inner diameter, density of briquette and crushing load is given by the equations below. Given the anomalous situation of Kaliakor, two different models are provided.

$L = -219 + 43.3\ D_1 - 66.5\ D_2 + 140?$; R = 0.662……….(1) (Including data from Kaliakoir)
$L = -277 + 42.4\ D_1 - 48.5\ D_2 + 166?$; R = 0.790 ………(2) (Excluding data from Kaliakoir)
Where, L = crushing load, kg/cm length
D_1 = outside diameter of briquette, cm
D_2 = inside diameter of briquette, cm
? = density of briquette, g/cc

From the above regression models, it can be said that the crushing load of briquette is directly proportional to density and outside diameter and inversely proportional to inside diameter. Model (2) gives better relationship with higher multiple R. The average outside diameter, inside diameter and true density of briquette were found to be 5.75 cm, 2.12 cm and 1.25 g/cc, respectively. The implication for this study is that briquettes produced by the new screw design should aim to achieve an average density of 1.25g/cc.

4.4.2 Preheating of Husk in the Feed Hopper

It has been noted that the briquettes have an average temperature of at least 150°C when they are extruded from the barrel. It was proposed to utilise this heat for preheating rice husk, in a modified feed hopper. A cross-sectional view of the modified hopper is shown in Figure 4.2. The Plate 4.1 shows the model built in BRRI for running trial runs.

The modification involved running tubes through the hopper to hold the hot briquettes. Seven tubes could be inserted without hampering the flow of husk to the outlet port. The total volume of hopper without tubes is about 0.3733 m^3, and with tubes placed inside it, is about 0.30 m^3. The hopper can still hold 42 kg of husk.

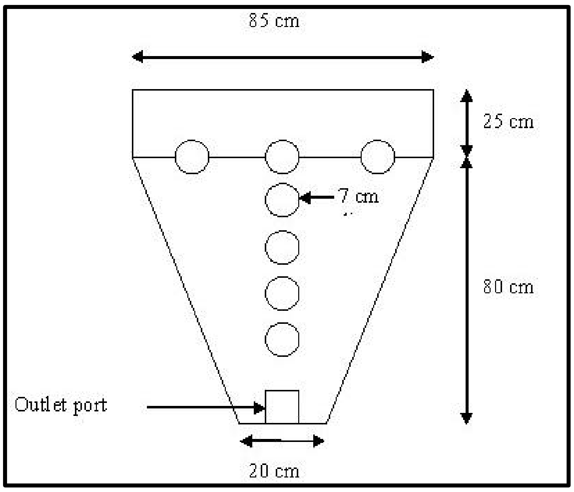


Fig 4.2 Diagram of the Preheating Hopper to Hold Hot Briquettes

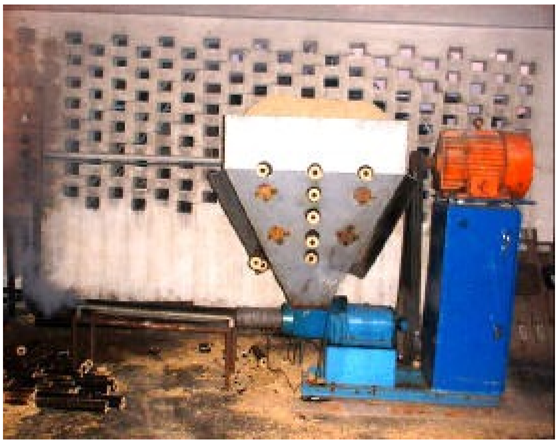


Plate 4.1 Showing Modified Hopper Built in BRRI

The operator removing the hot briquette from the barrel would insert it in one of the tubes to replace one which had cooled.

4.4.3 Performance of Pre-heating Hopper

The performance curve of pre-heating hopper is shown in Figure 4.3. It reveals that initially the feed husk temperature rose with the duration of operation. But after two hours of operation, the rise levels out. Only a temperature of 55°C could be obtained in the hopper. Mishra *et al.* (1995) note that husk must be pre-heated to at least 100°C to make a real difference.

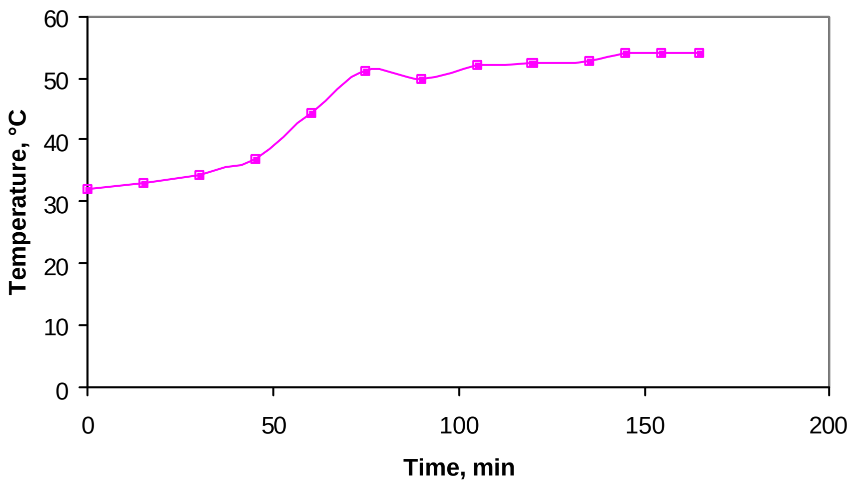


Fig 4.3 Showing that the Temperature Levels out after Two Hours of Operations in the Modified Hopper

Production of Briquettes: The performance of briquetting operations using husk at 55^{0}C was not encouraging either. Briquette production rate was found to be in the range of 75.21 kg/hr to 103.89 kg/hr (Table 4.6) and the average production rate was 95.0 kg/hr. The energy consumption rate was found to be 12.48 to 16.30 kWhr (average 14.43 kWhr) per 100 kg briquette production. Table 4.6 shows that there is no significant difference in energy consumptions between operations using pre-heated husk and those operations using husk at room temperature and the traditional screw. Given these results, no further effort was expended on this strategy to reduce energy consumption.

Table 4.6 Production of briquette using Heated Modified Hopper and Without Pre -heating

Test Run	Hopper type	Husk Type	Feed rate of husk (kg/hr)	Production rate of briquette (kg/hr)	Mass recovery (%)	Energy consumption (kWhr/100 kg of briquette)
1	Preheat	Un-parboiled	118.00	103.89	87.66	12.48
2	Normal	Un-parboiled	85.00	75.21	88.00	13.64
3	Preheat	Parboiled	97.00	90.91	93.11	16.00
4	Normal	Parboiled	118.00	99.00	83.90	14.14
5	Normal	Parboiled	122.00	100.75	82.32	16.30
6	Normal	Parboiled	122.00	100.00	81.97	14.00

4.4.4 Improved Screw Design

It is important to note here that the only baseline data available for performance comparison of the new screw is from units making briquettes from dry processed rice. The screw life in such units is 8.5 hours. The life of the traditional screw for making briquettes from husk of parboiled rice is about three hours.

Screw Design

The choice of material for making the new screw was important. Mishra (1995) had conducted tests on hard-facing of screw for wear resistance using different hard-facing materials. Arc welded screw with tungsten carbide gave the best results for preventing wear. He also noted that the performance of the hard-faced screw depended on welding expertise and the pre- and post- conditioning of the screw. So, the new improved screw for this project was made with hot die steel and with a tungsten carbide tip. The traditional screw is made with mild steel and hard-faced with hard craft arc rod. The length of the screw is 496 mm, shaft diameter at top end is 35 mm and falls to 21 mm at the narrower end, the number of threads is seven. These dimensions were used to make the new screw.

Performance comparison of briquette production by improved screw and traditional screw

The new screw was tested at BRRI using parboiled husk containing 9.32% to 10.44% moisture. The production rate ranged between 153 kg/hr to 96.04 kg/hr, with the average production rate at 123.48 kg/hr.

A local factory producing briquettes with husk of dry processed rice using the traditional screw was identified in Gazipur. A performance study was conducted in this unit to enable performance comparison of production with the traditional screw with that of the new, hard-faced screw. The production rate in this factory was found to range between 83.6 kg/hr to 72 kg/hr and the average production rate was 81.87 kg/hr (Fig. 4.4 and Appendix 4-A). This Appendix contains the raw data from which subsequent observations have been made.

Non-linear regression equations giving the relations between screw life and briquette production rate were set up and the coefficients of determinant (R^2) were obtained. The models showed a stronger relationship between screw life and briquette production rate for the new screw (R^2 = 0.8249) than for the traditional screw where R^2 is 0.4073 (Fig 4.4). It reveals that briquette production with new the screw is significantly more consistent than with the traditional screw. On an average, 1.5 times more briquettes could be produced per hour by the improved screw.

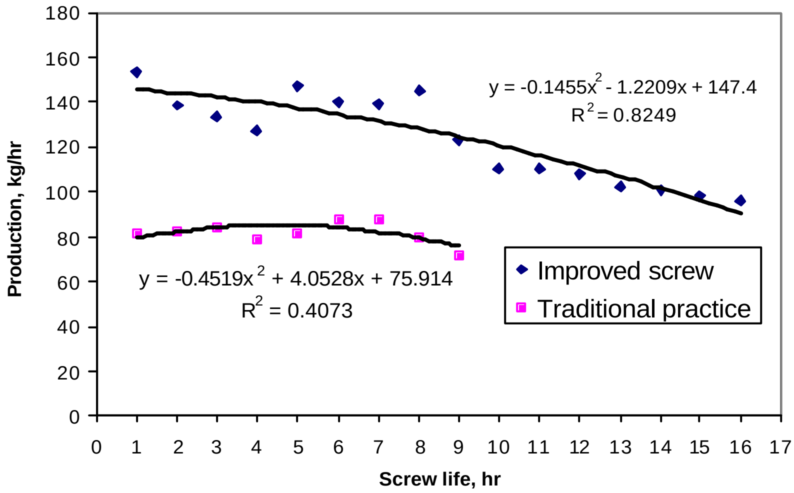


Fig. 4.4 Performance Comparison of Production rate and Screw Life for New and Traditional Screws

Screw life

Briquettes were successfully produced for 16 hours with the new screw. They were of good quality (Plate-4.2) for up to 16 hours, after which the briquettes were more fragile and broke into small pieces (Plate-4.3). In comparison, briquette production with traditional screw is limited to 8.5 hours. The new and worn out screws are shown in Plates-4.4 to 4.7.

Plate-4.2 Briquette Produced by New Screw during 1-16 hours, at BRRI

Plate-4.3 Broken Briquette Produced by New Screw after 16 hrs

Plate-4.4 New improved Screw of Hot Die Steel with Tungsten Carbide Tip

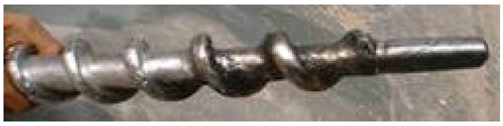


Plate-4.5 Traditional Screw Welded with Hard Craft Arc Rod

Plate-4.6 Worn Out New Screw after 16 Hours of Operation

Plate-4.7 Worn out Traditional Screw after 9 Hours of Operation

Energy consumption

Energy is used at two points in the production process; one, to run the motor; and two, to heat the die barrel of the extrusion process. These two together give the total energy consumption. It is important to note here that the die barrel temperature was kept within the optimum range of 280^0C-290^0C for the tests.

Tests with the new screw showed a decline in energy consumption for the first six hours, following which the consumption increased (Fig 4.5). This figure also shows that the average energy consumption for producing briquettes from parboiled rice husk using the improved screw is 111.6 kWh/ton; with average hourly power consumption rate of 14.10 kW/hr.

According to Alam (2003), energy consumption of the system using the traditional screw is 152.03 kWh/ton of briquette production. This gives an energy saving of 26.60% with the new screw when the die barrel temperature is kept within the optimum range. The survey in Phase 1 showed that commercial units in Sylhet and Chittagong use 25 kWh/100 kg briquettes. This would give an energy saving of 55% with the two improvements made by this study.

The higher die barrel temperature maintained by commercial units not only uses excess energy, it also burns the outer surface, and creates high levels of workplace smoke when briquettes are extruded (Plate-4.8). As Plate-4.9 shows with lower die barrel temperature used during tests at BRRI, less smoke is produced.

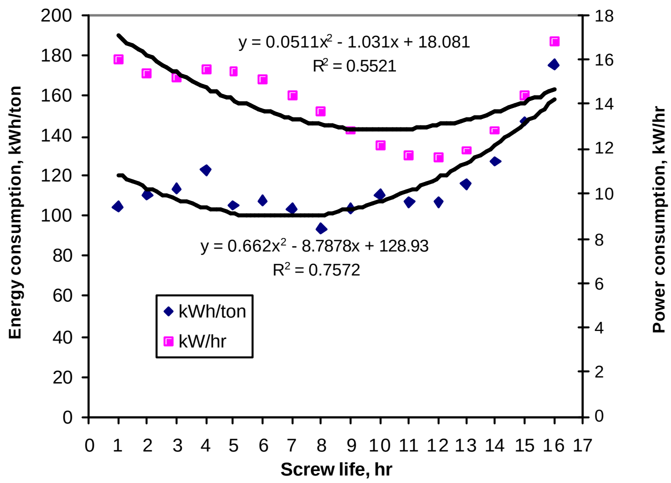


Fig 4.5 Energy Consumption per Ton of Briquette Production and Hourly Power Consumption for Life of Screw.

Plate-4.8 Traditional Briquette Production System Creates Considerable Amount of Smoke

Plate-4.9 Improved Briquette Production System Creates Less Smoke

4.4.5 Assessing Quality of Briquettes Produced by New Screw

During tests with the new screw, samples were collected every hour of the operation. Three aspects of these samples were tested to ascertain the quality of the briquettes. These tests relate to the density of briquettes, their crushing strength and the relationship between the crushing strength and the density of the briquette.

Briquette density: The pattern of change in briquette density during 16 hours of screw life is shown in Fig 4.6. It can be seen from this figure that the density of briquettes increases for up to 8 hrs of operation, when it reaches a density of 1.34 g/cc. Although the density declines after 11 hrs of operation, quality of the briquettes was maintained and the rate of briquette production was higher than for production with traditional screw.

After 16 hours of operation, the briquette density was maintained but briquettes broke up into small pieces (Plate-4.3) due to wear of screw. A similar trend was observed for traditional system after 8.5 hours of production. The average densities of briquettes were 1.25 g/cc and 1.21 g/cc for the improved and traditional systems, respectively. Density of briquettes by traditional screw is virtually constant. Although on average the new screw produces briquettes with higher density, the first two hours of operations produces briquettes with densities lower than those produced commercially. The density first increases and then drops, and overall it fitted a non-linear regression (Fig 4.6: $R^2 = 0.63$). It may be possible to reduce this by fine tuning the screw pitch and depth.

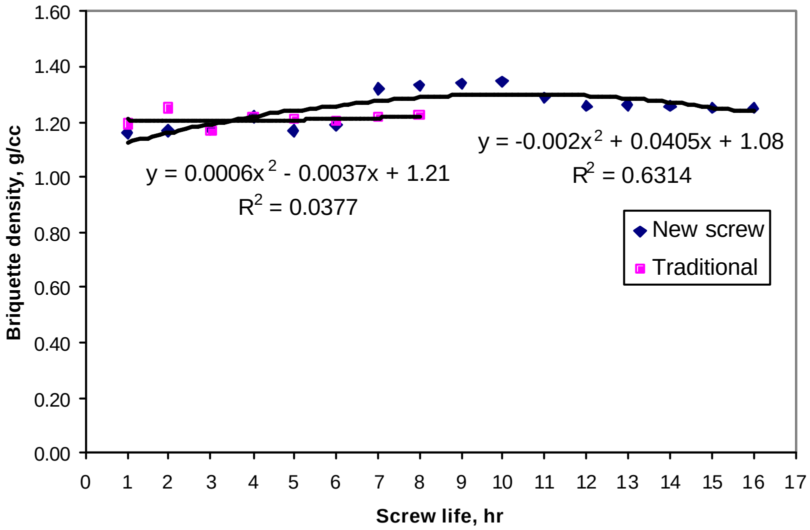


Fig.4.6 Variation in Density of briquette with respect to Life of Screw

Crushing strength: From Fig 4.7, it is observed that crushing strength of briquettes varied with the life of screw. For briquettes produced by the new screw the crushing load increased for the first ten hours of production, following which it declined. For briquettes produced commercially with the traditional screw the crushing load increased for the first four hours of operations, after which it declined.

It is important to note that the crushing load of briquette made with the new screw (on average=988 N/cm) is significantly higher than that of the traditional one (281 N/cm). Better correlation of results (Fig 4.7) were achieved with the traditional screw (R^2=0.9) than with the new screw (R^2=0.7).

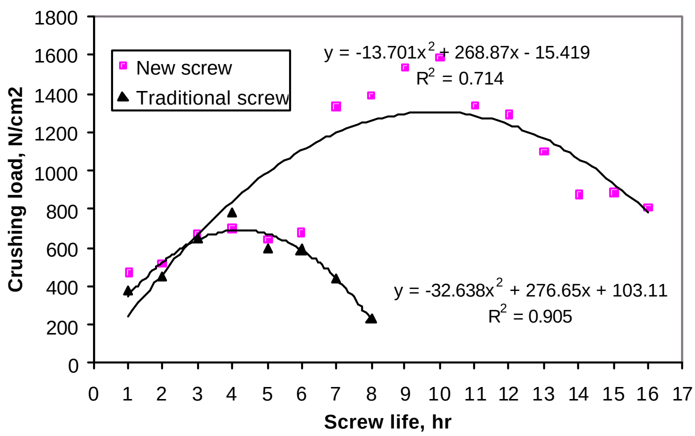


Fig. 4.7 Relationship between Screw Life and Briquette Quality in Terms of Crushing Strength

Relationship between crushing strength and density of briquette: Fig 4.8 shows that the crushing strength of briquettes is directly related to the density of briquette. This relationship is similar for outputs from both screws, but the crushing load of briquettes produced by the new screw is always higher than for those produced by the traditional screw.

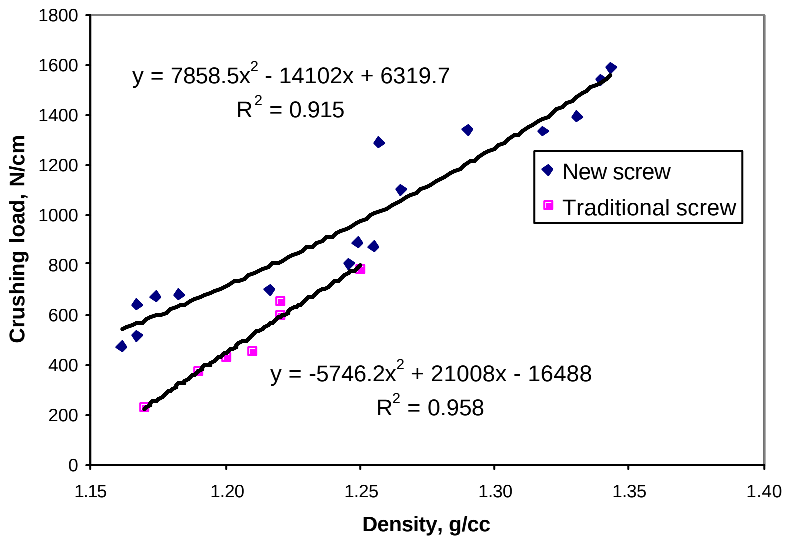


Fig. 4.8 Relationship between Briquette Density and Crushing Strength of Briquette

Overall, it can be said that the screw with hard-faced surfacing has a much longer life (16 hours) than the traditional screw made from mild steel (8.5hours). In the case of the former, there is some variation in the density of briquettes during the 11 hours of operation. This means that some fine tuning of the screw may be necessary during field tests. However, the crushing load of these briquettes is consistently higher than for those produced by traditional screw. Taken on the whole, the new screw gives higher productivity and better quality briquettes. Additionally, as shown in the next section, the use of the new screw will make briquetting of husk from parboiled rice more profitable than it is in units currently operating.

4.4.6 Potential Benefits of Improvements

The potential benefits of adopting the improvements made in this component are economic and environmental.

Economic Benefits: These benefits would accrue at the firm and at the regional/national levels.
Firm level: The performance comparison with existing units has shown that the improved screw is competitive even with the existing units using dry processed rice for briquettes. The gains are even more substantial when we look at the economics of making briquettes from husk of parboiled rice with the traditional screw. The screw life is only three hours. The improved screw producing briquettes from husk of parboiled rice has a screw life of 16 hours. This is significant improvement and makes the business of making briquettes from husk of parboiled rice a profitable business.

Furthermore, despite the higher initial cost of screw, it compares favourably with the overall production cost even in existing units using husk from dry processed rice. Increased profitability, as illustrated in Table 4.7, comes from estimated lower repair cost of screw per hour and 26% savings in electricity by maintaining the die barrel at the optimum temperature required for the release of lignin. There will be an increased profitability of Tk 3 per hour from simply using new screw. Additional savings from electricity would raise the profit rate to Tk 7.57 per hour.

Table 4.7 Comparative Costs of Production per Hour

Item of Cost	**Current Costs/hour in Taka**	**Costs with Improved Screw per hour in Taka**
Rice Husk	150	150
Diesel (3 litres)	51	51
Labour costs	10	10
Electricity (Tk 2.30/kWh)	35	32.43
Screw Repair	7	4
Screw Barrel Repair	3	3
Weight loss of Husk (10%)	12	12
Total Cost	268	260.43
Selling Price	450	450
Profit/hours	182	189.57

The cost of raw material (husk) currently accounts for 56.4% of the cost. Wider dissemination of the improved furnace and savings in rice husk could bring down the price of husk.

The prototype cost of improved screw is higher, about 3.5 times the current cost. However, it is expected that the higher productivity rate combined with the lower maintenance rate will roughly compensate the cost of the screw.

Regional and national levels: Briquetting of husk from parboiled rice will increase availability of a cheap, clean fuel and go towards reducing the use of firewood. Furthermore, since at present only a small amount is made into briquettes, it would open up new business opportunities and create scope for low income employment in rural Bangladesh.

As the main limitation is the higher cost of the screw, it will essential to convince the entrepreneurs (current and potential) of the overall profitability of the new, improved screw during dissemination.

Environmental Benefits: As noted above, energy consumption can be reduced by more than 26% by maintaining the optimum die-barrel temperature. Additionally, there is considerable improvement in workplace environment (Plate-4.9). The oxygen content in the room was normal, carbon dioxide was nil, and carbon monoxide level was 150-180 ppm at outlet of die and 5-7 ppm in the room for new system. In comparison, for the traditional system carbon monoxide was found 400-930 ppm at outlet of die and 12-16 ppm in the room (Table 4.8).

Table 4.8 Analysis of Emissions in the Working Environment of New and Traditional Systems

Parameter	Content for new screw		Content for traditional screw	
	At outlet of die	In the room	At outlet of die	In the room
Oxygen (O_2)	Normal	Normal	Normal	Normal
Carbon-monoxide (CO)	150-180 ppm	5-7 ppm	400-930 ppm	12-16 ppm
Carbon dioxide (CO_2)	Nil	Nil	Nil	Nil

4.5 Conclusions

It can be said that this project has been successful in improving the design of the screw used in the extrusion process for making briquettes with husk from parboiled rice. The briquettes produced are of good quality and have consistently higher crushing strength than briquettes being produced commercially. The higher initial cost of purchasing a new screw is expected to be compensated by the longer screw life of 16 hours and higher per hour production rate of briquettes.

5 Potential Socio-Economic Benefits and Impacts of the Project

5.1 Introduction

The aim of this chapter is to show the potential benefits that could accrue following uptake of the improvements discussed in Chapters 3 and 4. This will be done by:

(i) indicating the number of workers who could benefit from uptake of improved furnace technology;

(ii) showing the increased profitability for mill owners who adopt the improved furnace-boiler design;

(iii) showing that the saved husk and bran form essential inputs for poultry and cattle farming which are important activities of the rural poor; and

(iv) illustrating, that where available, rice-husk briquettes are becoming an alternative source of fuel for poor households and small food retailing units.

The main overall beneficiaries of this project will be the poor and low-income households, and the workers and owners of small rice mills. There will, of course, be variations in the level of impact depending on, such factors as uptake of recommended improvements, proximity to urban areas, transport facilities, and regional variation in demand for by-products of rice.

The analysis here is based on the information gathered during the field visits to Bangladesh over the project duration. Data were obtained from various sources. These include discussions and interviews with:

- relevant government officials at the central level in the Departments of Food and of Livestock Services;
- in-depth, participatory discussions with small mill owners and the workers;
- structured, questionnaire[1] based in-depth survey of 35 small rice mills;
- the Inspectorate of Boilers, Bangladesh;
- owners of poultry farms;
- owners of household ‘backyard’ poultry;
- private sector retail outlets selling inputs required for poultry rearing;
- rice husk briquette producers and retailers;
- owners of small retail outlets using briquettes; and
- Department of Livestock Services who provided the national statistics on livestock.

Plan of this chapter: Section 5.2 demonstrates the benefits that could accrue to mill owners and poor workers. Section 5.3 shows that poultry farming is an important activity of the rural poor where by-products of rice milling form important inputs. Section 5.4 discusses how rice-husk briquettes are an alternative source of fuel for poor households and for small retail units in Sylhet and Chittagong.

[1] Please see Appendix 2-B for questionnaire used.

5.2 Benefits to Rice Mill Owners and Workers

This section first briefly re-examines the risks and hazards faced by workers in parboiling rice mills and estimates the numbers of men and women workers who stand to benefit from enhancing safety in this sector. It then shows the profit that could accrue to owners following uptake of improved furnace.

5.2.1 Benefits of Enhancing Safety and Improving Working Conditions

Risks and hazards of present working conditions : It is has been demonstrated in chapter 3 that the working conditions in the small rice mills are hazardous and unsafe. When the furnace is in operation: flame exits from side ports and fuel inlet port; carbon monoxide is present at unacceptable levels (above 10,000ppm); there are high levels of radiation heat from the vessel and the large fuel inlet port; and the smouldering ash gets dumped in close proximity after its removal from the furnace. Incomplete combustion of the husk in the conventional furnace produces thick black smoke high in TSP.

Additionally, lack of instrumentation, particularly the risk of boiler explosion due to the absence of a safety valve, endangers the life of all present at the mill. In every area visited by the project team, there were reports of boiler explosions and death of workers. In Pabna district, the team visited a mill where the boiler had exploded and travelled about 50 meters across the drying yard to the rice bins, to fatally injure four workers and to leave one with severe injuries (Plate 5.1).

Plate 5.1 Showing the Aftermath of a Boiler Explosion

Discussions with workers, owners and trader-operators indicated that all were fully aware of the dangers involved in working in these mills. The workers are vulnerable and easily replaceable, and therefore have little say in the matter. The death of, and injury to, poor workers have severe ramifications for livelihood strategies of their entire household. The mill owner rarely pays the hospital bill. Study by Pryer (1993) in Khulna shows that in case of illness and/or injuries medical expenses are generally higher than the lost wages, pushing the household deeper into debt. Death of the principal wager earner can lead to considerable hardship for the surviving women and children. As for the owners, it was a question of getting away with it for as long as the system allows.

The improved furnace design has addressed all these issues and provides safer, cleaner and more comfortable working conditions. Removing hazards and risks at work for poor workers who have no bargaining power is considerable progress.

Number of workers who stand to benefit from safer boilers: To estimate the number of workers who might benefit from improvements in safety standards it was necessary to calculate the number of small mills operating in Bangladesh. The official estimates of the size of the small mill sector are regarded as not very reliable. The Bangladesh Statistical Bureau is only able to provide data based on Census 1990. The rice-milling sector had expanded considerably since then. The Food Department, Government of Bangladesh, provides the second estimate. The aim of Department was to assess the number of mills that would be eligible for awarding government contracts for processing rice. Hence, these data may not give an accurate picture of the size of the small scale rice-milling sector.

This project estimates the number of small scale rice mills from secondary information available and the survey data collected by the project team. It is estimated that there are approximately 6200 small rice-mills in Bangladesh. See Appendix 2-A for methodology used to estimate.

The project survey shows that there are on average 12 men and 10 women workers in each mill, i.e., a total of 22 workers. Therefore, the total number of workers in this sector is 136,400 (22x6200). All such workers could benefit directly from safer working conditions. Indirectly, it would benefit the households that rely on the workers' income. Furthermore, as shown in Box 5.1 the women are in highly exploitative wage relations. It is unlikely that in the near future these wage relations will be affected by technological improvements. However, safer working conditions will alleviate some of their difficulties.

Box 5.1 Exploitative Working Conditions of Women Workers in this Sector

Women make up nearly 45% of the workforce in small rice mills. Their tasks are no less arduous than those of the male workers. There are several activities to be performed in a parboiling rice mill. These have been already described. Women work alongside men workers in all activities (see Appendix 5-A).

However, the wage structures for men and women are quite different. In 23% of mills the women are not paid separately. They come as a family unit and only the male member is paid. For the other three-quarters of women, some of who are single women (widowed, abandoned) they are not paid in cash. Some receive a share of the broken rice. The going rate in 2001 appears to be 1.1 kg of broken rice for processing 100 kg of paddy. It is important to clarify the grade of broken rice they receive. Some broken rice is mixed with the whole grain of rice that is sold by the owner. Some remain mixed with the husk. This is separated and sold by the owners at Taka 7 per kg. The very small grains of broken rice that cannot be separated from the husk, hence cannot be sold, is given to the women. In other words, it costs the owner almost nothing to employ the women.

When the women are paid cash, the rates are derisory. They are paid Taka 1 for processing 40 kg of paddy. The men in the same unit are paid Taka 18-20 for processing the same amount of paddy. This gender bias is not peculiar to this sector. Rather it reflects the cleavages found in the labour market, in the country.

5.2.2 Saved Husk and Increased Profitability

It was noted in Chapter 3 that the improved furnace design can achieve, on average, 50% savings in rice husk use through reduction of specific consumption rate of rice husk and reduction of steam consumption rate.

A rice mill currently consuming 1000 kg of husk per day can save about 500 kg of husk per day. Considering 10 days of operation in a month and 8 months of operation in a year, the total saving will come to about 40 tonnes of rice husk per year, which will result in additional profit of Tk 40,000 per year (market cost of husk is Tk 1 per kg), i.e., US $ 700 per year. The annual benefit of the improved furnace is 60% of the capital investment. Thus, the furnace returns the capital investment within a period of two years.

5.3 Benefits for People in Poultry Rearing and Cattle Farming

This section first shows that poultry rearing and cattle farming are important to the rural poor. It then uses case studies to illustrate the profitability of the sector and important share of rice bran and husk in poultry and cattle feed.

5.3.1 Livestock husbandry

Livestock husbandry is an important part of rural and peri-urban livelihood. Rearing cattle, cow, goat, sheep, poultry and duck brings income, generates employment, supplies manure and assists in other farm activities like preparing land for crop production. As Table 5.1 shows this sector as a whole has a slow but steady growth. However, the main growth areas are poultry and duck rearing. Husk, bran and broken rice are important inputs in cattle and poultry farming.

Table 5.1 Annual Growth Rate in The Number Of Animals

	1995-96 No of Animals	1996-97 No of Animals	1997-98 No of Animals
Cow	23,198,000	23,320,000	23,400,000
Gr. Rate (%)		0.53	0.34
Buffalo	800,000	810,000	820,000
Gr. Rate (%)		1.25	1.23
Goat	33,020,000	33,331,000	33,500,000
Gr. Rate (%)		0.94	0.51
Sheep	1,068,000	1,080,000	1,110,000
Gr. Rate (%)		1.12	2.78
Poultry	127,500,000	130,200,000	138,200,000
Gr. Rate (%)		2.12	6.14
Duck	12,650,000	12,700,000	13,000,000
Gr. Rate (%)		0.40	2.36

Source: Department of Livestock Services, Govt. of Bangladesh (2000).

Poultry farming

A brief description of this sector will be useful to explain how the potential benefits might be distributed. Interviews with various actors in this sector showed that poultry farming was being carried out at three different scales. No official terminology was found to describe the scales of operation. However, the popular vocabulary describes the three categories as follows.

1. Large scale poultry farms that rear birds in batches of 10,000 or more. They rely on processed food and litter from large-scale private sector hatcheries and feed suppliers.

2. Medium scale units that rear birds in batches of 5000-10,000. These farms are reliant on small wholesale dealers to supply feed and litter.

3. Small scale units and household poultry farming which is, in terms of number of units, the largest of the three scales of activity. According to Department of Livestock Services (2000), 89% of rural households have backyard poultry. There is wide variation in size within this category. Some households may keep a dozen or less birds. However, the minimum size to produce enough to sell in the market through a middleman is a batch of 100 birds (interview with poultry feed dealer). Backyard poultry owners are predominantly women and poor farmers (*Ibid*), who retail their produce in the village.

   The so-called small-scale units are also household-based. On average, these units hold between 500-1000 birds in each batch.

Categories 2 and 3 are of relevance to this project. Government policy has been to actively encourage the growth of small and household sector by setting up hatcheries and breeding farms, and extending 'scientific' methods of rearing at household level. The private sector is also playing an important role in this development. It provides all necessary advice and equipment; detailed programme of feed, lighting and heating; and it sets standards for farm hygiene. It must be noted that all farmers interviewed strictly followed the instructions provided. Failure to adhere to instructions can lead to high mortality rate among the birds.

Warehouse owners often take care of marketing and credit facilities. They link up with small farms, those with a minimum of 500 birds, to provide an advance payment that effectively locks in the production. The flip side is that it enables households with limited assets to engage in this activity at a commercially viable scale.

The medium scale units have developed in response to (i) the growing urban market; and (ii) availability of inputs and technical advice for commercial scale farming. Both medium and small, household units rely on processed food, on by-products of the rice milling sector, and other agricultural produce.

The point being made here is that poultry farming is an important and growing activity for the poor and low income households. It is for them a highly profitable business. By-products of the rice-milling sector are important inputs in this sector. Bran is an essential ingredient in poultry feed and husk is used as litter. Furthermore, the husk from rice milled by Engleberg Hullers tends to contain bits of broken rice. Backyard poultry farmers often use it as feed. Field discussions indicate that the demand for these inputs is rising. Furthermore, the prices of these products have also increased over the last few years (though the exact increase could not be ascertained). In response to the demand from this sector, some mills are now separating bran from husk as it fetches a higher price. Bran mixed with rice polish[2] brings even greater returns. These developments and trends indicate that the saved husk-bran mixture will contribute directly to meeting some of the demand for these essential ingredients that are central to small household and backyard poultry farming.

Cattle rearing

One of the principal, traditional cattle feed is the husk-bran mixture. Before the widespread development of poultry farming this mixture of husk-bran was often collected free from rice mills. Today, poultry farming is competing for the same product. Releasing this mixture from fuel use will increase the overall availability and could slow down the price rise.

5.3.2 Case Studies

Three case studies are provided below to illustrate

- the profitability of poultry rearing at medium-scale and at household levels, hence its potential for growth, and thus, increasing demand for rice by-products; and
- the importance of husk and bran as inputs in poultry farming.

There are two types of poultry farms. Type one rears broilers; and type two rears 'layers', chickens for production of eggs. The demand for husk is different in these two sub-sectors of poultry farming

Case Study 1: Ibrahim Poultry Ltd.: MEDIUM SCALE unit

The owner is the sole proprietor, whose name cannot be revealed for reasons of confidentiality. However, he was happy to share all financial information with the project team. The farm occupies a total area of 7 bighas. It is designed to hold a batch of 5,000 broiler chicks. Initial investment made for building houses for birds is Tk 500,000 (see Appendix 5-A for illustration).

Process: One-day chicks are bought from hatcheries, and reared for 35-40 days, by which time they are expected to reach the weight of 1.5 kg. Throughout their life the broilers are kept on litter. Rice husk forms the litter. 200 bags of husk, of 40kg each (i.e. 8000 kg) are required for each batch. Six batches are run each year, generating an annual demand of 48,000 kg.

One bag of husk litter fetches a price of Tk 25 during the dry season and Tk 45 during the three months of the rainy season. The cost of buying litter in the dry season for 5 batches @ Tk 25 per bag, is Tk 25,000. The cost of buying litter for one batch during the wet season is @ Tk 45 per bag, is Tk 9000. The annual cost is Tk 34,000. This constitutes 8% of the total cost (Table 5.2). The important point is that though the cost of litter forms a small part of the total cost, it is an essential input in broiler farms.

[2] Rice polish: the process of hulling and polishing the grain also remove a fine layer of the rice kernel, which comes out in powdered form. This is referred to as 'rice polish'.

Table 5.2 Total Outgoings for 6 Batches (operational costs)

Item No.	Item	Cost in TK
1	Feed	208,500
2	Hatchery	130,000
3	Medicine	15,000
4	Labour cost	25,000
5	Fumigation/cleaning etc.	2,000
6	Electricity + overheads	6,000
7	Transport of chicks	6,200
8	Litter (husk)	34,000 (8%)
	Total outgoings	**426,700**

Source: Data provided by farm owner (22 Nov.2000)

The farm income is estimated below to show the profitability of the farm.
One batch consists of 5000 chicks, with a mortality rate of 200 deaths per 5000 broilers.
Therefore, the numbers sold are 4800 broilers per batch, with each bird weighing 1.5 kg.
The average price is Tk 57.5/kg (Price ranges from Tk 55 to Tk 60/kg).
Thus, the price of each chicken is Tk 86.25.
Gross income from 6 batches: Tk 2,484,000
Estimated net income: Tk 2,057,300

Case Study 2 Abuddin Bahamukhi Farm. MEDIUM SCALE Unit
The farm is jointly owned by two brothers**.** It occupies 3 bighas of land and is designed to hold 7000-10,000 layer chickens.

Process: One-day old chicks are bought from hatcheries and reared for 1.5 years. For the first 180 days the chicks are kept on litter of rice husk. Once a bird reaches maturity (at about 180 days) it produces one egg per day for 360 days. At the end of 1.5 years the batch of chickens is sold.

The demand for husk is 1500 bags of 40 kg each per year. At the end of 180 days this litter is sold to fish farms as fish feed.

Outgoings: the breakdown of outgoings was not available. However figures obtained from dealers in chicken feed and other poultry products indicate that the average cost of rearing a batch of 1000 chickens is around Tk 400,000. Based on this, the outgoings of this farm with 10,000 chickens can be estimated to be around Tk 4,000,000.

Estimating Farm Income
Layer chickens have a mortality rate of 4%. Hence in a batch of 10,000 chickens, 9,600 would be producing eggs.
No of eggs produced each day: 9600
Total number of eggs produced in 360 days: 34,560,00
Wholesale price of eggs: Tk 252 per 100 eggs.
Gross income from eggs: Tk 8,709,120.

Estimated net income from selling eggs: Tk 4,709,120

Other sources of income:
A chicken is sold at a price of Tk 80 per chicken (i.e. Tk 768,000 /batch at the end of 1.5 years).
There is income from sale of litter to fish farms, figures for which were not available.

Both these examples show that rearing broiler and layer chickens are very lucrative and partly explain the recent expansion in the number of farms. They also show that rice mill by-products are essential items in poultry rearing.

Case Study 3 HOUSEHOLD Unit
This poultry farm with 1000 layer birds was randomly selected. The owner, Md. Nazrul Islam is based in the village of Desipara, Gazipur District. He made an initial investment of Tk 1,700,00 to build a bird house and another Tk 62,000 for constructing cages. The poultry farm was started in June 2000 and the owner expects a profit of Tk1000/day at the end of the lead-time. The owner was unable and/or unwilling to share the financial information. However, he was clear about the feed programme for the birds and the constituent inputs.

On this farm the demand for rice by-products is for rice polish and rice husk. For a batch of 1000 birds the total demand (i.e., over 1.5 years) for rice polish is 216 kgs (4 bags of 54 kgs each) and 1,375 kgs of rice husk (55 bags of 25 kg each). The bran is mixed according to the percentage in the feed formula given below.

Nationally, the demand for bran and husk from the small and household poultry-farming sector will be considerable. Unfortunately, it is not possible to put a value to it, as the number of farms in this size category cannot be estimated. However, it is possible to indicate the overall importance of bran in poultry feed.

Share of bran in poultry feed
To ascertain the share of bran in poultry feed the retailers were interviewed. Rendac and Hendirx, two Dutch poultry feed companies, are major players. They determine the feed formula used by most farms. According to the dealers in poultry feed and households interviewed, even farms with a minimum of 100 birds are dependent on formula feed provided by them. Rice bran and rice polish are important components in their formulae. This is illustrated in Tables 5.3 and 5.4.

Table 5.3 Breakdown of Inputs for Feed (100 kg) for Layer Chicken

Ingredient	Layer starter 0-6 weeks	Layer grower 7-12 weeks	Pre-layer 13-19 weeks	Layer >20 weeks
Wheat/maize	55%	55%	55%	54%
Rice Bran	20%	20%	20%	18%
Soya bean	18%	17%	15%	14%
Rendac protein	6.5%	6%	6%	5%
Shells		1.5%	3.5%	8%
D.C.P.	500 gm	500 gm	500 gm	500 gm
Salt	300 gm	350 gm	400 gm	500 gm

Ingredient	Layer starter 0-6 weeks	Layer grower 7-12 weeks	Pre-layer 13-19 weeks	Layer >20 weeks
L.G.S.	300 gm	300 gm	300 gm	300 gm
Lysine	100 gm	100 gm	100 gm	100 gm
Methionine	50 gm	50 gm	50 gm	50 gm
(Was illegible)	50 gm	50 gm		
Crude Protein	19.96 %	19.96%	18.30%	16.97%
Energy (calories /kg)	3050	3012	2968	2818

Source: Rendac instruction sheet for mixing feed for layer chicken obtained from feed retailer.
NB. Rendac is a Dutch poultry feed producing company.

Table 5.4 Breakdown of Inputs for Feed (100kg) for Broiler Chicken

Ingredient	Starter (0-3 week) In Kg	Finisher In Kg
Maize	59.5	65.0
Rice Bran	4.0	3.0
Sesame oil	5.0	5.0
Soya 44	23.5	19.5
Hendrix super concentrate	8.0	7.5
Total	100	100

Source: Instruction sheet from Hendrix, The Netherlands. Data obtained from feed retailer.

Summing up: For the last decade, poultry rearing has been a growing sector in Bangladesh. It is popular because it can be profitable at many different scales of operation. Consequently, women in 89% of rural households keep a small battery of birds (chicken and ducks). Unfortunately, it was not possible to estimate the total number of birds reared in households as no government statistics were available. This growth is underpinned by government incentives and by the role played by the private sector. The latter has facilitated the development of small scale poultry farming and backyard poultry rearing by providing credit and detailed instructions for rearing birds and by selling feed in small quantities. Rice bran, rice polish and husk are important inputs for poultry feed. There has been a demand pull rise in the price of rice by-products. Releasing nearly 50% more bran in the market should increase availability and could slow down the price rise which affects the rural poor.

5.4 Rice Husk Briquettes - An Alternative, Clean Fuel for the Poor

The project team found that a majority of tea stalls and small food retailing units in Sylhet and Chittagong (Plate 5.2) had shifted from using firewood to rice husk briquettes. Interviews with retailers of briquettes revealed that the main buyers were poor households (Plate 5.3) and small retail units. Reasons cited for this shift were that firewood is becoming more expensive and that briquettes were smokeless and reached a higher temperature more quickly than coal or wood fires. Thus, where available, briquettes are a viable alternative fuel to the low-income group. A retailer interviewed in Chittagong had a sale of about 20,000 kg per month at Tk 2.93 per kg. Moral (1999) reported that in Chittagong the price of briquettes in 1995-96 was Tk 1.45 per kg. Similarly the price in Sylhet has risen from Tk1.18 per kg (Moral, 1999) to Tk 2.34 per kg (Survey data, 2001). Despite gradual increase in briquette production, the price continues to rice. At this stage it is difficult to say if this is a demand-pull increase or just an inflationary price rise.

At the macro level, a considerable amount of husk from parboiled rice could go towards making briquettes. This would create more jobs in the sector and inject considerable income into the economy.

Plate 5.2 Briquettes Being Used in a Small Food Stall in Chitttagong

Plate 5.3 Householder taking away Briquettes from the Factory

5.5 Conclusions

Clearly considerable economic benefits will accrue to the owners if they adopt the new furnace design and follow the operating instructions. However, it is unlikely that the owners will share the increased profit with the workers. Improvements in the working conditions, a safer and less hazardous work environment, will be a considerable improvement for these lowly paid, vulnerable workers. The position of women workers in this sector is particularly harsh. Improvements such as this will go towards alleviating their situation.

The indirect beneficiaries, among others, will be small poultry rearing units and household involved in poultry rearing. With the release of considerable amount of rice husk and bran in the market, it is expected to increase their local availability.

Briquettes where available, are popular among poor households and small food retailing units. Mills parboiling rice is widespread in Bangladesh. Even if half the amount of husk released by improved technology is used for making briquettes using the improved screw, the availability of a cheap, clean fuel would have substantial geographical spread. The production of briquettes would also generate more job opportunities for low income workers.

6 Demonstrating Alternative Value-Adding Use of Rice Husk Ash in Bangladesh

6.1 Introduction

Rice husk ash (RHA) is obtained as a waste product from the furnaces of rice parboiling units that utilise rice husk as their fuel. As noted earlier, the average annual paddy production of Bangladesh is about 29.86 million tonnes (FAO, 2000). From this production:

- 87% is processed annually by about 6,200 small scale rural rice mills;
- nearly 6 million tonnes of husk is produced annually as a milling by-product of which more than 90% is burnt in the mills to provide steam for parboiling paddy; and
- about 1.2 million tonnes of ash (20% of husk) are produced annually.

Ash from these furnaces is usually dumped on agricultural lands, contaminating the soil and polluting water sources. The ash particles have low bulk densities and are often very small. If not managed properly, these particles can be easily airborne and cause disease. The use of RHA as a component of construction material would considerably reduce the environmental impact.

Although many alternative uses of RHA have been developed in the last few decades; such as use of RHA as a component of clay brick, firebrick, hollow brick, sandcrete and concrete etc., these applications have not yet been tried in Bangladesh. This study examined some of these applications, given that RHA is known to be a pozzolana and to contain over 95% of silica, a major constituent of Ordinary Portland Cement (OPC).

Hence, the **fourth objective** of this project is to examine the pozzolanic characteristics of RHA that is produced in the conventional parboiling units in Bangladesh. At present very small fractions of RHA are being used as filler for marshy lands; potash fertiliser; insecticide, oil absorbent; cleaning agent for utensils; component of tooth powder; and pollution control.

To achieve this objective, two sets of tests were necessary. The first set of tests is to assess whether the RHA samples collected in Bangladesh possess any pozzolanic characteristics. The second set, to determine the load bearing capacity of the RHA-OPC cement blocks in order to establish whether RHA could be used as an alternative component of building material by replacing a certain percentage of OPC.

The plan of this chapter is as follows: section 6.2 describe some of the alternative applications of RHA attempted by various institutions/individuals in different countries of the world; section 6.3 describes the methodology used, and laboratory experiments undertaken in the of the School of Chemical and Life sciences, University of Greenwich Chatham Maritime, UK; section 6.4 describes the results of the laboratory tests and section 6.5 concludes the chapter.

6.2 Alternative Applications of RHA

A wide spectrum of literature on the various use of RHA was reviewed by this study. However, brief descriptions of some of the most pertinent uses are given below.

Pozzolana: The Greeks were the first to use pozzolanic materials such as volcanic tuffs known as "trass" from the island of Thera (now called Santorini) and is commonly known as Santorin earth. The Roman builders quarried a sand-like material, but on mixing it with lime, found that the mixture produced stronger concrete when compared with previous attempts. It was later established that the material was actually a fine volcanic ash consisting of silica and alumina. This volcanic ash was found around the Bay of Naples, and was also obtained from Pozzoli or Pozzuli of Italy; hence the material acquired the name "Pozzolana" (Lea, 1970). Thus, Pozzolana is defined as a siliceous or siliceous and aluminous material, which itself possesses little or no cementitious value, but in a finely ground form and in the presence of moisture, reacts chemically with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties (Bhatty, 1988). Artificial pozzolana can be produced by firing certain clays, shells and diatomaceous earths that contain the properties of clay. Other pozzolanas include microsilica, silica fume from metal alloy smelting furnaces, mineral silicas like silica from RHA.

6.2.1 Potential Uses of Rice Husk Ash

RHA can be used as unmodified ash and as a silica source for cement, in refractory and in silica derived materials. Some major potential uses of RHA are presented in Table 6.1.

Table 6.1 Potential Uses of RHA

Form of Use	Use	Comments
As ash	Fertiliser Organic use /filler pigment Insect powder Oil absorbent Insulant In steel production	Average selling price (US $270/ton in European market of 600- 700 tons/yr.)
As Silica Source for Construction Material	Cement Refractory	Production cost (US $ 30-40/ton) >20,000 tons /yr.
For Silica Chemicals	Soap Sodium silicate Active silica Silica sol Silicon tetrachloride Silicon carbide Silicon nitride	

Form of Use	Use	Comments
	Semi-conductors/ Metallurgical grade silicon Catalyst Supports	
Thermal Products of Rice Husk	Furfural, xylose Activated carbon	

6.2.2 Uses of RHA for Cement Production

The review of the literature shows that RHA can be used in combination with lime cement or blended with Portland cement. These are described below.

1. RHA-lime cement

The literature has focused on understanding the reaction of RHA-lime cement under different conditions and on assessing the compressive strengths of RHA-lime cement blocks.

RHA, like other pozzolanas, gives a cementitious composition when mixed with lime and water. Several studies on RHA-lime cements have been made (Cea, 1967; Shah, 1979; Mehta, 1977; Shirstha, 1981) but little detail is available on their hydration chemistry. Mehta, (1977) first developed and patented a process to make cement with RHA. He used a controlled supply of air and kept the temperature low, to produce a super pozzolana RHA containing more than 90% silica. The impurities were low and RHA exhibited a high specific surface area.

RHA-lime cements containing amorphous, low temperature reactive ash were found to exhibit higher early strength than those containing high temperature crystalline ash (Cea, 1967). On the other hand, even with amorphous RHA, widely varying strengths have been reported. It should be noted however, that clinker composition and the characteristics of the filler influence its reactivity (Mehta, 1977).

Yu *et al.* (1999) in their study confirmed that, at a temperature around 40^0C in the presence of water the RHA amorphous silica can react with calcium hydroxide to form one kind of C-S-H gel with a porous structure and large specific surface area containing particle with diameters ranging from 4.8 to 7.9 nm. When the product was heated it gradually lost water, but it maintained an amorphous form up to 750^0C and began to transform into a crystalline phase above 780^0C due to the formation of calcium silicate.

Compressive Strength: Cook (Cea, 1967) observed a decrease in strength of a 300-day old sample obtained in RHA-lime reaction. Similarly Yogananda *et al,* (1983) reported that the strength increased for 28 days and then decreased gradually with time even when amorphous RHA was used.

In contrast Rahim *et al.,* (1980; 1981) reported that cements of RHA origin exhibited little or no strength at all. On the other hand, crystalline RHA cements have been shown to produce increased strength with time, although the early strength was low (Yogananda *et al.,* 1983). Various ash-lime ratios ranging from 1:2 to 1:5 have been reported (Suryakumaran, 1967; UNIDO, 1984; Yogananda *et al.,* 1983; Fieger, 1947) as optimum for developing maximum strength. However, most of the ash-lime mixes did not show any increased strength beyond 28 days. The reason for this behaviour was not clear (James, *et al.,* 1992).

This review shows that for lime deficient RHA, the reaction of ash-lime mixtures is completed in a few days so that no strength is developed. To get consistently good performance of RHA, optimum ash-lime ratio is essential. As RHA is low in lime content (5.45%, Okpala, 1993), alternative uses of RHA was pursued in this study.

2. RHA-blended Portland cement

From the foregoing section it can be seen that a considerable amount of effort has been invested in the production of RHA-lime based cement. On the other hand, Ordinary Portland Cement (OPC) can be blended with finely ground RHA to produce high strength concrete. By using a small fraction of OPC with RHA, a better quality binder was developed and by further increasing the OPC content a high quality binder was obtained, which could compete with high quality OPC blended with condensed silica fume to attain high strength (Dalhusen, 1996). Mehta (1977) reported that cements blended with RHA tend to have superior resistance to acid and creep, and are more impermeable.

Stroeven, *et al.*, (1999) tested two types of mortar: (i) low-strength mortar for rural application; and (ii) high-strength mortar for urban/coastal applications made from RHA-OPC blended cement. In both the tests the OPC was blended with RHA in a specially designed furnace/kiln (Stroeven, *et al.*, 1999; Sbuni 1995; Stroeven, *et al.*, 1999 and Bui, 1995). The carbon content of the ash used in the tests varied from 12%-23%. The OPC content was increased in accordance to the American standard (ACI -363R-92). In every application RHA was ground for 14 to 18 hours. The development of compressive strength for low-strength mortar reached up to 13.6 MPa over a period of 1 year. However, to obtain high-strength mortar, a combination of superplasticiser and fine grain RHA is necessary to replace OPC by as much as 40%. At this combination compressive strength was found to exceed 50 Mpa in 7 days and 70 MPa after 28 days. For increased OPC content in accordance with ACI-R-92, a compressive strength approaching 100 Mpa was obtained after 28 days.

OPC mixed with RHA was fired at 450^{0}C, 70 ^{0}C and 1000^{0}C, in ratios of 5%, 15% and 25% RHA by mass, and pastes were made at water/solid ratio of 0.3 and then cured for 3-90 days (Elhosiny, 1997). The results indicated that the cement made from RHA fired at 450^{0}C and 700^{0}C gave a higher surface area than that made from RHA fired at 1000 ^{0}C. On the other hand cements made by Amer *et al.*, (1997) from RHA fired at 450 ^{0}C and blended with OPC showed that water consistency increases with increase of RHA content. Therefore, a water reducer (plasticiser) was used to reduce the water added. However, the addition of RHA consumes some of the liberated calcium hydroxide forming CSH. The results of the study made by Ajiwe *et al.,* (2000) confirmed that cement paste made by mixing 24.5% RHA were found to be similar in their physical characteristics and chemical composition to the commercial cement. Based on the test results, the production of cement from RHA has been recommended for developing countries.

The effect of RHA passed through sieves- No.200 and No.325- as 10%-30% replacement of OPC was studied by Ismail *et al.*, (1996) with a total of 200 samples tested over 3, 7, 28 and 150 days. Compressive and split tensile strengths obtained were over 70 MPa from cubes made without any replacement of OPC by RHA. Test results indicated that the strength of concrete decreased when OPC was partially replaced by RHA to maintain the same level of workability.

The effect of 3.0-wt% polyvinyl alcohol (PVA) was studied on the hydration of OPC in the presence and absence of 10% RHA. The results show that the two cements behaved in similar ways; hence replacement of 10% OPC by weight was found beneficial (Singh, 2002).

Singh *et al.,* (2002) studied the hydration of OPC blended with 10% RHA in the presence of 2 -wt% calcium chloride and 1 wt.% lignosulphonate. The results showed that the compressive strength of 10 -wt.% RHA-blended cement is a maximum in the presence of a mixture of 2 -wt.% calcium chloride and 1- wt.% lignosulphonate. The results of corrosion have shown that RHA-blended cement without any admixture of calcium chloride or lignosulphonate is more resistant to a corrosive atmosphere of N/60 sulphuric acid.

A mathematical relationship of a designed mix of parameters for OPC/RHA concrete was developed by Ikpong *et al.,* (1992). Using the designed mix, concrete blocks of 20, 25, 30 and 40 N/mm^2 strengths were prepared and tested. Compressive strength results obtained for mixes designed for 28-day with strengths up to 30 N/mm^2 show that the designed strengths were achieved, for up to 40% replacement of OPC with RHA. For the mixes designed for 40 N/mm^2, the desired strength could not be achieved at 28 days, indicating that strength values greater than 30N/mm^2 may not be achieved, unless at stages well beyond 28 days, after RHA is incorporated.

Okpala(1993), reported that chemical constituents of RHA with a specific gravity of 1.54 satisfied the BS 3892 and ASTM-618 requirements for pozzolanas. He found that addition of RHA in OPC paste increased both initial and final setting times. For a given period of hydration and mix proportions, the strengths of the cement-RHA blocks decreased with increasing RHA content. Sandcrete mix of 1:6 (cement/sand) ratio with up to 40% RHA content varied consistently. However, cement replacement by RHA at 1:8 ratio of up to 30% of RHA, were adequate for sandcrete block production for both urban and rural dwellings in Nigeria.

A study was carried out by Zhang *et al.*, (1996) on the effects of incorporation of RHA in OPC paste and concrete on the hydration and microstructure of the interfacial zone between the aggregate and paste. The results indicated that the incorporation of RHA in concrete had reduced calcium hydroxide content more than in the control (OPC) paste. It also reduced the porosity of the concrete and the interfacial zone between aggregate and the cement paste. However, the porosity in the interfacial zone of RHA composite was higher than that of silica fume composite. The incorporation of RHA in the OPC did not increase its compressive strength compared to that of the control. The higher compressive strength of RHA concrete compared to that of the control is due to probably to the reduced porosity, reduced calcium hydroxide, and reduced width of the interfacial zone between the paste and the aggregate.

In an another study Zhang *et al.*, (1996) found that RHA-OPC concrete had higher compressive strengths at various ages up to 730 days compared to that of the control concrete, but a lower value than that of the silica fume-OPC concrete. However, other parameters such as flexural and splitting tensile strength, modulus of elasticity, and drying shrinkage of RHA concrete are comparable with both of the control and silica fume concrete. Moreover, the RHA concrete had excellent resistance to chloride ion penetration, and the charge passed in coulombs was below 1000 both at 28 and 91 days. RHA concrete also showed excellent performance under freezing and thawing conditions, and its resistance to de-icing salt scaling was similar to that of the control concrete and marginally better than that of silica fume concrete.

The review shows that concrete blocks made with RHA-blended Portland cement can be used as construction material. Since OPC is the major cost component of rural housing, replacing a certain percentage of OPC with RHA will reduce the cost of rural housing and other low and medium strength constructions. However, it is first necessary to establish the pozzolanic characteristics of the rice husk.

6.2.3 Alternative Uses of RHA in India

It had been acknowledged in the project, that if the characteristics RHA in Bangladesh were found suitable for use in construction, a study visit to India would be made by one of the investigators. Following the completion of laboratory tests, this trip was undertaken in September 2003. The purpose of the visit was to exchange ideas and share knowledge on the successful technologies on the uses of rice husk and RHA. Some of the most important technologies on RHA are described below.

The Central Building Research Institute (CBRI) Roorkei, India has developed a number of technologies on the use of RHA such as:

- Cement and cementitious binders;
- Engineered fillers for low-lying land for construction of human settlements;
- Construction of ash dykes and embankments; and
- RHA-clay brick.

It is suggested that the best use of RHA would be as raw material for brick making in Bangladesh. For production of clay-RHA bricks, plastic clay has to be mechanically mixed with RHA for uniformity of mixing. But the ration of the mix depends on soil properties. So, it is necessary to analyse the soil at the first stage. It was suggested that the brick field should be within 100 km distance of ash production to minimise the transportation cost of ash.

Salient technical features RHA-clay brick making process developed by CBRI, India:

- ♦ Addition of ash (25-75%) by volume to the soil depending upon the physico-chemical and ceramic properties of soil /ash;
- ♦ Mechanical / manual mixing of clay and ash admixture;
- ♦ Shaping of bricks by manual or semi-mechanised process;
- ♦ Firing the bricks at 950-1050^0 C; and
- ♦ Bricks of grade 50-300 (IS 13757-1993) can be manufactured. These bricks can be used for all types of masonry and soiling.

The advantages of the RHA-clay brick are:

- ♦ Production of better burnt bricks, with an appreciable fuel saving (15 to 25%). Higher porosity of RHA means it absorbs water from the clay and then releases it easily from the mixture during the drying and burning processes. Hence, energy can be saved.
- ♦ Addition of RHA soils reduces excessive linear shrinkage of the brick during drying. RHA is more heat resistant than clay, thus reducing shrinkage.
- ♦ Drying and firing losses during brick production are checked.
- ♦ Strength of bricks is largely increased.
- ♦ Addition of RHA soil increased the production volume of brick from the same quantity of soil.
- ♦ RHA brick is lighter in weight and thereby reduces dead load on the structure.
- ♦ RHA bricks provide better thermal insulation to masonry walls.
- ♦ Reduction of drying and burning time.
- ♦ Environment friendly: firing of RHA-clay bricks requires less time, hence less fuel. It also reduces the levels of carbon dioxide produced.

The above information shows that RHA could be used as a component of cementing materials. If practical uses of RHA were to be developed in Bangladesh the following benefits could be generated

- Problem of ash disposal would be partially addressed.
- The use of RHA in medium load application would be a sustainable conversion of the waste product into a cost effective building material.
- The use of RHA in making clay bricks/hollow blocks will lower the production of the green house gas.

6.3 Materials and Methods

6.3.1 Materials Used

Rice husk: In order to determine the percentages of silica and carbon in rice husk, eight husk samples were examined under thermogravimetric analysis. Photographs of selected husk samples are presented in Figure 6.1. Remaining pictures of husks may be seen in the Appendix 6-C Figure 1. Sources of husk samples are presented in Table 6.2.

a. b. c.

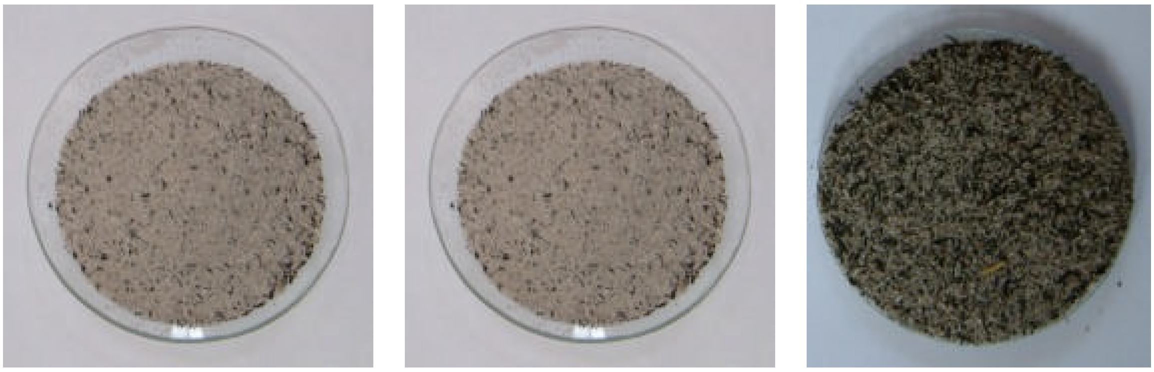
Fig 6.1 Rice Husk Samples from different Rice Mills of Bangladesh.

a. Dry processed husk from a modern rubber rolled huller (free from bran),
b. Parboiled husk from a modern rubber rolled hullers (free from bran),
c. Parboiled husk from an Engleberg huller mill (ground and mixed with bran).

Table 6.2 Sources of Rice Husk Samples

Sample No.	Name of mill	Location	Type of huller	Husk condition
1	M/S Bengle Auto Rice Mill	Dinajpur	Rubber rolled	Unparboiled Free from bran
2	M/S Daradi auto Rice Mill	Dinajpur	Rubber rolled	Unparboiled Free from bran
3	M/S Kanchan Auto Rice Mill	Dinajpur	Rubber rolled	Unparboiled Free from bran
4	M./S Babul Brothers Rice Mill	Mymensingh	Rubber rolled	Unparboiled Free from bran
5	M/S Daradi Auto Rice Mill	Dinajpur	Rubber rolled	Parboiled Free from bran
6	M/S Medina Rice Mill	Gazipur	Rubber rolled	Unparboiled Free from bran
7	M/S A Shahid Rice Mill	Jessor	Engleberg	Parboiled, ground Mixed with bran
8	M/S Purbasha Rice Mill	Pabna	Engleberg	Parboiled, ground Mixed with bran

Rice husk ash: To determine the pozzolanic characteristics of RHA, fourteen samples were collected from different rice processing zones of Bangla desh. Selected samples of rice husk ash are presented in Figure 6.2. Remaining pictures of RHA samples are presented in Appendix 6-C Figure 2. Sources of RHA samples are presented in Table 6.3. The RHA samples were collected from both traditional and improved grated furnaces where no effort was made to control the temperature. Three more RHA samples were collected from the newly designed furnace at intervals of 0.5 hour, 5.5 hour and 4 days after parboiling was completed. The RHA samples were sieved by 2.0 mm sieve to remove foreign matters, stones, clods, iron nails and other impurities.



a. b. c.

Figure 6.2 Rice Husk Ash Samples From Different Rice Parboiling Units of Bangladesh

a. RHA from an improved grated furnace.

b. RHA from a newly designed improved furnace.

c. RHA from an inefficient traditional furnace.

Table 6.3 Sources of RHA Samples from Parboiling Units

Sample	Name of Rice Mill	Location	Capacity (t/hr)	Type of huller	Type of furnace
1	M/S Babul & Bros. A. R. Mill	Mymensingh	2	Rubber roll	Conventional
2	M/S Ehan Rice Mill	Dianajpur	2	Engleberg	Conventional
3	M/S Daradi Auto Rice Mill	Dinajpur	2	Rubber roll	Grated
4	M/S Ansar Ali Rice Mill	Pabna	1	Engleberg	Conventional
5	M/S Alam Rice Mill	Dinajpur	2	Engleberg	Conventional
6	M/S Kanchan Auto Rice Mill	Dinajpur	2	Rubber roll	Grated
7	M/s Bengal Auto Rice Mill	Dinajpur	2	Rubber roll	Grated
8	M/S Kawser Auto Rice Mill	Dinajpur	2	Rubber roll	Grated
9	M/S A. Shahid Rice Mill	Jessor	1	Engleberg	Conventional
10	M/ S Millat Rice Mill	Gazipur	1	Engleberg	Conventional
11	M/S Momtaj Rice Mill	Gazipur	1	Engleberg	Conventional
12	M/S Shahid Sarker	Gazipur	1	Engleberg	Conventional
13	M/s Mobin Rice Mill	Gazipur	1	Engleberg	Conventional
14	M/S Bholanath Rice Mill	Gazipur	1	Engleberg	Conventional

6.3.2 Methods of Analysis

Certain properties of rice husk had to be established. Tests conducted are:

- thermogravimetric analysis (TGA) of rice husk to determine the percentage of ash in RHA samples; and
- moisture contents of husk samples to identify the allowable moisture content of the sample for laboratory tests.

Several properties of RHA have to be established to ascertain its pozzolanic characteristics. The following physico-chemical and structural properties of selected ash samples had to be determined:

- moisture contents of RHA samples to identify the allowable moisture content of the sample for laboratory test;
- particle size distribution of RHA samples to determine the fineness compared to Ordinary Portland Cement (OPC);
- specific surface area and pore-size of RHA to assess the ability to combine with other materials. Yalcin and Sevinc (2000) indicated that greater the surface area of a material the greater is the ability to react with other material;
- bulk density and specific gravity of RHA to determine the volume of per unit weight of RHA compared to OPC;

- x-ray diffraction of RHA particles to determine the amorphousness of RHA. It was reported (Rahim, *et al.*, 1981, Idm, *et al.*, 1977) that the degree of amorphousness can be correlated to the reactivity of pozzolanic material;
- carbon, hydrogen and nitrogen content (CHN) of RHA to determine the allowable percentage of CHN, because for a good pozzolanic material the carbon content should not be higher than 12% (UKQAA 2000);
- scanning electron microscopy (SEM) of RHA particles to understand the morphology of the RHA as higher porosity of materials lower the strength;
- infra-red spectra of RHA to confirm the tests results of amorphousness of RHA and to determine the presence of hydroxyl group in RHA; and
- to ascertain the compressive strength of OPC-RHA cement blocks to determine its load bearing capacity.

The detailed procedure of characterisation of rice husk and RHA samples and equipment used are presented in the Appendix 6-A.The RHA samples collected from the new furnace were characterised only by X-ray diffraction, SEM and FT-IR spectra in order to compare the amorphousness with sample taken from traditional furnace.

6.4 Results and Discussions

This section reports the results of the tests noted in section 6.3.2.

6.4.1 Characterisation of Husk and RHA Samples

6.4.1.1 Moisture Content of Husk Samples

The moisture content of the husk samples varies from 3.4% to 5.9%. However, moisture content of husk samples collected from the mill using Engleberg huller (sample no. 7 and 8 of Table 6.3) was slightly higher than the moisture content of those collected from mills with rubber rolled hullers (Appendix 6-B Table 1). However, this level of moisture content would have no implications for the laboratory tests results.

6.4.1.2 Thermogravimetric Analysis (TGA) of Husk Samples

Figures 6.3a and 6.3b show the TGA patterns of the rice husk degradation subjected to high temperature. The patterns of remaining husk samples are similar in nature and are presented in Appendix 6-C Figure 3. The results indicate that the thermal decomposition of rice husk was completed in three stages. Irrespective of the surrounding atmosphere (static air or nitrogen) there was an initial weight loss of about 7-11% at temperatures below 100 ^{0}C for all samples. The second stage was completed below 300 ^{0}C, the weight loss being 8-14%, for husk collected from rubber roll hullers. However, the weight loss of husk collected from mills using Engleberg hullers was up to 27%. In the third stage the weight loss was very sharp and a maximum loss of 76% to 87% occurred under static air; whereas; a greater weight loss of 76% to 94% occurred under nitrogen (Table 6.4). The weight loss that occurred during the first stage can be attributed to the loss of free water whilst in the second and third stages the losses are attributed to the breakdown of cellulose and lignin constituents, respectively, to combustible components, carbon dioxide, water and char. The results showed that bulk of the residue was silica.

Table 6.4 Thermogravimetric Analysis (TGA) of Husk Samples

Temperature (^{0}C)	Wt. Loss under static air (%)	Wt. Loss under nitrogen (%)
> 100	7.9	8.8
> 300	9.4	10.6
> 500	76.8	49.0
> 1000	75.6	75.9

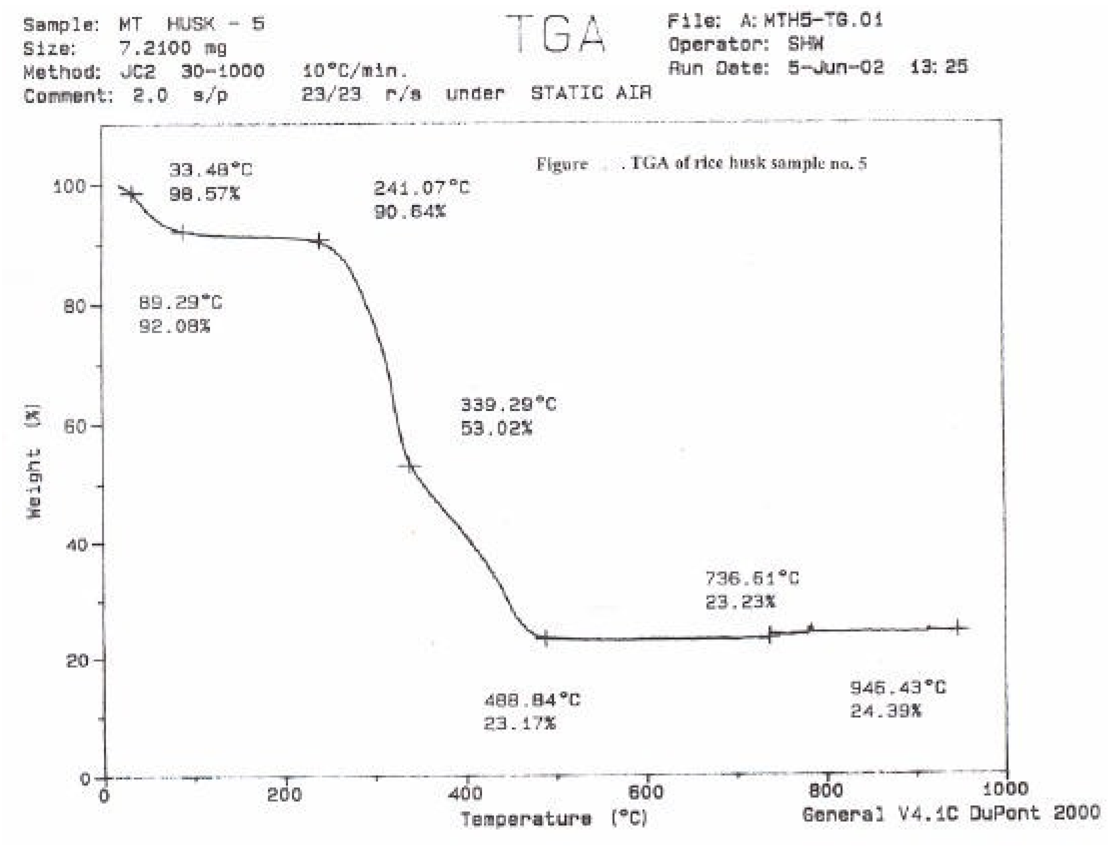


Fig 6.3 (a)

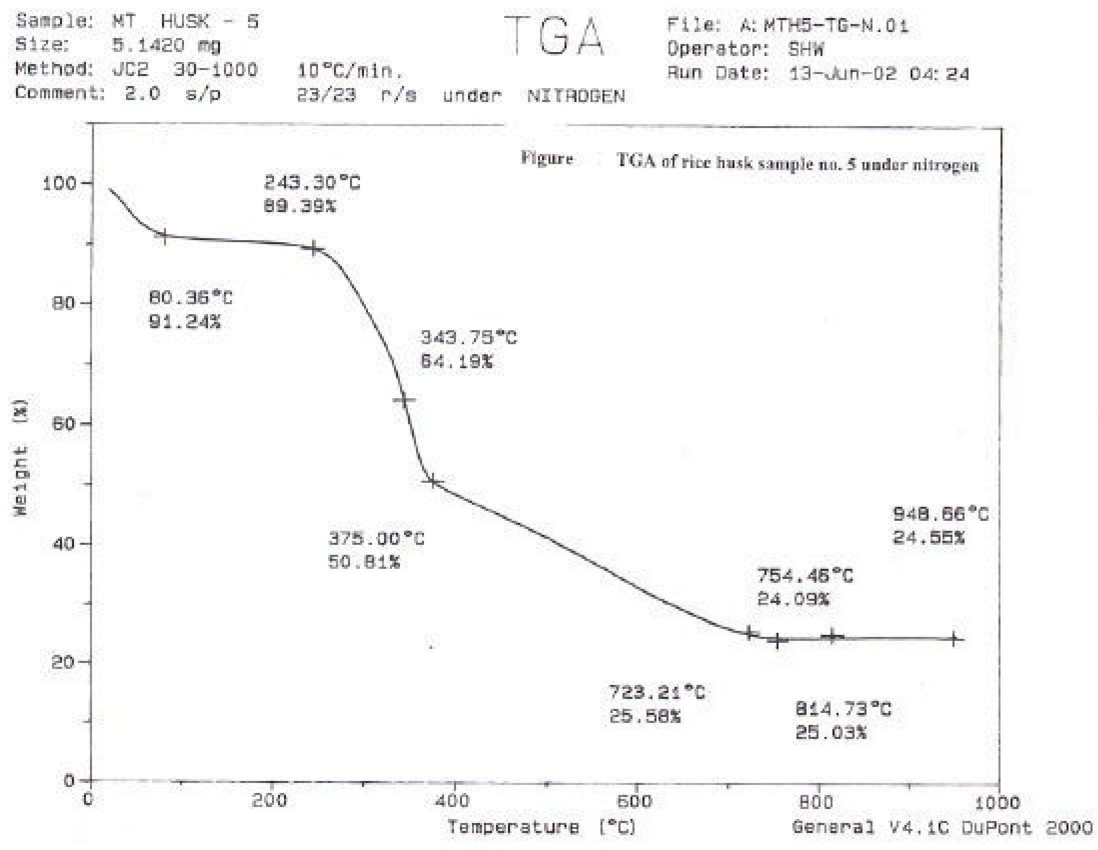


Fig 6.3 (b)

Figure 6.3 TGA Patterns of Rice Husk Degradation
(a) Under static air; (b) Under nitrogen)

6.4.1.3 Moisture Content of RHA Samples

The moisture content of all the ash samples varied from 0.0 to 0.06% (dry basis) this can be taken as negligible (Appendix 6-B Table 2).

6.4.1.4 Grain Size Distribution of RHA Particles

Results of sieve analysis are presented in Figure 6.4. This shows that 40%– 80 % of RHA particles by weight were over 250 microns in size and a maximum of 15% were below 63 microns. It should be noted that these results have no significant effect on the surface area of RHA, which occurs as a consequence of internal porosity. Table 6.5 shows the comparative fineness of OPC and RHA particles. Comparative sieve analysis between OPC and RHA particles showed that 100% of OPC particles passed through the 125 micron sieve whereas, 75%-96% RHA particles were retained on the 125 sieve. This indicates that in order to blend RHA with OPC, RHA needs to be pulverised.

Table 6.5 Comparative Fineness of OPC and RHA Particles

Sieve size (microns)	Percent weight retained on sieve	
	OPC	RHA (at range of all samples)
250	0.00	40-80
125	0.00	75-96
63	18.7	85-99

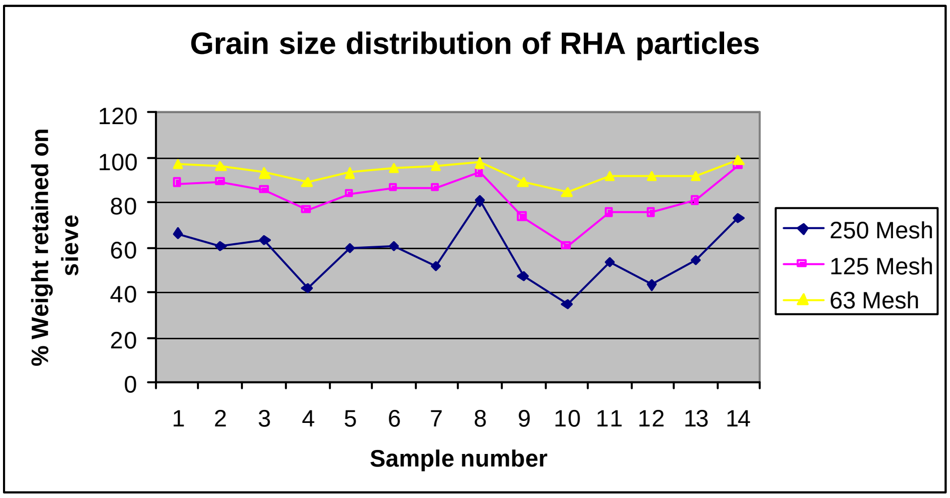


Figure 6.4 Grain Size Distribution of RHA Particles

6.4.1.5 Surface Area of RHA Particles

Specific surface areas of a range of ash samples varied between about 30 and 160 m^2 g^{-1}. Sample No. 10 had the greatest surface area. It measured 161.5m^2g^{-1} (Appendix 6-B Table 3) and so the pore size distribution was determined from the full adsorption/desorption isotherm. The pore diameters of ash particles varied between 2 and about 20 nm (see Appendix 6-C Figures 4). The high value of surface area of up to 160 m^2g^{-1} obtained from the analysis of RHA collected from existing furnaces indicates that the RHA particles should contain very high pozzolanic characteristics. The results are comparable to the results obtained by Yalcin (2000).

6.4.1.6 Bulk Density and Specific Gravity of RHA Particles

The dry bulk density of RHA particles of sample from the new furnace was 0.55 g/cm^3 whilst the specific gravity was 2.03. The value of 2.03 is comparably lower than the specific gravity of OPC (3.08). This indicates that the quantity of RHA by volume would be more than OPC per unit weight.

6.4.1.7 CHN Analysis of RHA Samples

The results of CHN analysis of RHA sample no.8 gave the values of carbon, hydrogen and nitrogen elements as 6.35%, 0.08% and 0.0% respectively. This shows that all the cellulose and lignin components of rice husk have decomposed during burning and the black colour of the ash is due to the residual carbon char. The carbon content of one black sample was about 6%. Most RHA samples were grey suggesting that their carbon contents were much lower than this. There is evidence in the literature that the presence of carbon in ash may have a beneficial effect on its cementing performance (Lea, 1970; Bhatty, 1988).

6.4.1.8 X-ray Diffraction Analysis

The aim of X-ray diffraction analysis was to see whether the silica in the ash samples was crystalline or amorphous (or a mixture of both). The X-ray diffraction patterns of RHA of samples taken from conventional furnaces are presented in Figures 6.5a, 6.5b and Appendix 6-C Figure 5. These results indicate that the degree of crystallinity varies considerably between samples. The RHA from traditional furnaces seemed to produce less crystalline silica (Sample Nos.1, 4, 5, 9, 10, 11 and 13) than the samples collected from furnaces containing step grates. In a XRD analysis by Siemens D500 diffractometer, it was found that Sample Nos. 1 and 10 collected from conventional furnaces contained very low crystalline silica of 1.16% and 1.63% respectively (Appendix 6-B Table 4).

The X-ray diffraction patterns of RHA from the new furnace are presented in Figure 6.6. The X-ray diffraction patterns show that RHA particles are non-crystalline (see also Appendix 6-C Figure 6).

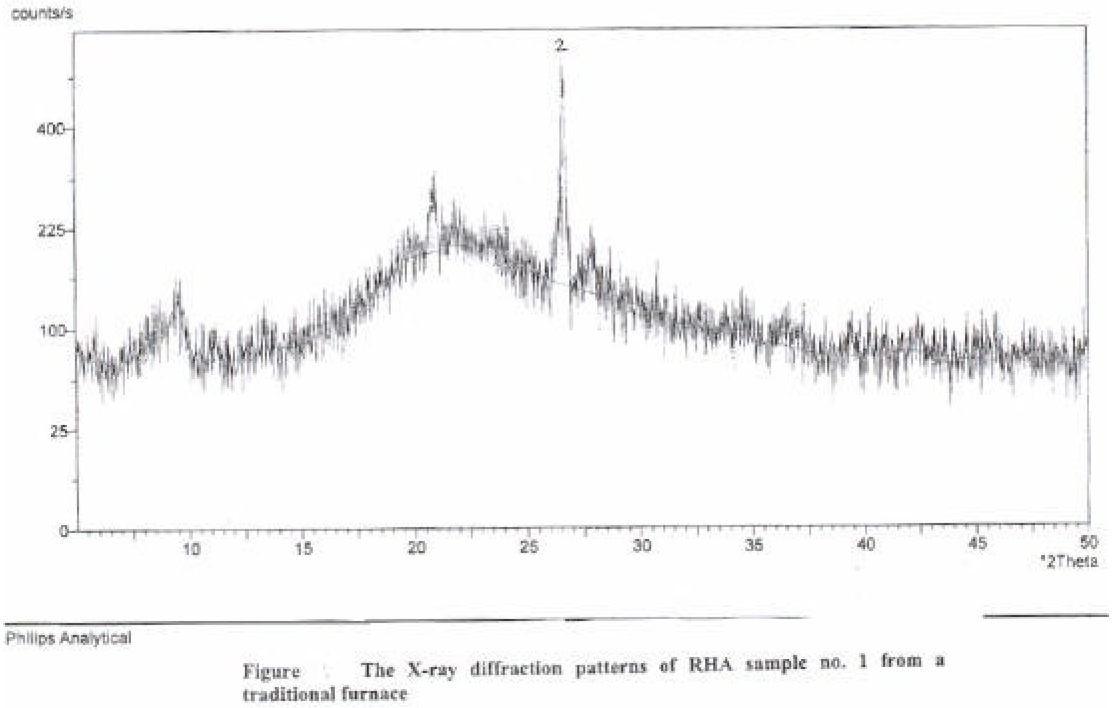


Figure 6.5 (a)

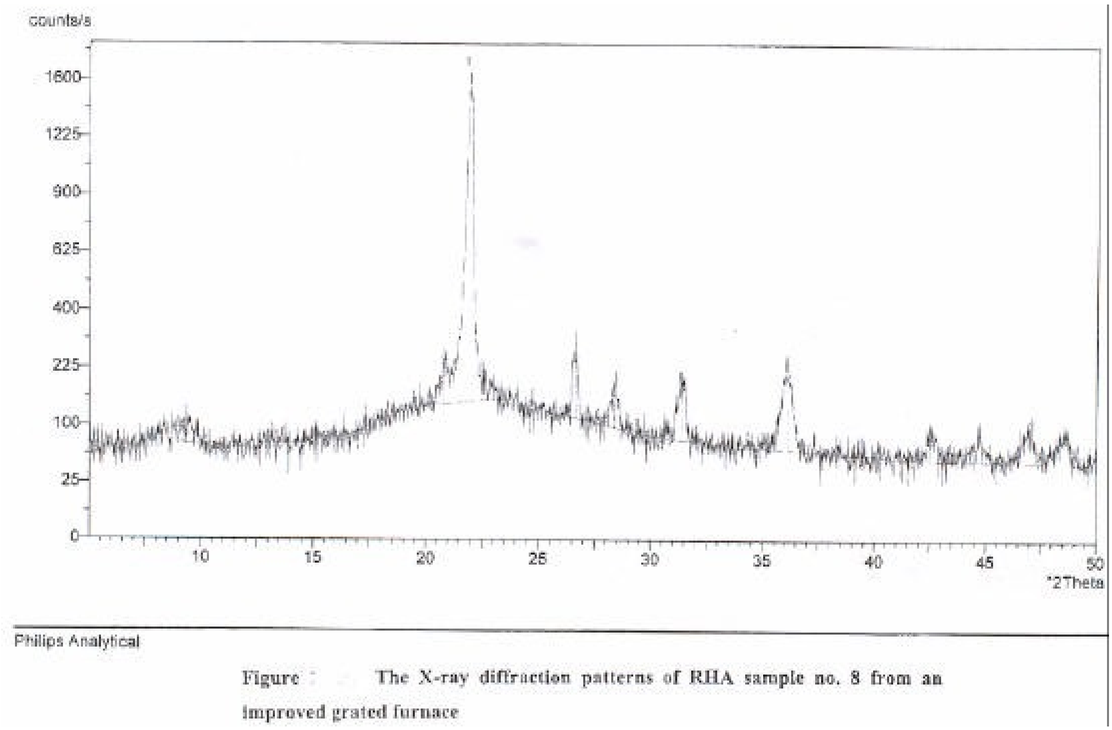


Figure 6 5 (b)

Figure 6 5 X-ray Diffraction Patterns of RHA from Conventional Furnace (a) Sample No.1; (b) Sample No. 8)

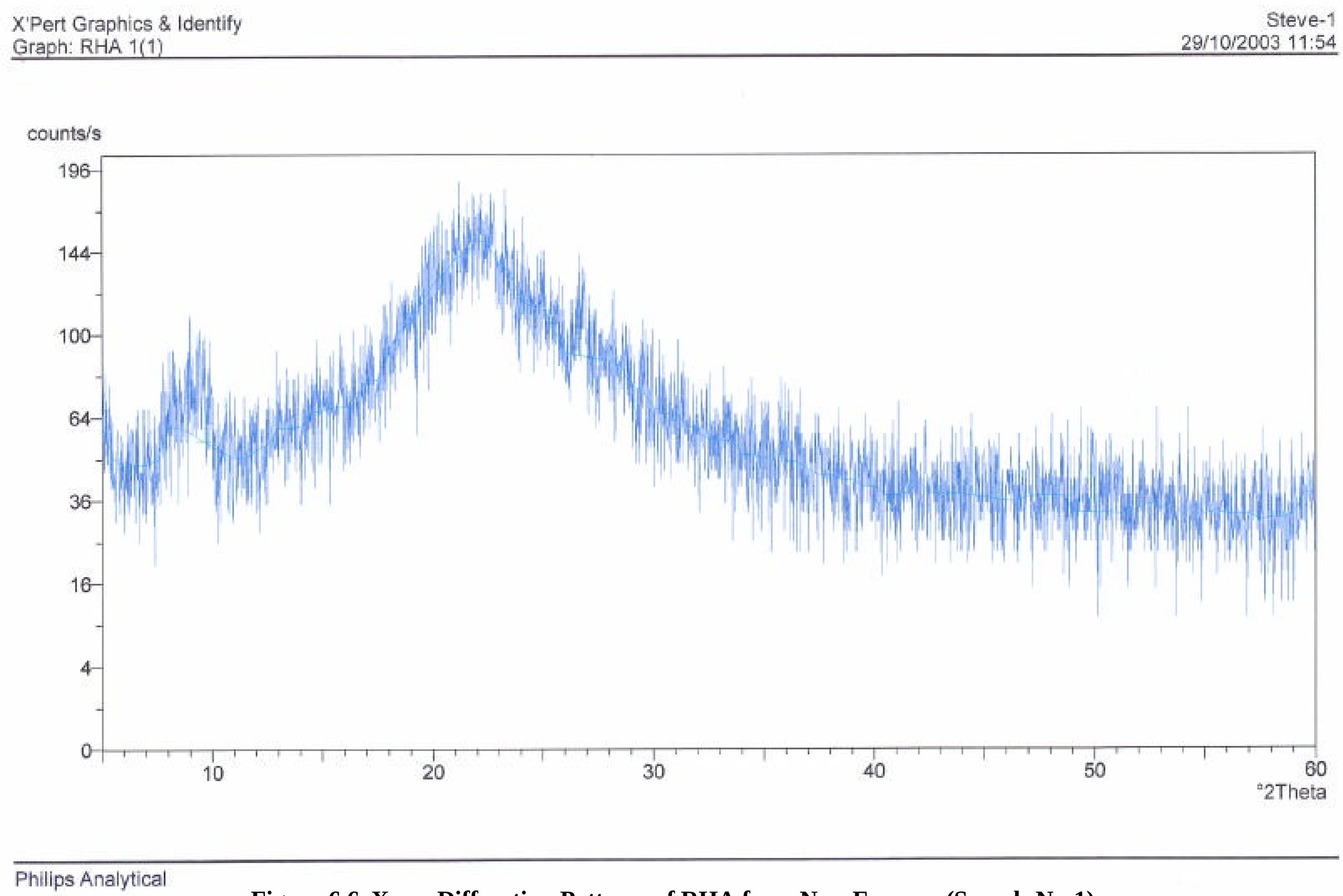


Figure 6.6 X-ray Diffraction Patterns of RHA from New Furnace (Sample No.1)

6.4.1.9 SEM of RHA Particles

Scanning electron microscopic (SEM) images of a selected sample of RHA from the new furnace are presented in Figure 6.7 (see also Appendix 6-C Figure 7). The SEM pictures appear to have a structure similar to the original rice husk. The pictures indicate that the rice husk ash under study was porous, confirming the results obtained by nitrogen adsorption. The SEM pictures of RHA of the previous study can also be seen in Figures 6.8 and Appendix 6-C Figure 8. This indicates that RHA particles of samples from conventional furnace were more porous than the particles of RHA from the new furnace.

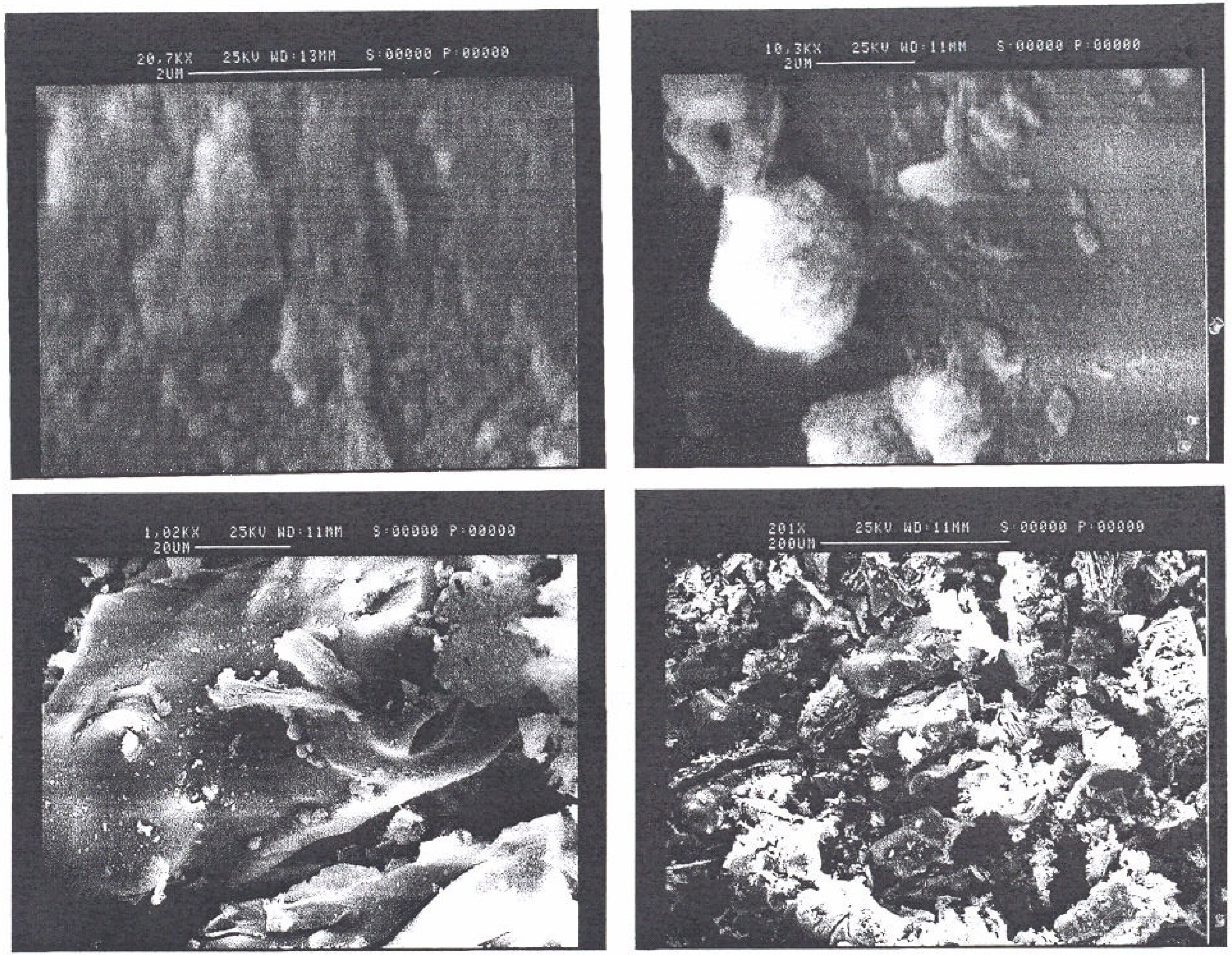


Figure 6.7 SEM Pictures of RHA from the New Furnace (Sample No.1)

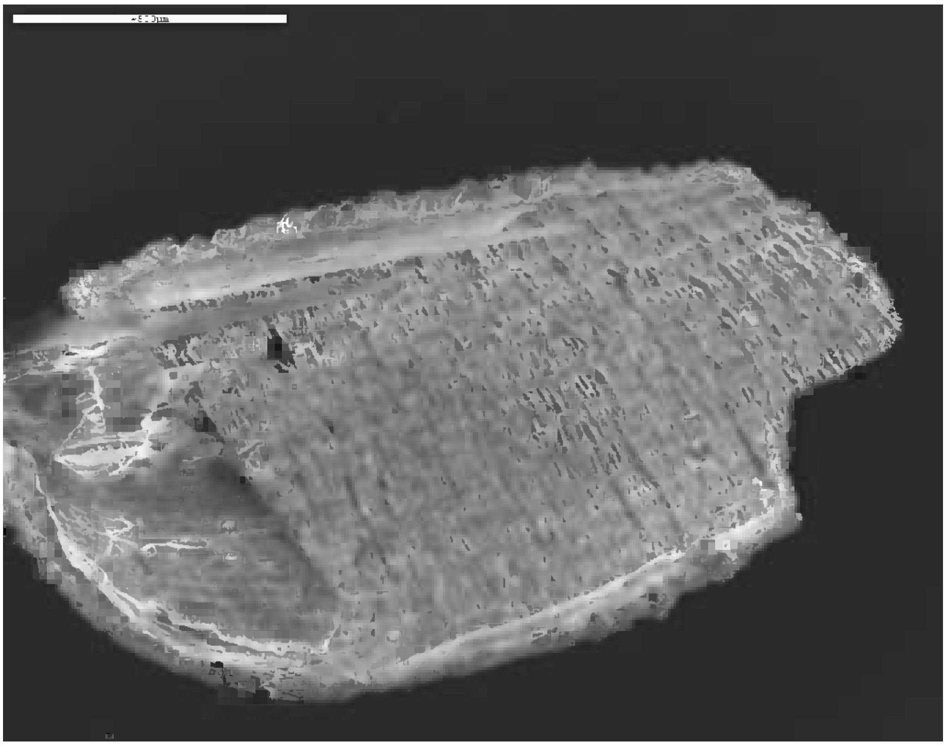


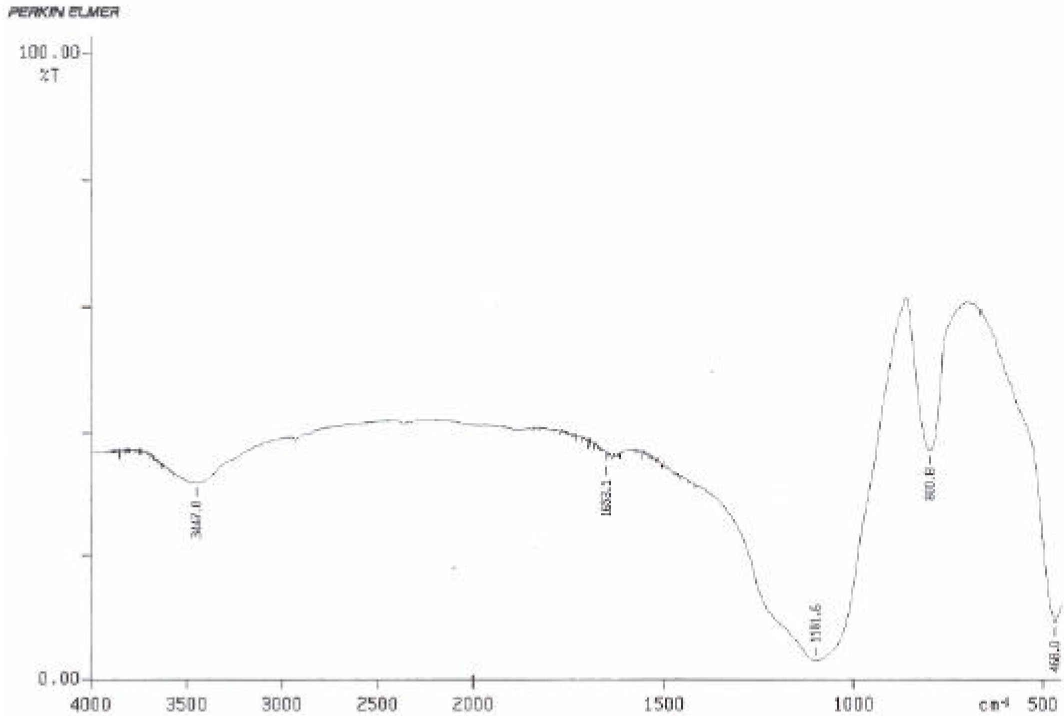
Figure 6.8 SEM Picture of RHA from Old Furnace (Showing Porous Structure)

6.4.1.10 FT-IR Spectra of RHA Samples

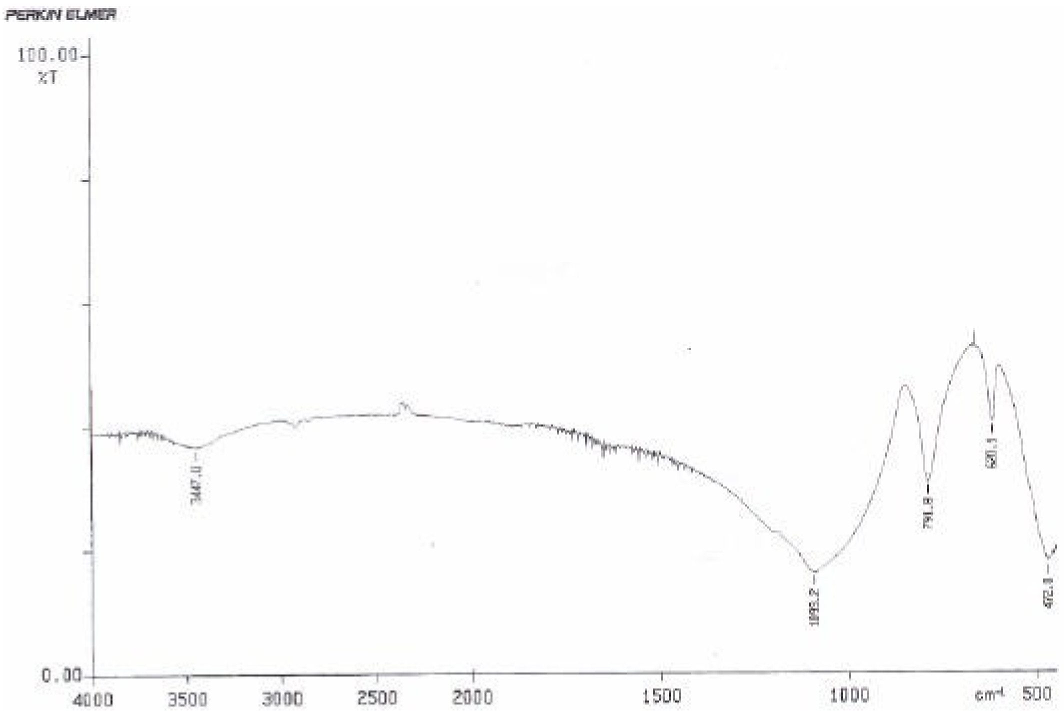
The Fourier Transform-Infra Red (FT-IR) data obtained from the spectra of RHA from conventional furnace are presented in the Figures 6.9a and 6.9b and Appendix 6-C Figure 9. All RHA samples showed FT-IR bands at about 3400, 1600, 1100, 600 and 450 cm^{-1}. The bands in the region of 3400 and 1600 cm^{-1} indicate the presence of hydroxyl group in the silica molecules of the RHA samples. The spectra of all samples studied gave a band at about 800 cm^{-1}; although in some spectra (black sample), these peaks appear to split into two; with an additional peak at around 620 cm^{-1} (Appendix 6-C Figure 9b). These bands confirm the presence of cristobalite, quartz, opaline silica and other forms of silica in the ash samples. The band at 620 cm^{-1} appeared when a high degree of crystallinity was observed by XRD suggesting that this band is due to crystalline silica.

FT-IR spectra indicated that the ash samples from traditional furnaces most probably contain silica in the form of cristobalite, quartz or opaline silica. The FT-IR bands at 1100 cm^{-1} are due to the Si-O-Si asymmetric stretch in all forms of silica ash. Lyon (1967) observed similar spectra in his study. Similar results were also reported by Takamura *et al.,* (1964). In another study it was indicated that bands at 800 cm^{-1} and 481 cm^{-1} are due to the presence of cristobalite; and the bands at 700 cm^{-1} are due to quartz (Farmer, 1974).

The FT-IR data obtained from spectra of RHA from the new furnace is presented in Figure 6.10 (see also Appendix 6-C Figure 10). The FT-IR spectra of RHA from the newly designed furnace produce bands at 3400, 1600, 1100, 600 and 550 cm^{-1}, which confirms the presence of silica in amorphous state. There was no evidence of crystalline forms of silica in agreement with the X-ray diffraction results of RHA from new furnace. In all samples however, there was evidence of incomplete combustion of the organic matter in the samples as peaks indicated the presence of hydrocarbon in the spectra.



(a)



(b)

Figure 6.9 RHA from old furnace showing spectra at 3400, 1600, 1100, 800 and 450 cm^{-1}
(a) Sample No.1; (b) Sample No.8

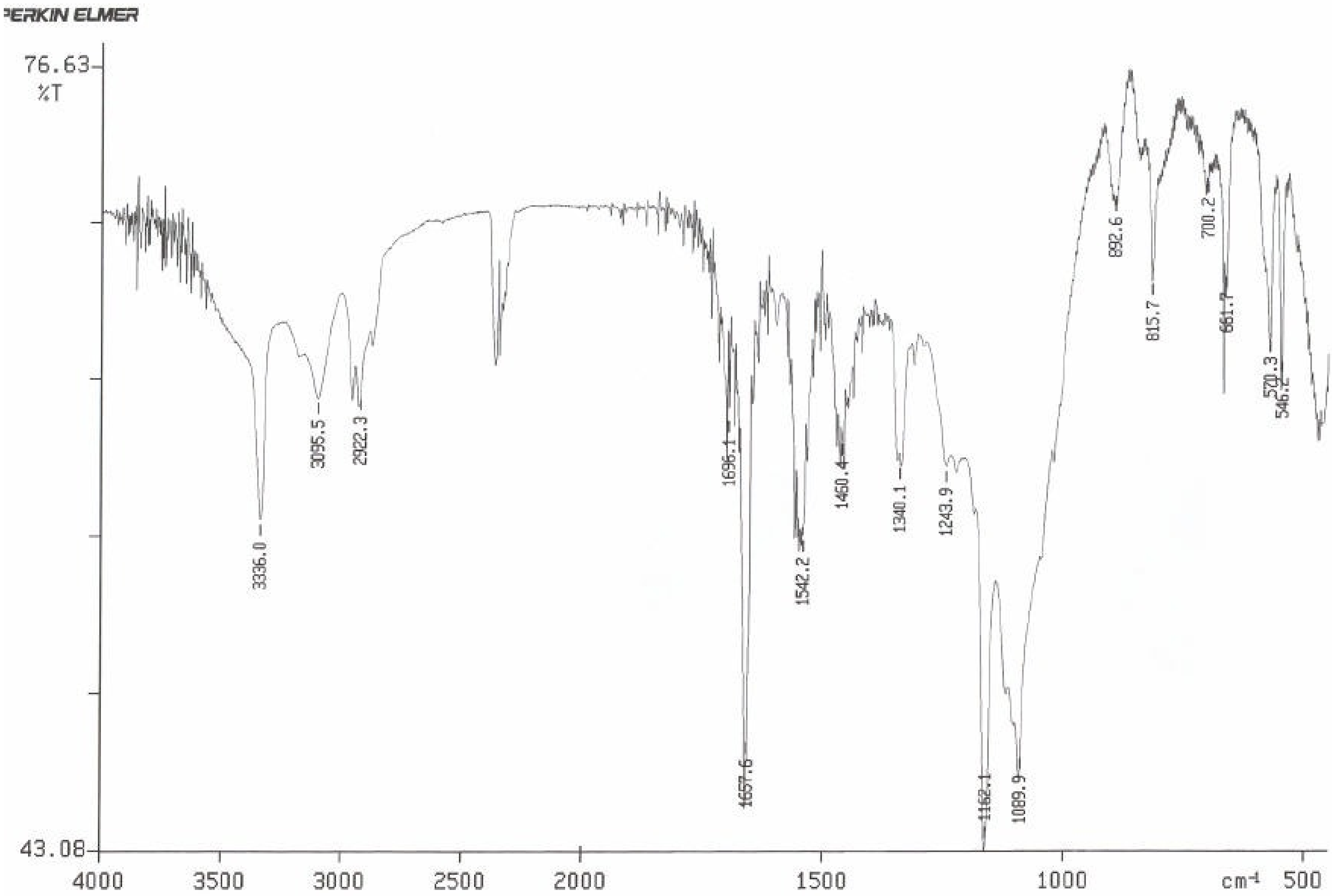


Figure 6.10 RHA from New Furnace Showing Spectra at 3400, 1600, 1100, 800, 600 and 550 cm^{-1}
(a) Sample No.1

The following **conclusions** can be drawn from the results given above.

- The TGA results indicated that about 14% to 22% RHA could be obtained from the husk collected in Bangladesh. It is high in silica (76% – 86%), with small percentage of carbon (about 6%), which is less than the permissible limit (12%, UKQAA, 2000). It also contained some unburned materials indicating that RHA in Bangladesh could be used as a pozzolanic component.
- The sieve analysis showed that the RHA particles are coarser than OPC particles indicating that RHA particles need to be pulverised for good dispersion with cement during mixing. RHA particles can be easily ground, so the grinding requirements as specified for Pulverised Fly Ash (PFA) would not seem to be appropriate for RHA. Grinding could be done in a specialised ball mill.
- The high value of surface area as obtained from the analysis (up to 161 m^2g^{-1}) indicates that the RHA particles should contain very high pozzolanic characteristics.
- FT-IR spectra indicated that the ash samples from the old furnace most probably contain silica in the form of cristobalite, quartz or opaline silica at high crystalline form, which confirms the need for grinding. The FT-IR bands at 3400, 1600 indicates the presence of hydroxyl group in the RHA. Bands in the region of 800 cm^{-1} and 481 cm^{-1} are due to the presence of cristobalite and the bands at 700 cm^{-1} are due to quartz, which also confirms high crystallinty of RHA. However, in the recent tests RHA samples from new furnace showed no sign of crystallinity.
- The X-ray diffraction patterns of the selected samples show that the degree of crystallinity varies widely. It was observed that ash samples taken from traditional furnaces seemed to produce less crystallinity than those from furnaces of improved design, suggesting that the combustion temperature is lower in traditional furnaces.
- However, in the recent tests RHA samples from new furnace showed no sign of crystallinity. This is one of the important value-added by the new furnace.

Based on the results obtained so far RHA obtained in Bangladesh appears to possess a spectrum of excellent properties such as high surface area, good purity, cheapness, low crystallinity (although some samples showed high crystallinty), easy availability compared to other popular pozzolanas. This suggests that it could be used as a blending component in cement to replace OPC to a certain percentage, and in clay bricks. So the next steps of this study were to assess the compressive strengths of OPC–RHA blocks with different OPC-RHA ratios.

6.4.2 Compressive Strength of OPC-RHA Cement Blocks

The test results of the compressive strength of standard 7.05cm OPC-RHA cubes made from RHA of newly designed improved furnace are presented in Figures 6.11 and 6.12 (see also Appendix 6-B Tables 5 to 7). Figure 6.11 Shows that the average compressive strength of the OPC-RHA blocks, made by 10% replacement of OPC by RHA without grinding and after 28 days of curing, is 1315 N/cm^2 (13.0 N/mm^2). This corresponds to a loss of about 9% of strength when compared with the blocks made from 100% OPC. However, by using ground RHA at 10% replacement of OPC the average strength was increased to 1928.0 N/cm^2 (19.3 N/mm^2), which is 3% above that of the blocks made from 100% OPC (Figure 6.12).

Another test was conducted with cubes made by 10% replacement of OPC by ground RHA to determine the water solid ratio of mixes; where compressive strength of OPC-RHA block was found to be 16% higher (202 N/cm^2 ; or 20.2 N/mm^2) than the strength of 100% OPC after 28 days of curing at 38.5% of water (by weight). The compressive strength of same RHA blocks after 35 days of curing was increased to 2310 N/cm^2 (23.1 N/mm^2) which is about 26% higher than that 100% OPC blocks (Appendix 6.B Table -6).

The literature indicates that OPC-RHA concrete blocks can produce higher strengths than that of OPC-RHA cement blocks. Ikpong *et al.* (1992) also obtained results on concrete mixes with strengths of up to 30.0 N/mm^2 at 10% replacement of OPC. The results of compressive strength (from 13.2 N/mm^2 to 23.1 N/mm^2) of OPC-RHA cement blocks in Bangladesh are therefore within the acceptable range for medium load constructions. It is important to note that characteristics of RHA vary widely due to source and production processes; hence RHA samples need be tested before use as a blending component.

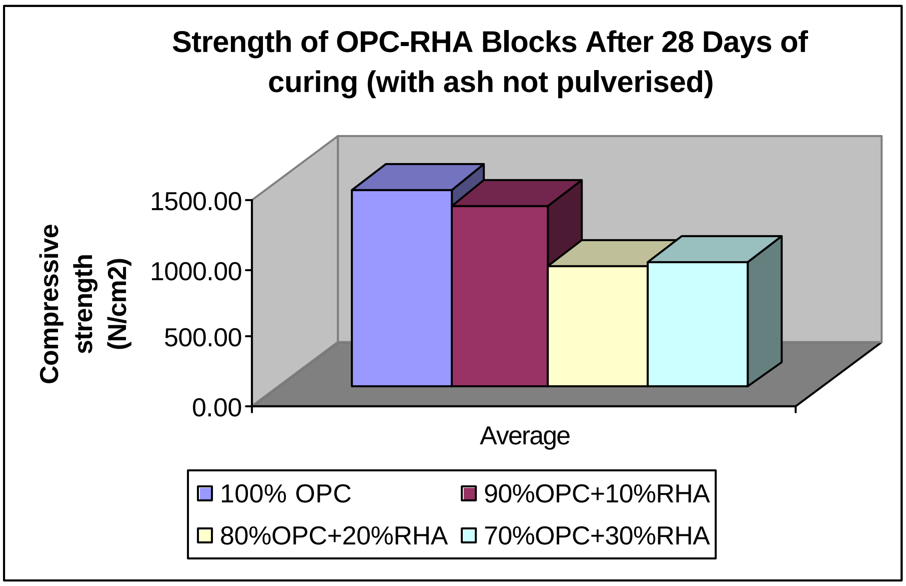


Figure 6.11 Compressive Strengths of OPC-RHA Blocks Made from Different OPC and RHA Mixes (RHA from New Furnace)

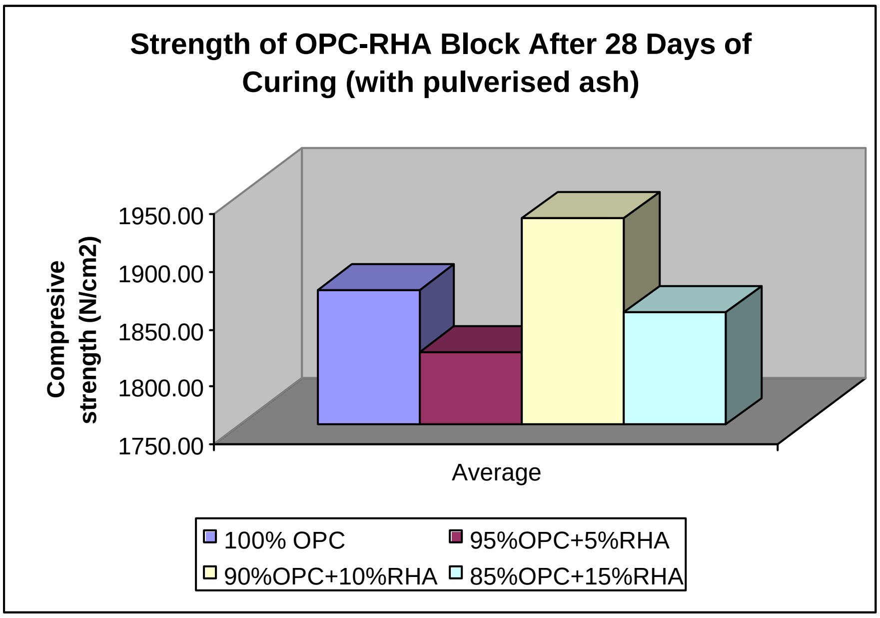


Figure 6.12 Compressive Strengths of OPC-RHA Blocks Made with Different Mixes of OPC and Ground RHA (RHA from New Furnace)

6.5 Conclusions

1.2 million Tonnes of rice husk ash are dumped in rural areas of Bangladesh every year. Research and experience outside Bangladesh showed that RHA, if it possesses pozzolanic properties, could be blended with Portland cement to build low to medium strength constructions. It could also reduce the cost of rural construction, as OPC is expensive. The tests conducted to assess the possibilities of such use have been positive. It could also be used to make clay-RHA bricks.

- Based on the results obtained so far RHA appears to possess a spectrum of excellent physico-chemical properties such as: high surface area, good purity, cheapness, low crystallinity and easy to grind; compared to other popular forms of pozzolana. This suggests that it could be used as a blending component in cement to replace OPC by a certain percentage.
- Compressive strength tests of OPC-RHA blocks with 90% OPC and 10% ground RHA obtained from the new furnace indicate satisfactory compressive strength; thus permitting its use in medium load construction. This also indicates suitability for use in clay-RHA bricks.
- The percentage of water in the mix should be 38.5% as this ratio gives the highest strength to the OPC-RHA blended cement.
- Specifications for use of RHA with OPC have to be developed for the industry following further field research.
- The crystallinity of RHA determines whether it needs to be pulverised before blending with OPC. Hence, any producer of this blended cement would need to assess the crystallinity of RHA before use.

7 Dissemination of Project Findings

7.1 Introduction

The aim of this chapter is to describe the dissemination activities already undertaken as part of project activities and to indicate further dissemination activities that could be supported by DFID to build on the outputs of this project.

This chapter is divided into three sections. Section 7.2 briefly states the characteristics of the rice mill sector that influenced the dissemination activities. It then describes the dissemination activities already undertaken in Bangladesh and the outcomes of these activities. Section 7.3 discusses the process by which Vietnam was selected for third-country dissemination. It then reports the dissemination activities in Vietnam and their outcomes. Section 7.4 identifies further dissemination activities that could be funded to enhance the uptake of the technologies improved by this project.

7.2 Dissemination Activities Undertaken in Bangladesh

7.2.1 Key Factors Influencing Dissemination Activities

Chapter 2 noted the socio-economic and organisational characteristics of the small-scale rice mill sector that have implications for dissemination activities in Bangladesh. These are briefly noted here. They are as follows:

- The mill operating arrangements are complex. 55% of the mills are operated by the owners. The other 45% is a combination of arrangements between owners and *beparis* where the owners keep control of the assets while *beparis* run the mill. This means it is important to target both owners and *beparis* during dissemination.
- The rice mill sector is dominated by low levels of educational achievement and technical knowledge. There is a total reliance on the local technician or the *mistri* for any technical information, design and maintenance of the boiler-furnace unit. It is essential to include both the owner and the *mistri* in the design stage and during dissemination.
- The target group is ambivalent of what technological change means. There is confusion between expansion of scale of operations using the same technology and technological change. Most find it difficult to imagine anything other than what they use. Consequently demonstration effect is strong.
- Most were positively inclined to improvements if it meant safer, more efficient technology at affordable price. Issues of affordability were addressed in the design of the improved boiler furnace unit.

It was noted in Chapter 4 that the owners of briquetting units and mill owners located outside the eastern districts of Sylhet and Chittagong were open to any improvements that would make it cost effective to use husk of parboiled rice for briquetting. It was noted that the current cost of disposal of unused rice husk was increasing.

7.2.2 Dissemination Workshop in Dhaka

The aim of the dissemination activities in Bangladesh was to inform the stakeholders of the project outputs and to demonstrate the technological improvements made in the use of rice husk as a fuel. The stakeholders include user groups, the policy makers, the wider research community and the civil society organisations. With this is mind a two-day workshop was planned. It was held in Dhaka on 25 and 26 June 2003.

The first day targeted the user group of the furnace-boiler unit, i.e., rice-mill owners, mill operators, technicians and briquette producers based near Dhaka. It was important to dedicate a day to this user group; a constituency central to successful dissemination of project benefits. The second day focused on dissemination of project findings to relevant institutions, government officials, non-governmental Organisations, researchers and academics. Appendix 7-A gives the workshop programme.

Day One

The proceedings were conducted in Bengali for the benefit of the target group. The target group was invited from the 35 mills that were visited by the project team that had carried out the baseline survey in Phase 1 of the study. Transport cost and a small per diem had to be offered as is the practice in Bangladesh. 50% of the target group invited were present.

A handout had been prepared in Bengali (see Appendix 7-B) giving an overview of the project and its activities. The technical session first demonstrated the comparative performance advantage of the improved furnace-boiler unit as against the conventional system. This was followed by a video presentation showing the improved system in operation. The participants were then taken to the demonstration unit to observe the improved system in operation. The technicians were involved in long and useful discussions with the project team and with the technician of the mill where the demonstration unit is based.

Outcomes: The post-lunch session focused on getting feedback from the user group on the design and operation of the new furnace and on the need for further dissemination. The principal outcomes of this discussion were:

1. The user group would like to see the system in operation over a longer period. This could be addressed by setting up demonstration units in some of the other clusters identified by this study.
2. The technicians would need training and more detailed technical information than was possible to share during a one-day session.
3. Need for more clarity on the issue of chimney height for rice mills. As noted in Chapter 3, the Department of Food sets the required height at 30 feet for mills supplying grain to the government. This height is not based on any environmental parameters relating to this sector. The Department of Food adopts the standards set by the Department of Environment for the brick kiln industry which is a far more polluting sector. The required chimney height for the improved furnace is only 15 feet.

The uptake of the improved technology with its shorter chimney stack will not be a problem for mills that do not supply the government with rice. However, for those that do supply, it could be a constraint. However, it was noted that mills will have to continue to build 30 feet chimney stacks even with the more efficient furnace, till more relevant environmental standards are set by the authorities. This will mean un-necessary and additional costs. It is crucial that the Department of Environment set compliance criteria related to emissions in this sector.

Day Two

The aim here was to disseminate improvements and findings relevant to rice mills, briquette production and alternative use of rice husk ash. Hence, the targeted audience was bigger and a more diverse group. This included the wider research community in Bangladesh, i.e., Bangladesh Agricultural Research Council, Bangladesh Agriculture University, Bangladesh Institute of Technology, Bangladesh University of Engineering and Technology; owners of briquetting units, government officials, NGOs working with environmental issues, staff from BRRI, independent researchers, and members of a private sector construction firm. Unfortunately there were no representatives from DFID-Dhaka.

A leaflet in English with project aims and outputs were provided to the participants (see Appendix 7-C). The session was opened with a background of the project and an overview of the methodology. The different members of the project team then presented papers on the findings of the three project components. Each presentation was followed by a question-answer session. In the post-lunch session a participatory feedback exercise was carried out. The aim was to obtain views on the strategies for future dissemination activities of project findings. The participants were asked to write their response to the four questions given below on cards provided. (The completed cards were later collected for future reference). Each participant was then asked to share their response with the group. These questions are:

1. What feature did you like most about the improved technologies?
2. What feature did you like least about the findings and improvements?
3 What should be done to disseminate the improved furnace design and the briquetting technique?
4. What should be the dissemination channels and who would be the appropriate agency to disseminate?

Outcome : The views and suggestions can be categorised under the three project components.

1. The improved furnace-boiler unit: In response to the first question, there was unanimous support for improvements in safety conditions. The improvements in efficiency received second place. The group was ambivalent about Question 2 and no clear view(s) emerged. However, a participant noted that if insulated bricks had been used in the construction of the furnace instead of ordinary bricks, more energy savings could have been made. It was observed by the team that it would have increased the cost substantially. It was also noted by a participant that manual feeding of furnace should be replaced by mechanical feeder for safety reasons. While this is true, these issues are beyond the remit of this project.

Further Dissemination: There was a general consensus that these improvements should be disseminated. As one participant from BUET noted " …we must remind ourselves that we can save an enormous amount of firewood, coal and gas if the saved husk can be used for briquetting. If we calculate the true cost, the project is the real winner".

The overall emphasis of the participants was

- on the need for training of technicians, distribution of technical information through leaflets, improving motivation for change among owners and operators, focus group discussions and setting up more dissemination units;
- on the need to persuade the Inspectorate of Boilers and the Department of Food to develop more relevant environmental policy with respect to the small scale rice mill sector;
- no subsidy should be given, rather owners should be encouraged to seek alternative sources of finance;
- there should be more than one strategy for dissemination. Different stakeholders should be identified and a coherent strategy developed; and
- the need to identify proper and appropriate agencies for dissemination. Suggested agencies were NGOs, Centre for Mass Education, BRRI, the private sector, Rice Mill Owners' Association. In reality, adequate dissemination would require partnership between multiple agencies.

2. Improvements in briquette making: Most participants were unaware that briquettes, where available, were of growing importance to poor households and small food retail businesses. However, all were aware that disposal of surplus husk was a problem in clusters of rice mills. The participants focused on the production of the improved screw in Bangladesh. The screw with improved design was manufactured in India, where the material and know-how were available. The discussions centred on the scope for producing the screw in Bangladesh and on the cost advantage of manufacturing in India and importing it. Currently a substantial amount of industrial spare parts and tools are imported from India.

With respect to dissemination, it was observed that demonstration effect would be strong in enhancing uptake. To maximise this effect the location of the demonstration unit would require careful consideration.

3. Rice husk ash: A majority of participants were aware that ash from the furnace was dumped on rice fields and ponds, but gave it little thought. Ironically most were aware that internationally considerable amount of research had been undertaken to identify value-added use of rice husk ash. The Workshop concluded that an important contribution of this project was that it ascertained the characteristics of rice husk ash in Bangladesh, (it varies from place to place) so that alternative uses could be identified.

The **conclusions** from the workshop are: (i) demonstration effect is strong among the user groups given their low levels of technical knowledge and attitude to change; (ii) before demonstration units are set up, the user groups should be provided with detailed information through leaflets and focus group discussions; (iii) the choice of location of demonstration units is important for maximum impact; (iv) the issue of setting appropriate environmental standards for the rice milling sector needs to be pursued by BRRI with the Departments of Food and the Environment; and (v) any future dissemination has to be inclusive of the different stakeholders and should be held together by a coherent strategy.

7.3 Dissemination in Vietnam

Section 7.3.1 gives the reasons, and the methodology used, for selecting Vietnam for third-country dissemination. Section 7.3.2 describes the dissemination activities in Vietnam and their outcomes.

7.3.1 Selecting Vietnam

It was recognised from the start that work and methodologies developed in this project could have wider regional applicability. It was planned that they should be assessed against available information on the rice industry and rice husk utilisation in some other countries, in addition to Bangladesh. Then it was proposed to identify one additional country where it would be appropriate to disseminate the findings of this project. It was envisaged that the additional country would be from the following: India, Indonesia, Philippines, Sri Lanka and Vietnam. These countries were reviewed to identify the target venue country. This was done by looking at: rice production and other indicators in rice producing countries; overall national energy consumption; biomass energy utilisation in general; and rice husk use in particular.

Reviewing statistical and other information on the rice producing countries has been facilitated through reference to 'A Profile of Country Rice Facts' (CORIFA) which is an activity of the International Rice Commission. CORIFA assembled key statistics for 66 rice producing countries including all the regional Asian countries of interest in this exercise.

There is also much information available on overall energy use. However, biomass energy statistics are more difficult to access and need to be carefully assessed. For the purpose of this work, the overview energy perspective has been obtained through information from FAO Regional Wood Energy Development Programme (RWED), Bangkok. This programme has members from 15 rice-producing Asian countries.

An initial review is made of rice production information for these 15 countries (see Appendix 7-D) to derive a reduced list of 8 countries. The available energy data is then reviewed for them to identify the third-country for dissemination.

Information on Rice Producing Countries

The data in Table 7.1 have been compiled from 'A profile of Country Rice Facts' (CORIFA) for various countries where energy use of rice husks could be of significant importance. It is evident that there are restrictions to trying to compare at the national level, especially for the larger countries where in-country variations are important and yet are obscured by this approach. Also making only a one-year comparison imposes restrictions. Nevertheless, some outline categorisation has been applied to the assembled data as follows.

Population

	High (>200m)	China
	Medium (50-200m):	Bangladesh, Indonesia , Pakistan, Philippines, Thailand, Vietnam

GDP/Capita

	High (>US$1000):	Indonesia, Malaysia, Myanmar,
	Medium (US$500-1000):	China, Pakistan, Sri Lanka, Thailand, Philippines

Rice Consumption

	High (>200kg/yr):	Bangladesh, Cambodia, Indonesia, Laos,
	Low (<50kg/yr):	Bhutan, Pakistan, Myanmar, Vietnam

Average Yield

	High (>5ton/ha/yr):	China
	Low (<2.5ton/ha/yr):	Bhutan, Cambodia, Nepal, Thailand

Table 7.1 Data for Rice Producing Countries (1995)

Country	National Statistics		Rice Statistics			
	Population	GDP/ Capita	Production	Net Export	Consumption	Av. Yield
	millions	US$/person	million tons	million tons	kg/person/yr	tons/ha
Bangladesh	118.3	280	26.4	-1.57	219.4	2.7
Bhutan	1.8	166	0.05	-0.027	43	1.7
Cambodia	10.0	130	3.3	-0.081	245	1.7
China	1220.0	582	189.3	-1.41	137	6
India	929.0	365	119.4	4.91	114	2.8
Indonesia	197.5	1,019	49.7	-3.16	219	4.3
Laos	4.9	359	1.42	-0.016	259	2.5
Malaysia	20.1	4,313	2.13	-0.425	132	3.1
Myanmar	45.1	2,399	19.6	0.353	314	3.2
Nepal	21.4	203	3.6	-0.04	118	2.4
Pakistan	136.3	504	5.92	1.85	21	2.7
Philippines	67.8	1,093	10.54	-0.26	136	2.8
Sri Lanka	17.9	716	2.81	0.034	131	3.2
Thailand	58.2	2,896	21.13	6.2	175	2.3
Vietnam	73.8	270	24.96	1.98	247	3.7

Two preliminary comments on the assembled data can be made. China is exceptional due to the large population and scale of production, and the developed technology evident from the high average yield attained. It would be beyond the scope of this project to address issues in this country. Myanmar is also an inappropriate venue country for this exercise.

The categories of GDP/capita and Consumption/capita are crude indices of poverty and commodity priority. These therefore warrant more consideration and by applying an exclusion principle, Indonesia, Malaysia and Philippines can be excluded on the basis of their relative wealth, and Bhutan and Pakistan on the basis of low consumption of rice.

In this way the ‘candidate’ countries are reduced to seven, which are the ones highlighted in the Table 7.2 together with Bangladesh. Further comparison of these countries is made below in terms of energy utilisation patterns with the aim to identify one target country for more dissemination.

Energy Utilisation Patterns

Information on energy utilisation in the selected countries has been drawn from work of the FAO-UNDP Regional Wood Energy Development Programme (RWED), Bangkok. Their report entitled, FD 50 ‘Regional Study on Wood Energy Today and Tomorrow in Asia’, 1997, provides compiled tables which include best estimates of biomass energy from wood and other biomass/combustible renewables. It also gives a useful résumé of the derivation of these statistics. The overall position is summarised in Table 7.2. The figure for total biomass energy includes wood energy.

Table 7.2 Consumption of Conventional, Wood and Biomass Energy in (1993-94)

Country	Total Energy	Total Energy per Capita x 10^6	Conven-tional Energy	Wood Energy	Total Biomass Energy	Total Biomass Energy per Capita x 10^6	% Wood Energy in Total Energy	% Total Biomass Energy in Total Energy
Bangladesh	714.0	6.1	210	141	504	4.3	20%	71%
Cambodia	94.0	9.4	14	79	81	8.1	84%	86%
India	8,751.0	9.4	5,822	2,603	2,929	3.2	30%	33%
Laos	47.0	9.6	5	42	42	8.5	89%	89%
Nepal	279.0	13.0	23	192	256	12	69%	92%
Sri Lanka	174.0	9.7	79	85	95	5.3	49%	55%
Thailand	1,837.0	31.6	1,352	353	485	8.3	19%	26%
Vietnam	1,076.0	14.6	260	423	816	11.1	39%	76%

The influence of availability of biomass for fuel is obscure but low biomass per capita use in India and Bangladesh suggest that this is an important factor. Some significant observations that can be made from Table 7.2 are:

Total Energy Use

- In absolute terms India has the highest energy use; and
- Thailand is by far the most energy intensive on a per capita basis;

Total Biomass

- India has the highest total use of biomass (mainly wood), but this position is reversed on a per capita basis when it the lowest;
- Countries with high per capita use of biomass are Cambodia, Laos, Nepal, Thailand and Vietnam; and
- Countries with a high proportion of use of non-wood biomass are Bangladesh and Vietnam.

Conclusion: Of the countries listed in Table 7.2 and considered for this exercise, Vietnam comes to the fore. It has a comparable scale of rice production and GDP/capita as Bangladesh. It also has very high per capita rice consumption. Vietnam uses a large amount of biomass energy and a major proportion of this is non-wood biomass. Work on the improved use of rice husk for smaller scale combustion is also known to be underway. Vietnam was therefore considered appropriate for disseminating the outcomes of this project.

7.3.2 Dissemination Activities in Vietnam

Dissemination in Vietnam was undertaken in February 2003 by NRI and TERI team members. The main contacts had been established in Hanoi and it was the centre of dissemination activities. The activities and their outcomes are described below.

1. Meeting with Dr Taon, Deputy Director, The Institute of Energy. The team first did a presentation of project aims, objectives and findings. Several topics were discussed but of relevance here is fruit drying in Northern Vietnam. Currently it is done on small coal fire. The fire is difficult to control and results in uneven drying of the products, which fetches a very low price. It was suggested by this project team that the improved furnace could be used to produce flue gas for drying rather than steam, as in the case of Bangladesh.

2. At the joint meeting with The Institute of Rural Engineering and Institute of Energy problem of drying agricultural produce was again discussed. It was suggested by the Institute of Rural Engineering they would put together a proposal for collaboration and forward it to TERI and NRI. Following TERI's and NRI's inputs it will be returned to the Institute, who will submit the proposal for funding. The project team is waiting to receive the proposal.

3. Meeting at the Institute of Material Sciences (IMS): A presentation was made to all members of the faculty on improved furnace design and on use of rice husk briquettes. Currently there is no briquetting of rice husk, it is burnt loose, a highly inefficient process. Following the meeting Prof. P.H. Khoi, President of Vietnam Physics Society and Chair of Scientific Council of IMS requested that a joint proposal be submitted to set up a demonstration briquetting machine in northern Vietnam, where very inefficient use of husk takes place. A field visit to such an area was planned for the next day.

4. Field Visit to Thoan Oae community, 40 Km Southeast of Hanoi. The team visited several households. It was observed that households burn loose rice husk for cooking which was extremely inefficient (Plates 7.1 and 7.2). Additionally, this causes high indoor pollution and an overall unhealthy working condition. Plate 7.3 shows tar dripping from the ceiling. Commune leaders accompanying the team agreed that no attention has been given to problems of indoor pollution. No briquetting of rice husk was being undertaken here or anywhere in Vietnam. Briquettes as household fuel are cleaner, easy to store and allow easier control of heat.

Unfortunately, the team was unable to visit any agro-processing unit that was in operation. However, both problems of indoor pollution and unsatisfactory drying techniques currently used were discussed with Prof Khoi and the commune leaders.

Plate 7.1 Pans to be covered with Rice Husk in Preparation for Cooking.

Plate 7.2 Rice husk is set alight. Cooking is in progress.

Plate 7.3 Rafters in the Kitchen covered with Tar.

5 Meeting with ENTEC: The government of Vietnam has acknowledged that it is not cost effective to supply energy on national grid to remote areas of Vietnam. It is promoting the development of micro-hydro power and more efficient use of biomass fuel in such areas. The NGO called ENTEC is working in the hilly regions of northern Vietnam to promote the use of micro-hydro units. The project team met the representatives of the company to discuss the scope for developing more efficient use of biomass fuel in the region. Currently, despite the government policy, there are no efforts to use biomass resources. Additionally, information was obtained on the inefficient use of rice husk in brick kilns throughout Vietnam. This is another area where use of briquettes would enhance efficiency considerably.

6. Meeting with Simon Lucas, DFID-Vietnam Infrastructure Advisor: The project leader briefed Simon Lucas about the project and noted that NRI and TERI would be interested in submitting a proposal targeting indoor pollution in rural households. Simon Lucas suggested that this proposal could be linked to the Rural Livelihoods Projects in the North Eastern Provinces. He has provided information on the project. NRI to follow up on this at the conclusion of this project.

At the same meeting Second Rural Transport Project was discussed. One of the aims of this project is to use local raw material for road construction. The Mekong Delta region has no easy access to gravel. In this region the project would like to use bricks for rural road construction, as in Bangladesh. Currently, good quality bricks are being produced but in highly polluting units using coal and firewood and rice husk. Rice husk briquettes could be used, but would require redesign of the furnace. A follow up on this discussion has resulted in NRI proposing to DFID a knowledge enhancement study on the use of rice husk briquettes in brick kilns. NRI agreed to submit a proposal.

This visit highlighted the fact that disseminating the use of rice husk briquettes in Vietnam would directly benefit the poor households and small agro-industries. The technique of briquetting has yet to be introduced in Vietnam. The visit has also allowed links to be established with several organisations and institutions that could benefit from this project.

7.4 Dissemination Plan

This plan identifies further dissemination activities in Bangladesh and Vietnam that could be funded to enhance the uptake of technologies improved by this project. It estimates the time that will be required to implement each of the plan components. It does not provide cost estimates as this depends on the details of the dissemination activities; the level of financial support available; and donor agency requirements.

This project has three sets of project outcomes to promote. These relate to

1. Improved design for furnace and boiler for small scale, parboiling rice mills.
2. Improved screw design for making briquettes from husk of parboiled rice.
3. Use of rice husk ash in low to medium strength construction.

There are two countries where these are to be disseminated, Bangladesh and Vietnam[1]. The dissemination plan has therefore three components. These are:

A. Strategies to promote the improved furnace-boiler system and improved screw design for briquette making in Bangladesh. Approximate time to implement: 2.5 years.

B. Proposals to field test the use of rice husk ash used in combination with clay and/or cement in Bangladesh and to identify actors for uptake. Approximate time to implement: 2.5 years

C. Proposals to disseminate the production of, and use of, rice husk briquettes in Vietnam. Approximate time to implement: 2 years, including a project inception phase.

A. Strategy to promote the improved furnace-boiler system and improved screw design for briquette making in Bangladesh.

Given the implications for dissemination identified in this project, the strategy to promote the uptake of improved technologies in parboiling rice and in briquette making would be two pronged (Fig. 7.1). One would be *direct action*, jointly with other stakeholders, at cluster level to promote the technological improvements; and the other would be *activities to affect institutional changes* that are necessary to facilitate uptake. The two sets of action are interdependent. The success of the second activity will affect the overall success of the first set of activities.

Direct Action: the aim of this strategy would be to work directly with the user groups in at least two clusters to promote the uptake of improved furnace-boiler unit and the improved screw design. It is appropriate to promote the two improvements together because improved rice husk combustion will generate more rice husk surplus, and briquetting of this husk would not only go towards reducing the

[1] India is not targeted for dissemination activities. Small scale rice milling using Engleberg huller has been banned for the last forty years as it damages the grain and produces a high percentage of broken rice. Rice milling in India is essentially large scale and produces bran and husk as separate streams, which are then sold for animal and poultry feed and/or for making briquettes.

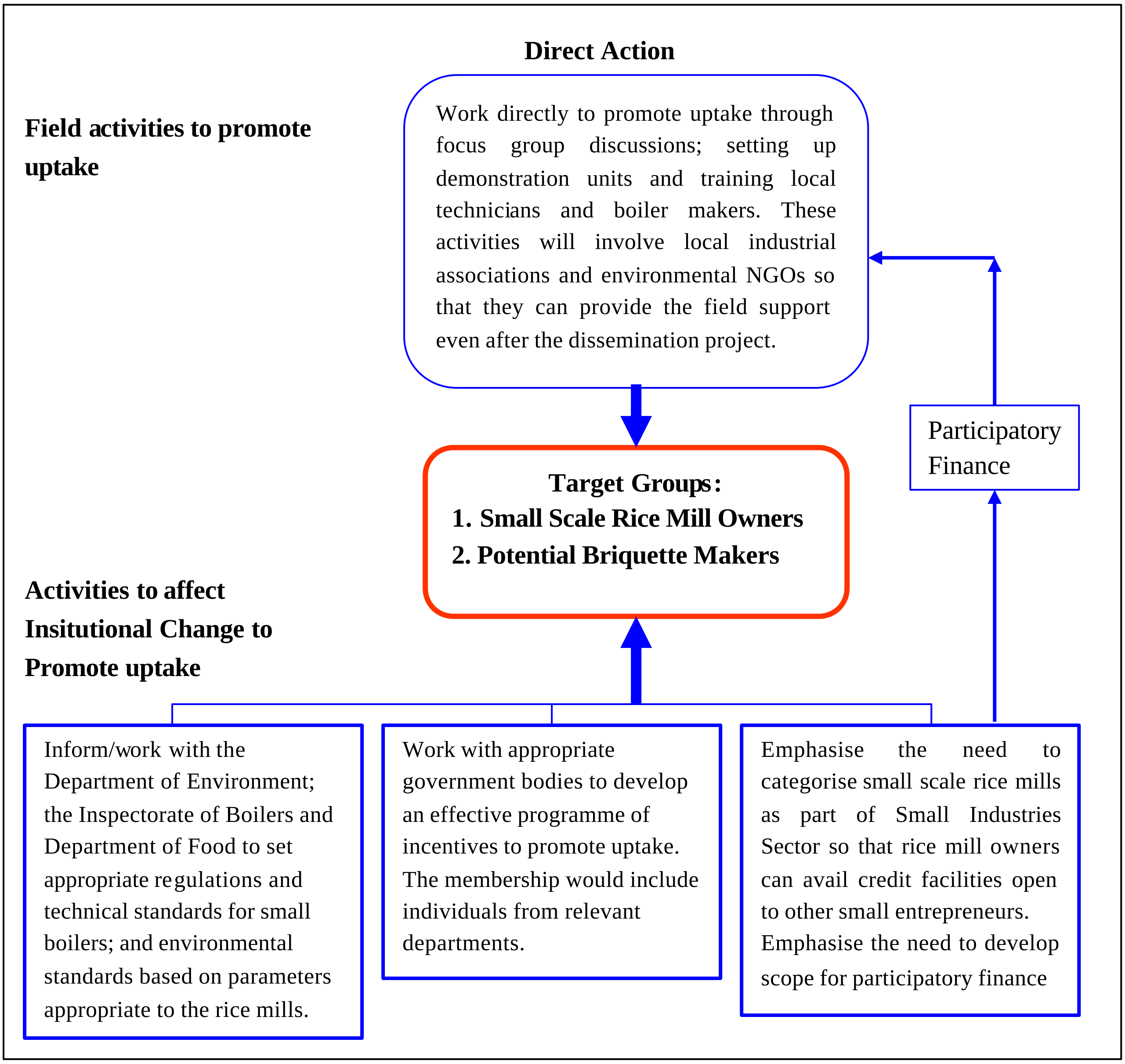
problem of husk disposal it would also generate additional income for any existing or potential briquette producer.

For effective dissemination all stakeholders should be involved. The channels for disseminating could be one or many. These could be:

For the improved furnace-boiler system:

- Focus group discussions with rice mill owners, operators (*beparis*), briquette producers, local environmental NGOs, members of rice mills owners associations (together or separately, as is seen fit) to share information and to illustrate the benefits of improving the combustion efficiency of the rice mills; and of increased briquetting of husk from parboiled rice.
- Following information sharing, set up a demonstration unit;
- Involving local *mistris* and other boiler fabricators during the construction of the furnace and boiler as part of their training.

Figure 7.1 Dissemination Strategies to Promote Uptake of Improved Technologies of Improved Furnace and the new Screw design for Making Briquettes in Bangladesh



- Create more trainers to train the local *mistris* and to create awareness among rice mill owners in different clusters of rice mills in Bangladesh.

For improved screw for briquette making:

- Identifying local engineering firms that currently manufacture screws for briquetting rice husk and examining the scope for local production of the improved screw. This would allow a cost comparison with prototype screw imported from India. As noted above there is considerable import trade in engineering parts between India and Bangladesh, and importing the screw was considered a realistic possibility at the national workshop held by this project.
- Fine tuning of screw pitch and depth to reduce variation in quality with length of operations.
- Targeting bad and unsafe work practices during dissemination of improved screw.

Overall,

- The programme of direct action would include information sharing with local manufacturers, NGOs, local government departments, local industrial associations, user forum and agencies for awareness raising and extension services.

Activities to promote institutional change: these activities would aim to target some of the institutional constraints to uptake. The institutional problems as identified in this study are lack of any appropriate environmental and technical standards for small scale rice mills in rural Bangladesh; and the lack of recognition of this sector by the Department of Industries, hence its exclusion from credit facilities accessible to other small entrepreneurs. Though small scale rice mills process about 80% of the rice produced in Bangladesh, there is very little or no importance given to this sector at the official level.

There are two reasons why there is need for clear technical and environmental standards to be set for the small rice mills. These are: one, to facilitate uptake of the improved furnace design with its lower chimney stack; and two, to develop a package of incentives there is need for a clear statement of the standards the industry needs to comply with. Official recognition of these small rice mills as small industrial units is pre-requisite to access industrial credit or to arrange any system of participatory finance for initial capital investment required for upgrading technology. Moreover, recognition is fundamental to developing any package of incentives.

Of course, it can be argued that official recognition of this sector of small scale rice mills will bring greater official control, which would not please some of the owners. However, given that most mills make a profit and yet they run extremely dangerous and hazardous operations, this may move the sector in the right direction.

The government agencies to be targeted would be the Inspectorate of Boiler, Department of Environment, Department of Food and the Department of Industries. The following initiatives would help to promote uptake.

- Informing officials at top level in the above agencies of the need for change.

- Demonstrating to the officials of Inspectorate of Boilers and of the Department of Environment at site the safe and cleans operations of the new furnace-boiler system.
- Enabling these agencies to develop standards based on parameters relevant to the small scale rice mills.
- Understanding the difficulties the Department of Industries has in granting recognition to these rice mills as industrial units and examining the way forward.
- Developing government regulations directed to support programmes promoting improved furnace. Guidelines for change can be disseminated through such programmes.
- Credit policy, operated through commercial banks, with an annual lending target for upgrading technology. No subsidy is proposed as most programmes that start with subsidy do not progress once the subsidy is withdrawn.
- Participatory finance is one of the more effective ways of disseminating the improved furnace. Such participatory programmes give a better sense of ownership of technology and change among the user group.

B Field test the use of rice husk ash used in combination with clay and/or cement in Bangladesh and to identify actors for uptake.

More applied research is necessary to promote the use of ash as a building material, both in clay-RHA bricks and as an OPC blending component. Specifications for such use have to be developed in collaboration with industry and the relevant government organisations. It will be important to involve the Local Government Engineering Division in this research initiative as it is one of the largest providers of rural infrastructure in Bangladesh.

C Disseminate the use of rice husk briquettes in Vietnam

The visit to Vietnam indicated the importance of improving the combustion of rice husk used in households for cooking and in small scale agro-processing units for drying produce. The husk is burnt loose as shown in the previous section. In households, this leads to high levels of indoor pollution affecting mostly women, children and the aged who remain indoors. In agro-processing units, loose burning of husk allows little control over the heat used in the drying process. This leads to uneven drying and low price for dried products.

NRI and TERI propose to develop a joint proposal to introduce rice husk briquetting at the commune level. This would involve setting up a unit producing briquettes and helping a targeted number of small units to redesign their combustion and fruit drying systems. At the household level, it would mean identifying an existing design of stove that could use briquettes. The project has to work through, and with, the commune leaders. They are still very influential. It is believed that, if the commune leaders can be convinced of the benefits of the project, dissemination will be facilitated by them. It has been suggested by DFID in Vietnam, that this proposal be linked to the Rural Livelihoods Project in north eastern provinces of the country.

7.5 Conclusions

There are three technical components to this project. These include demonstrating improved combustion efficiency of furnaces used in small scale rice mills, identifying ways to enhance the use of husk from parboiled rice in briquetting; and identifying alternative value-added uses of rice husk ash. Dissemination activities so far have been related to the first two components. The outputs for the third component cannot be disseminated without field trials, which is beyond the scope of this current project.

A two-day workshop in Dhaka involved user groups, government officials, NGOs, private sector representatives, academics and researcher. The main conclusions of this workshop were related to the first component. The participants noted the importance of demonstration effect among the targeted user group; the need for information sharing with user groups prior to the construction of a demonstration unit; and the need to address the institutional constraints to uptake of the improved technology. Regarding the improved screw for briquette production which was manufactured in India for this project, the participants were of the view that the scope for local production and of imports from India should both be investigated, since considerable benefits can accrue from increased availability of a cheap, clean fuel. These views have influenced the design of the Dissemination Plan for Bangladesh outlined in section 7.4.

The visit to Vietnam revealed that while rice husk is widely used as a fuel in households and small industries, methods of combustion are highly inefficient and polluting. This could be addressed by briquetting the rice husk before combustion. These facts have informed the proposal to introduce briquetting in Vietnam described in section 7.4.

Research into alternative use of rice husk ash has shown that it could be used in low and medium strength constructions. However, before this potential use can be shared with prospective users, field tests have to be conducted. Proposals for field testing, and activities to identify prospective users have been set out in the Dissemination Plan.

In the Dissemination Plan potential initiatives and activities have been sub-summed into three strategies:

- ♦ Strategies to promote the improved furnace-boiler system and improved screw design for briquette making in Bangladesh;
- ♦ Proposals to field test the use of rice husk ash used in combination with clay and/or cement in Bangladesh and to identify actors for uptake; and
- ♦ Strategies to disseminate the production of, and use of, rice husk briquettes in Vietnam.

8 Conclusions and Recommendations

8.1 Project Objectives

The principal research objectives were (i) improve furnace design and increase combustion efficiency by at least 15% to save the husk and bran mixture used as fuel in small-scale operations for parboiling rice; (ii) identify ways to enhance the use of husk from parboiled rice in briquetting; (iii) assess alternative utilisation of rice husk ash; and (iv) assess the socio-economic impact of improved utilisation of husk and create a dissemination plan for the findings of the project. There can be three approaches to promoting the findings and outcomes: project, policies and research. The appropriate approach will be noted.

Section 8.2 briefly restates the issues researched and the outcomes of the project. There are considerable potential benefits from the uptake of the improvements made by this project. However, to realise these gains there are certain policy and research issues that need to be addressed to promote the uptake of improvements. These are discussed in section 8.3. Additionally, the scope and need for applied research to enhance efficiency of use of rice husk in Vietnam are also discussed in this section.

8.2 Issues Examined and Outcomes of Project Activities

8.2.1 Importance of Increasing Efficiency of Rice Husk Combustion

In Bangladesh 64% of the total energy supply is derived from biomass. This energy is obtained from various biomass sources of which rice husk is the largest (22%) single category. Husk and bran are by-products of rice milling. Approximately 0.30Mt of husk and bran are produced each year. Only 10% of paddy production is dry processed where bran and husk are generated in separate streams. These are sold to the poultry industry and for briquette making, respectively. 87% of paddy in Bangladesh is parboiled and processed in small mills. These small mills dominate rice milling in number and total production.

The primary use of rice husk as fuel is in these rural, small scale parboiling mills. It is burnt as furnace fuel to generate steam for parboiling. Since bran catches fire easily it is not separated from the husk used as fuel. Bran and husk, separately and together, are important feed inputs for poultry rearing, which is an important and a growing activity for poor and low income households.

The combustion systems in these small scale mills are inefficient, inefficacious, unsafe and polluting. The objectives were to increase the efficiency by at least 15% to save about 0.77 Mt per of husk per year; make the work environment safe, whilst keeping the cost of the improved furnace affordable. The saved husk could be made into briquettes, a cheap, clean fuel for the poor; and the saved bran could increase the supply of feed for poultry rearing.

Outcomes: The improved furnace design has increased the furnace efficiency by 22% as against the project objective of 15%. This brings the average efficiency of the new furnace to 44% against the average efficiency of 20% found in furnaces operating in rice mills. According to the Specific Fuel Consumption rate the rice husk savings is in the range of 44% to 54%, giving an average savings of 49%. The boiler is made safe and emissions brought down to acceptable levels. The cost of the improved furnace-boiler unit is Taka 64,000 compared to the current cost of TK 96,000.

The model designated Mark 0 was built and used for trial runs and field testing. User group feedback was used to fine-tune the design. As two distinct user groups, in terms of production capacity and steam demand were identified, two models (Mark 1 and Mark 2) have been developed to cater to these two groups. Drawings have been provided to construct the furnace with or without the grate. Additionally, information has also been made available for the construction of the chimney at the ground level, as per user demand.

8.2.2 Improvements for Briquetting Rice Husk from Parboiled Rice

The conversion of biomass materials into a densified, solid product is not a new technology, though it appeared in Bangladesh only about 10 years ago. However, only a marginal amount of husk of parboiled rice is made into briquettes. As already noted, most of it is used as fuel, the remainder is often dumped. Yet, if it is be made into briquettes it could provide cheap, clean fuel for the poor household and small retail units. At present Sylhet and Chittagong are the main districts for dry processing rice and also the main areas for making briquettes.

The baseline survey made by this project showed that briquette making is technically sound and economically feasible. This study therefore, made no attempt to alter the overall production processes. The view of the industry is that parboiled husk is no more difficult to briquette than husk from dry processed rice. However, it is the more abrasive nature of husk from parboiled rice and its higher moisture content that increased screw wear. The high cost of screw repair and its frequent replacement did not make it cost effective. The main focus of this component was to improve the screw life for making briquettes with husk of parboiled rice; and to reduce the energy loss during the production process.

Outcomes: Review of research showed that arc welded screw with tungsten carbide tip gave best results for preventing wear. So, the new improved screw for this project was made with hot die steel with a tungsten carbide tip. The traditional screw is made with mild steel and hard-faced with hard craft arc rod. The length of the traditional screw is 496 mm, shaft diameter at top end is 35 mm and falls to 21 mm at the narrower end; and the number of threads is seven. These dimensions were used to make the new screw.

The improved screw was used to run trials. A local factory producing briquettes with husk from dry processed rice was identified and performance comparison was made. It reveals that briquette production with new the screw is significantly more consistent than with the traditional screw.

Briquettes were successfully produced for 16 hours with the new screw. They were of good quality for up to 16 hours, after which the briquettes were more fragile and broke into small pieces. In comparison, briquette production with traditional screw is limited to 8.5 hours. It is pertinent to note that briquette production with husk from parboiled rice with the traditional screw is limited to three hours. The quality assessment showed that the crushing load of briquettes produced with the new screw is consistently higher, even though there is a slightly higher variation in density than for briquettes produced in commercial units

The energy consumption was reduced by 26% by maintaining the die-barrel temperature at the optimum range of 280^0C to 290^0C, instead of at 350^0C-400^0C as is generally the practice in commercial units. The prototype cost of the new screw is about 3.5 times higher than the traditional screw. However, it is expected that this will be roughly compensated by increased productivity. Furthermore, there will be an increased profitability of Tk 3 per hour if only the new screw is used because of lower repair and maintenance costs. Additional savings from electricity would raise the profit rate to Tk 7.57 per hour.

8.2.3 Alternative Use of Rice Husk Ash

5.40 million tonnes of rice husk is used as fuel in rice parboiling mills. This generates about 1.2 million tonnes of ash. While in most rice producing countries disposal of husk is a problem, in Bangladesh it is the disposal of rice husk ash that poses a major problem. Ash deposits are dumped on agricultural land and ponds, contaminating the soil and polluting the water sources. The ash particles have low bulk densities and are often very small. If not managed properly, these particles can be easily airborne and cause disease.

Although many alternative uses of RHA have been developed in the last few decades; such as use of RHA as a component of clay brick, firebrick, hollow brick, sandcrete and concrete etc., these applications have not yet been tried in Bangladesh. This study examined some of these applications, given that RHA is known to be a pozzolana and to contain over 95% of silica, a major constituent of Ordinary Portland Cement (OPC). The use of RHA as a component of construction material would considerably reduce the environmental impact of existing disposal routes.

However, before any applications can be recommended the pozzolanic characteristics of the ash in Bangladesh had to be determined. If the ash did possess pozzolanic properties, the load bearing capacities of RHA-OPC blocks had to be determined. These tests constituted the main activities of this component.

Outcomes: The first set of tests indicated that the RHA appears to posses a spectrum of suitable physico-chemical properties such as: high surface area; good purity; and low crystallinity, hence being easy to pulverise. Additionally, it is a low cost raw material. These properties suggested that it could be used as a blending component in cement to replace the OPC by a certain percentage and in Clay-RHA bricks.

Compressive strength tests of OPC-RHA blocks with 90% OPC and 10% pulverised RHA obtained from new furnace indicate satisfactory compressive strength; thus permitting its use in medium load construction.

8.3 Potential Benefits and Strategies to Realise these Benefits

8.3.1 Potential Benefits

The package of improvements made under this project could generate considerable benefits. Savings of 49% in rice husk and bran in small mills will provide significant additional income for mill owners with the payback of capital investment within a period of two years. The saved husk and bran, separately and together, constitute essential inputs for poultry and livestock feed. In the past few years there has been a demand pull rise in price. Poultry rearing is actively supported by the government and has become an important economic activity for rural households.

The rice husk could also be used to produce briquettes, which are being used by poor household and retail units, where available. Additionally, the new screw can make it cost effective and even profitable to produce briquettes with husk of parboiled rice. This would generate business opportunities and enhance the scope for low income employment in rural Bangladesh.

Equally important as the economic benefits, the improved furnace design provides safer, cleaner and more comfortable working conditions. Removing hazards and risks at work for poor workers, who have no economic bargaining power is considerable progress. These improvements are particularly significant to women workers who are tied by very poor wage relations. Nearly 50% of the workers in rice mills are women.

Alternative use of rice husk ash will go towards addressing the rural environmental problems of land and water contamination.

8.3.2 Issues that need to be Addressed to Promote Uptake

Promoting the uptake of the improved furnace design will be fundamental to realising the potential benefits. However, there are some policy issues at national level and social-attitudinal aspects at the sectoral level that need to be addressed in the dissemination strategy.

At the national level, the small scale rice milling sector needs greater official attention. It appears to be ignored by most government departments even though it processes nearly 90% of the principal food grain in the country. The Department of Small Industries does not recognise these mills as small industries because of their rural location. This means that rice mill owners are excluded from subsidised credit open to small entrepreneurs located in the urban areas. This has implications for developing any participatory financing schemes to promote uptake of improved furnace.

The Inspectorate of Boilers still operates under regulations passed in 1923. It has made no attempt to develop standards for boilers with lower capacities as used in small industries. Albeit, the organisation is under funded and poorly staffed. Nevertheless, 6,500 small rice mills can at present time operate unsafe boilers with total disregard to issues of safety.

The absence of safety standards for this sector means that there are no technical benchmarks that would allow official recognition for improved and/or new technology in this sector. Without official recognition, the improvements cannot be made obligatory. The Inspectorate of Boilers could continue to argue that without the ability to monitor change, any new regulations will be ineffectual. Perhaps some resources need to be allocated for updating this organisation.

Additionally, the Department of Environment has not set any specified environmental standards for small scale rice mills. Consequently, the Department of Food uses the standards set for the brick kiln industry, which is much more polluting as it uses more polluting fuels. The chimney stack of a rice mill must be at least 30 feet (appropriate for the brick kiln) for it to qualify as a supplier of grain to the government. This again has implications for promoting the new furnace since husk is a cleaner fuel, and the furnace requires a shorter stack. This also helps to keep the overall cost of construction down. It is important that the Department of Environment develops standards related to the parameters in this sector.

At the sectoral level, the analysis showed that levels of educational achievements among owners and operators were very low. They had little technical knowledge and were totally reliant on their technicians. It would therefore, be important to involve the technicians from the start in running field tests and in any dissemination activity that may be undertaken. Furthermore, it is evident that the demonstration effect among the user group is strong. This implies the need for further dissemination units in large clusters to maximise its impact.

In promoting the uptake of the new screw design for briquettes, the main limitation is the higher cost of the screw. Hence, it will be essential to convince the entrepreneurs (current and potential) of the overall profitability of the new, improved screw during dissemination. It would be cost effective to run the dissemination activities for this component and for the improved furnace design in the same clusters.

There is need to address the bad practices found in briquetting units. It was observed that most briquetting machines were installed in confined spaces, leading to very difficult and even hazardous conditions for the operators. Few of the machines had even rudimentary fume extraction systems; but generally atmospheric contamination made breathing difficult, even for short contact times.

8.3.3 Strategies to Promote Uptake

Strategies to promote uptake would require interventions at project and at policy levels. A two-pronged approach could combine these interventions. One would be direct action, jointly with stakeholders, at cluster level to promote the package of improvements made by this project; and the other would be activities at policy level to affect institutional changes that are necessary to facilitate uptake. This has been illustrated in Fig 7.1. The two sets of actions are interdependent.

More applied research is necessary to promote the use of ash as a building material, both in clay-RHA bricks and as OPC substitute. Specifications for such use have to be developed in collaboration with the industry and the relevant government organisations. It will be important to involve the Local Government Engineering Division in this research initiative as it is one of the largest providers of rural infrastructure in Bangladesh.

The visit to Vietnam indicated the importance of improving the combustion of rice husk used in households for cooking and in small scale agro-processing units for drying produce. The husk is burnt loose. In households, this leads to high levels of indoor pollution affecting mostly women, children and the aged who remain indoors. In agro-processing units, loose burning of husk allows little control over the heat used in the drying process. This leads to uneven drying and low price for dried products.

At the project level, targeted field research could be undertaken with the aim to setting up a unit for producing briquettes and helping a pre-determined number of small units to redesign their combustion and fruit drying systems. At the household level, it would mean identifying an existing design of stove that could use briquettes. The project has to work through, and with, the commune leaders. They are still very influential. It is believed that, if the commune leaders can be convinced of the benefits of the project, dissemination will be facilitated by them. Given this, promotion of improvements may be more straightforward than in Bangladesh.

8.4 Conclusions

A great number of people in South and South-East Asia rely on the use of rice husk as an important source of fuel. However, its use is inefficient, with detrimental effects on the health of users and workers involved. This wasteful use continues largely because they do not have access to relatively simple and cheap technology that has already been developed and that can increase the conversion efficiency of rice husk and make more productive use of the husk. The focus of donor agencies should be on disseminating such technology for improved use of biomass. This becomes all the more important as national governments in this region increasingly recognise the difficulties of reaching all the rural poor by the national electricity network.

Appendix 1-A
References

References

Ajiwe, V.I. E, C.A. Okeke, F.C. Akegwe (2000) A Preliminary Study of Manufacture of Cement From Rice Husk Ash. *Bioresearch Technology*, 73 (1): 37-39, May, Elsevier Science Ltd., Oxford.

Alam, M (2003) Improvement and Extension of Rice Husk Briquetting Technology. Research and Extension in Farm Power Issues Project. Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. Pp.25.

Amer, A. A H.ElDidamony, S .A. S. ElHemaly and S. El Alfi (1997) Rice Husk Ash Pozzolanic Cement. Silicate Industries. 62 (7-8): 141-147 Jul-Aug. *Belgian Ceramic Society*, Mons.

Baqui, M. A. (2002) Benefits from Improved Rice Husk Combustion Efficiency (Study on the Utilisation of Ash from Rice Husk Combustion, *Interim Report*, October), University of Greenwich, Chatham Maritime.

Bhatty, J. I. K, J. Dollimore, D . Gamlen, G. A, Mangabhai, R. J. Rogers, P. F. Shah, T. H (1988). The Derivation of Kinetic Parameters in Analysis of Portland Cement for Portladite and Carbonate by Thermogravimetry, Composition Analysis by Thermogravimetry ASTM, Philadelphia, p 204-215.

Bui, D.D. (1995) Gap-Graded Concrete with Very Fine Sand Using Portland RHA Blended Cement. Report 03.21.1.32.04, Fac. Civ. Engr., Delft Univ. Techn., August, 1994. SP 154-14, *Natural Resources Canada*, Ottawa, p.263-78.

Cea, F.M. & Sustasria B.B (1967) *Nat Appl Sci Buletinl*, University of Philadelphia, 20, 113.

Cook, D. J. 167 , (Cea, F.M & Sustasria B.B. 1967).

Dalhuisen, D.H., Stroven. P. Bui, D.D, Q .Y .N.T (1996) Replacement of Condensed Silica Fume by Rice Husk Ash for the Production of High Strength of Concrete in Developing Countries. *Proc Int. Conf. Utilization of High Strength/High Performance Concrete*, Press Pont et Chussees, Paris, 235-43.

Dasgupta, N. (1997) Greening Small Recycling Firms: the Case of Lead Smelting Units in Calcutta. *Environment and Urbanisations*, 9(2), 289-305.

Dasgupta, N. (2000) Environmental Enforcement and Small Industries in India: Reworking the Problem in the Poverty Context. *World Development*, Vol. 28, No 5, 945-967.

Dasgupta, N. (2001). Benefits from Improved Rice Husk Combustion Efficiency, (*overview of progress*, DFID project- R7659), April.

Department of Livestock (2000) *An Overview*. Government of Bangladesh.

ElHosiny, F.I., S. A. AboELEnein, I.M. Helmy and K A Khalil (1997) Effect of Thermal Treatment of Rice Husk Ash on Surface Properties of Hydrated Portland Cement-Rice Husk Ash Pastes. *Journal of Thermal Analysis,* 48(4): 801-817 April. John Wiley & Sons Ltd,. W. Sussex.

FAO (2000) Food and Agricultural Organisations, United Nations.

Farmer, V. C., (1974) The Infrared Spectra of Minerals. *Mineralogical Society*, London SW7 5HR, pp365-370.

Fieger, E.A., Chopin, A.R and Tucker P.W. (1947) *Rice J* 50 (9)(1947) 9, 50(10)(1947) 16; 50(11) (2).

Ikpong, A. A and D.C. Okpala, (1992) Strength Characteristics of Medium Workaility Ordinary Portland Cement-Rice Husk Ash Concrete. *Building and Environment*. 27 (1): 105-111, Jan., Pergamon-Elsevier Science Ltd., Oxford.

Ismail, M.S and A.M Waliuddin (1996) Effect of Rice Husk Ash on High Strength Concrete. *Construction and Building Materials*, 10 (7): 521-526, Oct. Butterworth-Heinemann Ltd, Oxford.

James, J and M. Subba Rao (1992) Rice Husk Ash – A Review. *Journal of Scientific & Industrial Research.* Vol. 51, May, pp 383-393. New Delhi, India.

Khangaonkar, P.R, Azmirahmat and K.G. (1992) Kinetic Study of the Hydro-Thermal Reaction between Lime and Rice Husk Ash Silica. *Cement and Concrete Research.* Vol. 22, pp. 577-588, Pargamon press Ltd. USA.

Lea, F.M. (1970) Chemistry of Cement and Concrete, Edward Arnold Publishers Ltd.

Lei, P.C. K. & Yang, D.S.C. (1993) The Implementation of Controls over the Management of Chemical Waste in Hong Kong. In *Proceedings of the Pacific Basin Conference on Hazardous Waste*.

Lewis, R. C., Elkem Microsilica (1990) The Quality Assured Product for Superior Concrete, Elkem Materials Ltd.

Lyon, K. J. P. (1967) Infrared Confirmation of 6-Fold Co-Ordination of Silicon in Stishovite. *Nature,* London. 196, 266-267.

Mehta, P. K. (1977) Properties of Blended Cements Made from Rice Husk Ash, *ACI Journal Proc.*, 74V (9) p 440-441.

Okpla, D.C. (1993) Some Engineering Properties of Sandcrete Blocks Containing Rice Husk. *Building and Environment.* 28 (3): 235-241, Jul. Pergamon-Elsevier Science Ltd., Oxford.

Pryer, J. (1993) The Impact of Ill Health on Household Income and Nutrition in Khulna, Bangladesh. *Environment and Urbanisation,* Vol. 5, No 2.

Rahim, B.Chong, C.M and Yeoh, A.K. (1981) Rice Husk Ash Cement, (Standard and Industrial Research Institute of Malaysia).

Sabuni, E.L. (1995) Physico-Chemical Investigation of Tanzanian Rice Husks and of Rice Husk Ash for Use of Rural Tanzania. Report 03.21.1.32.21, Jan 1995 and Research into the Potentialities of Rice Husk Ash Cement for Application in Rural Tanzania. Report 03.21.1.32.05, Fac. Civ. Engr., Delft Univ. Techn., Jan.

Scott, A. (1998) The Environmental Impact of Small Scale Industries. *Third World-ESRC Global Environmental Change Programme Briefings*, 19 May.

Sethuraman, S.V. (1992) Introduction. In A.S.Bhalla, Environment, Development and Employment (1-9). A WEP Study, ILO Geneva.

Shah, R A., (1979) UNIDO/ESCAP/RETT. Follow up Meeting on Rice Husk Cement, Malaysia.

Shristha, R. D. (1981) ESCAP/RCTT Workshop on Rice Husk Cement, New Delhi.

Singh, N.B, V.D. Sing, Sarita, R and Shiveni Chaturvedi (2002) Effect Lignosulphonate, Calcium Chloride and their Mixture on the Hydration of RHA-Blended Portland Cement. Cement and Concrete Research, 32 (3): 387-392, Mar. *Pergamon-Elsevier Science Ltd.*, Oxford.

Stroeven, P., Bui, D.D, Sabuni, E. (1999) Ash of Vegetable Waste Used for Economic Production of Low to High Strength Hydraulic Binders. Delft Univ. of Tech., Stevingweg 4, 2628 CN Delft, The Netherlands, Hanoi Univ.of Civ. Engg. Vietnam, Act-Incofin (T) Ltd. Arusa, Tanzania. *Elsevier Science Ltd.* Fuel, 78 (2) 153-159.

Stroven, P., Dalhuisen D.H, Q.Y NT, Bui D.D, Dong A.V (1999) Toward Gap-Graded HPC In Vietnam Using Crushed Rock, Very Fine Sand, And RHA Blended Cement. Proceedings- Second CANMET/ACI *Int Symposium: Advanced in Concrete Technology.*

Suryakumaran, R & Ismail, M. G .M (1967) *National. Applied. Science. Bulletin*, University of Philadelphia, 20,57.

Takamura, T., Yoshida H. & Inazuka K (1964) IR Characteristic Bands of Highly Dispersed Silica. Kolloidzeitschrift, 195, 12-16.

UKQAA, (2000) United Kingdom Quality Ash Association, Technical datasheet 1.1.

UNIDO (1984) Rice Husk Ash Cement; their Development and Application, UNIDO Report.

Yalcin, N., & Sevinc V (2000) Studies of the Surface Area and Porosity of Activated Carbons Prepared from Rice Husks. Carbon, 38, 1943-1945
Yogananda, M.R., Jagadish K .S. and Kumar R (1983) Alternative Building Series-9, Indian Institute of Science, Bangalore.

Yu, Q. J, K Sawayama, S.Sugita, M. Shoya and Y.Isojima (1999) The Reaction Between Rice Husk Ash And Ca (OH)(2) Solution and Nature of Its Product. *Cement and Concrete Research*, 29(1): 37-43, Jan.

Zhang, M.H., R. Lastra, V. M. Malhotra (1996) Rice Husk Ash Paste and Concrete: Some Aspects of Hydration and The Microstructure of the Interfacial Zone between the Aggregate and Paste. *Cement and Concrete research,* 26 (6): 963-977 Jun. Pergamon-Elsevier Science Ltd., Oxford.

Zhang M H, R Lastra. V. M.Malhotra (1996) High-Performance Concrete Incorporating Rice Husk Ash as A Supplementary Cementing Material. *ACI Material Journal*, 93 (6): 629-636, Nov.-Dec., Amer concrete Institute, Farminton Hills.

Appendices 2-A to 2-C
Data Relating to Field Survey 2000

Appendix 2-A

Estimating the Size of Small Scale Rice Milling Sector

Growth in Rice Production in Bangladesh

Year	Million tonnes paddy	Year	Million tonnes paddy
1980	20.821	1990	26.778
1981	20.446	1991	27.377
1982	21.325	1992	27.510
1983	21.761	1993	27.048
1984	21.933	1994	25.312
1985	22.556	1995	26.398
1986	23.110	1996	28.184
1987	23.121	1997	28.152
1988	23.316	1998	28.293
1989	26.784	1999	29.857
		2000	29.857

Source: FAO (2000)

The sample survey of 35 mills show that the total rice processed by these units annually is 84,805 tons. Hence, the average production per mill is 2423 tons per annum.

Of the 29.857 m tons of paddy produced nationally, 30% is processed by households and do not enter the market.

Another 20% is processed in large mills. 50% of the total paddy production is thus processed in small mills. This means that in 1999, 14.93m tons were processed in this sector.

Given that the average processing capacity in these mills is estimated to be 2423 tons, the total number of small mills is estimated to be **6200.**

Appendix 2-B
Questionnaire used for Survey of Rice Mills

QUESTIONNAIRE CODE: 1000 | **MILL OWNER** | **Questionnaire No. …….**

1. Location

1.1. District ……………………………………………………………………………………………………..

1.2. Address …………………………………………………………………………………………………….

1.3. Name of Owner …………………………………………………………………………………………….

2. Age of firm, ownership and size

2.1. When was the mill set up?	Year:
2.2. Who set it up?	
2.3. Initial Investment	
2.4. History of ownership?	

2.5. Operating arrangements

	Leased to group of 'Beparis'
	Operated by the owner

2.6. No. of workers:

	Permanent	Temporary	Full-Time	Part-Time
M				
F				

2.7. Who employs the workers?

	The Beparis
	The owner

2.8. How are the workers paid?

Male workers
Female workers

3. Structure of firm: (input/output/turnover – paddy/husk)

3.1. How many days in the week do you run the mill?	
3.2. Closure due to religious holidays/ repairs/ any other in the year?	

3.3. How many kilos of paddy do you process each week?

3.4. For mill owners – How much do you charge to process a bag of paddy?

OR

3.5. Beparis – How much do you pay for a bag of paddy?

By-products:

3.6. What is the proportion of husk to a bag of paddy?

3.7. How much husk is sold as feed?

3.8. At what price do you sell the husk?

3.9. How much 'kura' is produced?

3.10. At what price do you sell the 'kura'?

3.11. Who do you sell the 'kura' to?

3.12. How much 'khud' is produced?

3.13. If sold, what is the price at which it is sold?

4. Operating Costs

4.1. Cost of paddy? (if operated by beparis)

4.2. Transport cost

4.3. Unloading cost

4.4. Filling soaking tanks

4.5. Other labour charges for processing

4.6. Milling cost/charge

4.7. How many times do you mill the rice?

4.8. Cost of other materials like sacking etc

4.9. What is the expenditure on maintenance per week/month?

4.10. Overheads (electricity, etc)

4.11. Supervisory staff (operator, manager, helper)

5. Technology

5.1. What is the cost of running the furnace?

5.2. Have you made any changes to the furnace?

5.3. If yes, who advised and how much did you spend?

5.4. If no, do you think improvements can be made to technology/methods you use?

5.5. What changes do you think will improve your income?

5.6. Would you be prepared to invest in the chula part of your boiler, to save husk, if it is not more difficult to operate and not more costly?

6 Affordability

6.1 Are you the sole bread-earner in your family?

6.2 How much of your income is spent on household expenses?

6.3 What are your additional expenses (illness, death, festivals)?

6.4 Have any NGOs helped with loans to your family members?

6.5 Literacy Level

Codes:

Literacy:

0= No schooling; 1= Primary; 2=SSE; 3=matric; 4=graduate

Units established by

1=present owner; 2=father of the present owner; 3=previous owner; 4=partner

History of ownership

1=in same hands; 4=leased; 5=to be demolished; 6=changed ownership

Operation arrangements

1=owner operated; 2=bepari operated; 3=owner and beparis operated; 4=taken on leasehold; 5=abandoned by owner.

Inclination to improve boiler/furnace

1=Yes; 2=No.

Appendix 2-C SMALL MILL SURVEY DATA

Table 1 Small-Scale Rice Mill Survey Data Giving Background Information

Mill No	District	Address	Owner	Literacy	Mill started	by	Initial investment, Tk	History of ownership	Opearting Arrange-ments
1	Gazipur	Lakhipur vill	Md Nurul Islam	2	1981	2	10,000,000	4	2
2	Gazipur	Barkat Rice Mill	Ianuddin Barkat	3	1985	1	50,000	1	1
3	Ghazipur	Longhani Rice Mill	Md Qasim	3	1976	1		4	2
4	Ghazipur	Small husking mill	Md Bakamia	1	1988	1	120,000	4	3
5	Gazipur	Talotia (husking mill)	Jam. Mullah	1	1985	1	80,000	5	1
6	Jessore	Hashimpur Bazar	Hummayan Kabir	4	1989	1		1	1
7	Ghazipur	Naopara	Abu Sahid	0	1985	1	500,000	4	4
8	Kaliakar	Sarkar Rice Mill	Murad Hussien	4	1975	2	300,000	1	1
9	Pabna	Near Iswardi	MdAmsarali Param	0	1990	1		1	1
10	Pabna	Bourichora vill	Md Abdul (L)	2	1985	1	100,000	4	4
11	Pabna	Purbahash Rice Mill	Nazul Islam	3	1979	1		1	1
12	Nawabgang	Bhai-Bhai Trader	Md Sahid Rahman	4	1999	1	60,000	1	3
13	Nawabgang	Sonali Auto Mill	Md Taish. Rahman	3	1998	1	22,000,000	1	1
14	Nawabgang	Masun Rice Mill	Nurul Islam	3	1995	1	300,000	1	3
15	Nawabgang	Jahan Auto Mill	Md Anwar Shah	2	1990	1	30,000,000	1	2
16	Nawabgang	Hanan Mill	Abdul Hanan	1	1985	3		6	2
17	Naogaon	Beauty Rice Mill	Allaz.A.D. Sheikh	0	1992	1	100,000	1	1
18	Naogaon	Mahaboub Rice Mill	Falnur Rahman	2	1994	4	450,000	1	1
19	Naogaon	Shapahar Rice Mill	Shaibur Rahman	3	1996	1	20,000,000	1	1
20	Dinajpur	Subsingh Husk Mill	Aji. Manal	3	2000	1	400,000	1	1
21	Dinajpur	Eshan Rice Mill	Hafiji Rahman	3	2000	1	450,000	1	1
22	Dinajpur	F.Rahman Husking	Faizur Rahman	3	1975	1	500,000	4	4
23	Dinajpur	Amanod Industries	Abu Bakkar Sidiqu	4	1994	1	14,000,000	1	2
24	Dinajpur	BG Mkt Society	Sri Shannkar	0	1930	5	65,000,000	0	0
25	Dinajpur	Wajid Ali Husking	Malika Firdausa	4	1975	2	550,000	1	2
26	Dinajpur	Mittal Industries	Ian Ul Haq	0	1969	1	10,000,000	1	2
27	Mymensing	Babul &Br Rice mill	Abdul Rahman	3	1986	1	400,000	1	1
28	Mymensing	Bhai-Bhai Trader	Kajal Mia	3	1997	1	600,000	1	1

29	Mymensing	Mala Rice Mill	Abdul Jabber	3	1983	2	350,000	1	1
30	Mymensing	Faroor Rice Mill	Ak/LR/HR (partner)	3	1986	1	500,000	1	3
31	Mymensing	Sarkar Rice Mill	Abdul Mana	2	1982	1	200,000	1	1
32	Mymensing	Agamoni Rice Mill	Monohar Fardus	3	2000	1	10,000,000	1	1
33	Munshigang	Dacca Rice Mill	Amanullah Mia	2	1980	6	850,000	2	2
34	Munshigang	Dastogi Rice Mill	Md Hussien	1		4	300,000	2	0
35	Munshigang	Abi Rice Mill	Hussien Sahib	0	1980	1	100,000,000	1	1

Table 2 Small-Scale Rice Mill Survey Data: Breakdown of Costs

Mill No	No of worke	No of female workers	Total cost, male Tk/tonne	Total labour cost, female Tk/tonne	Load unload Tk/tonne	Soak Tk/tonne	Other labour Tk/tonne	Milling Tk/tonne	Electricity Tk/tonne	Mainten Tk/tonn	Furnace operator Tk/tonne
1	7	7	16	1	13	13	400	533	44	8	
2	9	9	381	37	76	19	57		8	7	
3	3	7	3	37	53	53		293	9	1	
4	0	0	0						4		
5	1	0	11				9	240	23		
6	4	6	20				69		107	25	
7	4	8	481	158	27				147	19	
8	25	15	357	115	13			267	255	159	
9	4	2	107	23	27			213	11	19	7
10	10	3	107	8	11			357			
11	80	20	239	80					1130	73	
12	4	21	92	151	27	160			51	6	
13	15	15	180						147	33	
14	6	10	318		67		200	207	156	78	
15	7	45	279	165			200		164		
16	2	6	245					400	182	14	
17	5	5	80	150				67			
18	12	12	196	37				160	1381	30	
19	60	40	73	70	27				80	27	
20	16	0	267		27			213	109	62	
21	5	0	213				53	160			

22	5	4	130	28	27			293	62	8	
23	8	4	114	67	27			213	112	14	
24	10	12	93	40				320			
25	6	4	331	68	53			293		94	
26	6	4	113	16					93	98	
27	14	2	504	36				267	455		23
28	8	10	310	118			133		89	11	
29	10	5	179	64				80	80	53	2
30	10	5	179	64				80	80	53	2
31	8	6	163	309					107	27	
32	6	4	158	32			213		110	6	
33	8	8	966	20	267			400	102	26	
34	8	8	716	36					92	20	
35	20	20	134	107					29	15	

Table 3 Small-Scale Rice Mill Survey Data: Production Details

Mill No	Transport cost Tk/tonne	Other materials Tk/tonne	Annual capacity tonne	Paddy cost Tk/tonne	Rice price Tk/tonne	Husk production tonne/tonne	Husk sale tonne/tonne	Bran/ Polish mix tonne/tonne	Bran/polish/ husk	Broken rice tonne/tonne
1	267	240	7699	8533	11627	0.20	0.00	0.003		0.0003
2			8213	8533	11627	0.10	0.00	0.100		0.0053
3	231	15	2943	8533	11627			0.014		
4			9555	8533	11627					
5		3	1815							
6	133	149	2412	8133	11253	0.32	0.13			0.0133
7		2	754	9333	11253			0.080		
8	800		1877	9333	11253		0.20	0.110		
9	160	617	341			0.20	0.05	0.133		
10	311	12	2002	7600	10320	0.19	0.06	0.112		0.0187
11	200		4095	6933	10320	0.20	0.05	0.160		0.0133
12	267	41	2340	13600	19920	0.20				
13			4550			0.11		0.003		
14	533	39	614	13600	19920			0.060		0.0267
15	2667		1820			0.20			0.10	0.0060
16	173	12	428	7360	11253	0.20			0.07	0.0119

17	40		384	6667	11253	0.16			0.07	
18	1867	6	1170	7200	11253	0.20			0.10	0.0064
19	187	18	5932	6933	11253	0.30			0.16	0.0037
20	53	14	768			0.20	0.07	0.003		0.0018
21	40	6	293	8000	11120		0.07		0.14	
22	133	4	1536	8000	11120		0.07		0.24	0.0133
23	107	6	853	6400	11120		0.15		0.30	0.0053
24			4095			0.18	0.18	0.105		0.0083
25	213	171	176	6933	11120		0.05		0.25	0.0124
26	187	1	1463	6667	11120		0.05		0.19	0.0167
27	533		527	8000	10427	0.10	0.04	0.040		0.0080
28	53	9	1138	7467	10427	0.08	0.02	0.093		0.0213
29	107	3	878	7467	10427	0.14	0.00	0.110		0.0100
30	107	4	878	8800	10427	0.14	0.02	0.013		0.0200
31	113	8	878	9067	10427	0.06	0.00	0.119		0.0150
32	80	33	2438	6933	10427	0.33	0.33	0.080		0.0133
33	533	34	585	6933	10267	0.13	0.04	0.090		0.0100
34	853	26	1170	6000	10267	0.07	0.00	0.090		0.0080
35	667	6	8190	6267	10267	0.07	0.04	0.100		0.0100

Table 4 Small-Scale Rice Mill Survey Data: Mill Owner/Operators' Views on Technical Change

Mill	Changes to furnace	Advised by	Desired Technological improvements	Inclination to improve boiler/furnace
1	none		added water pump	1
2	chula	mistri	chimney	1
3	pan boiler	mistri	no thoughts	1
4				
5				
6	none	mistri	auto dryer	1
7	drum boiler	demonstration effect	not thought of	1
8	none		install auto dryer	1
9	none		no scope for change	1
10	pan boiler	self	no scope for change	1
11	chimney	self	thinking	1
12	bricked	mistri	inc. thickness of boiler	1

13	none		none;no business sense	1
14	none	demonstration effect	needs operating capital	1
15	none		install auto dryer	1
16	none	mistri	none	1
17				
18	new boiler	mistri	none	1
19	new boiler	mistri	separate bran and hsuk	1
20	none	mistri	expansion	1
21		mistri	crushing machine	1
22	water pump	mistri	change cleaning and processing rice	1
23	from drum	mistri	no	1
24	none		automill	1
25	none	mistri	auto; no scope for other	1
26	new boiler	no advice	ask wks to improve qual	1
27	none	mistri	expansion not change	1
28	none	no advice	auto;	1
29	none	mistri	no thoughts	1
30	none	mistri	no thoughts	1
31	none	mistri	auto	1
32	none	mistri	no	1
33	none	mistri	gas boiler	1
34	none	mistri	no	1
35	yes	mistri	change technique(vague)	1

Appendices 3A-3G

Data and Drawing Related t the Development of the New Furnace Design

Appendix 3-A: Showing the Stages in Parboiling to Sun-drying of Paddy

Empty bin with the Perforated Steam Pipe

Loading the Bin with Soaked Paddy

Removal of Paddy after Steaming

Transporting the Parboiled Paddy to the Courtyard for Drying

Sun Drying of Paddy in Open Courtyards

Appendix 3-B: Views of Conventional Furnace in Operation

Semi-cylindrical Furnace in Operation

A View of the Smoke Just After the Flashfire from the Husk Feeding Port

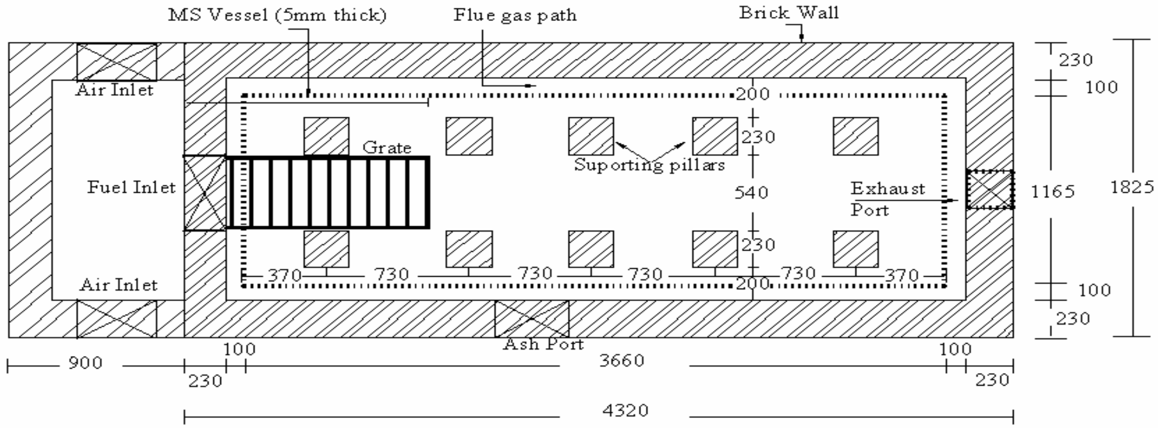
Furnace with Cylindrical Vessel in Operation

Bran is mixed with the husk for sustaining the fire. The thick smoke exits with heavy pollutants.

View of the Conventional Furnace Showing Two Persons Feeding the Husk Simultaneously

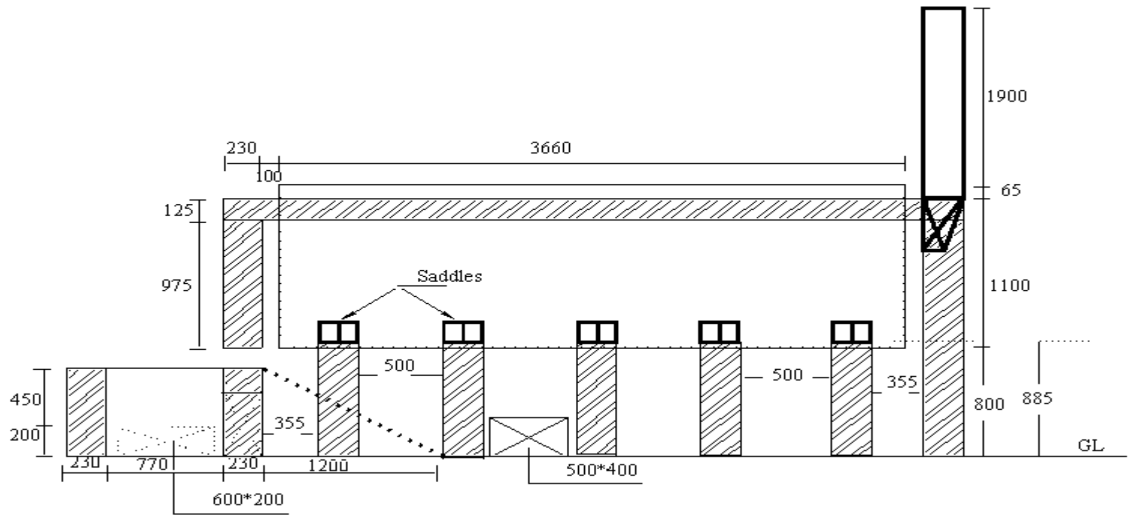
Heat Loss from Side Port and Ash Port

Appendix 3-C: Drawings and Performance of Mark 0



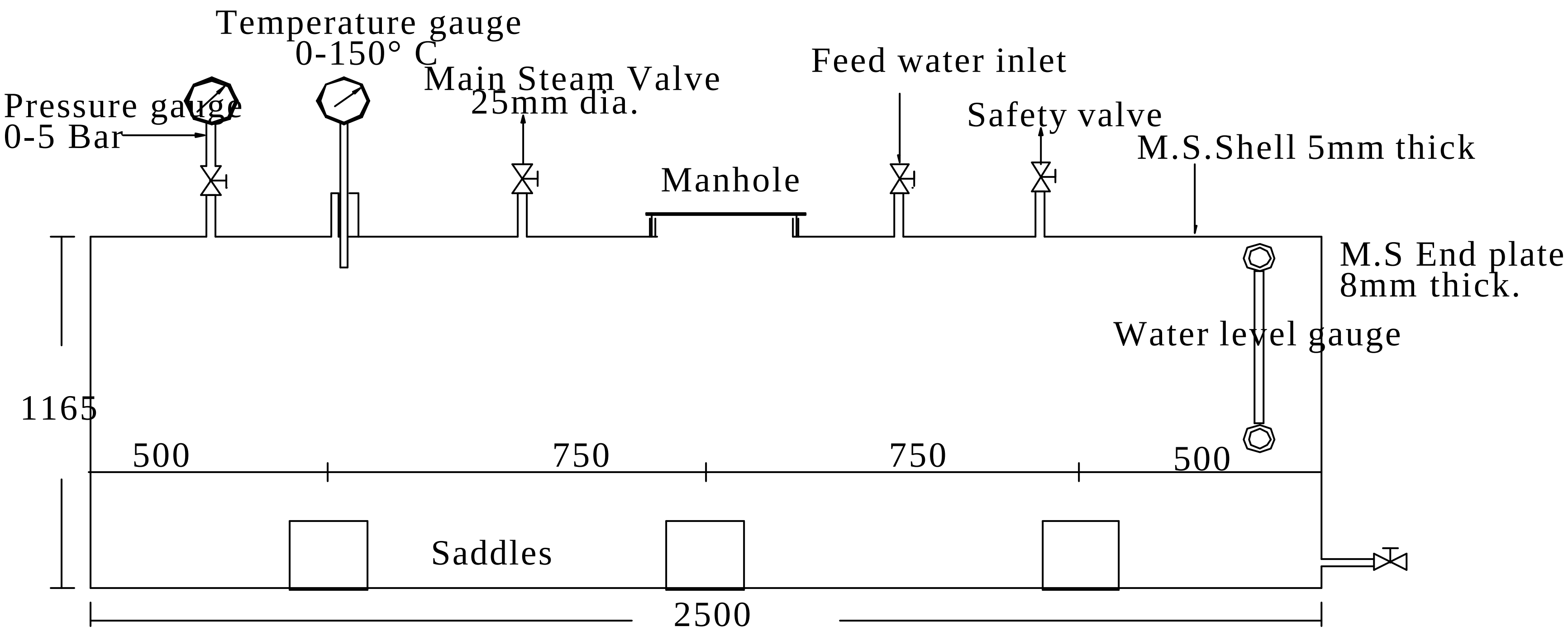
Plan of the Furnace – Details of Walls and Pillars

Appendix 3-C: Drawings and Performance of Mark 0



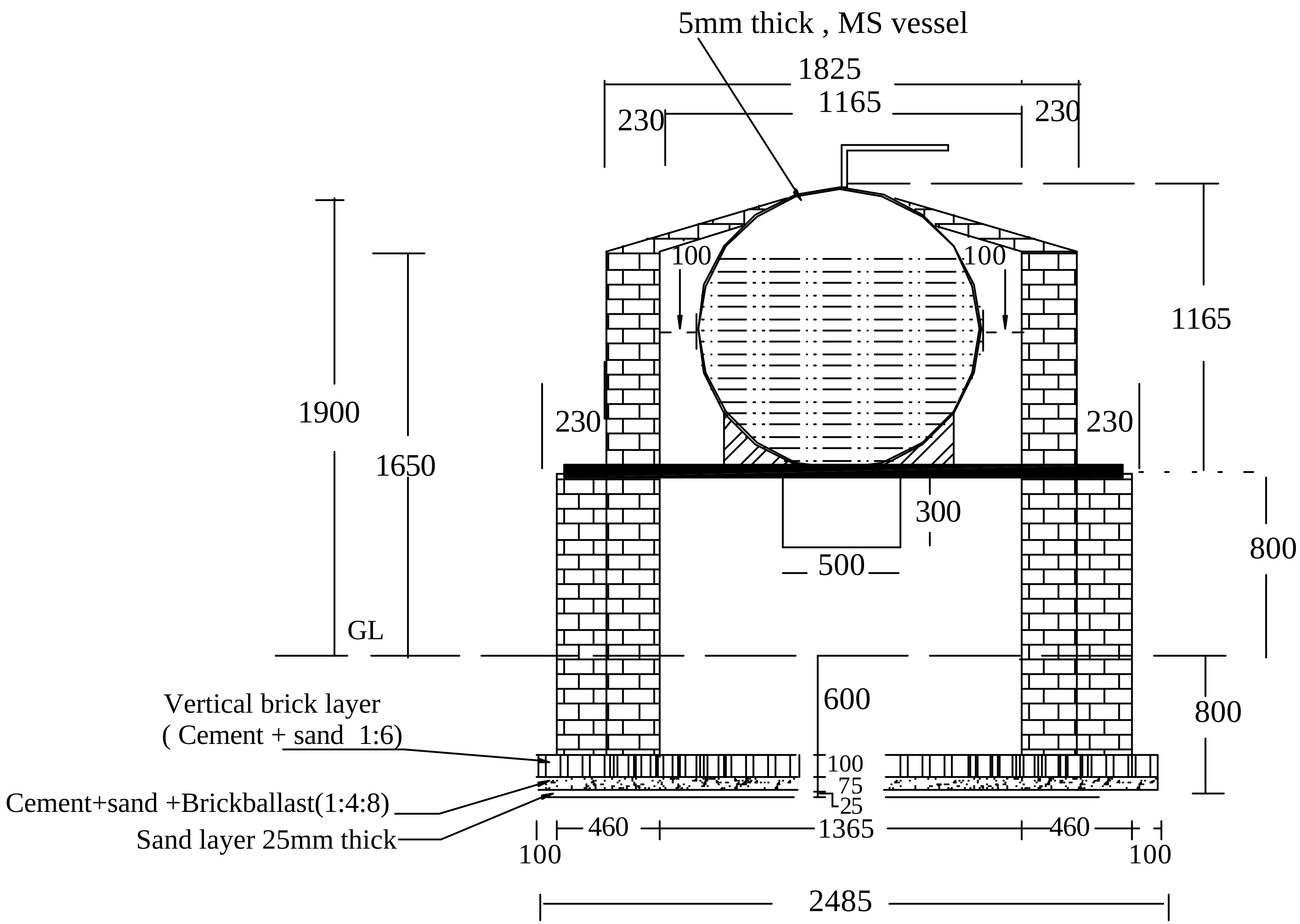
Sectional View of the Furnace - Lengthwise

Appendix 3-C: Drawings and Performance of Mark 0



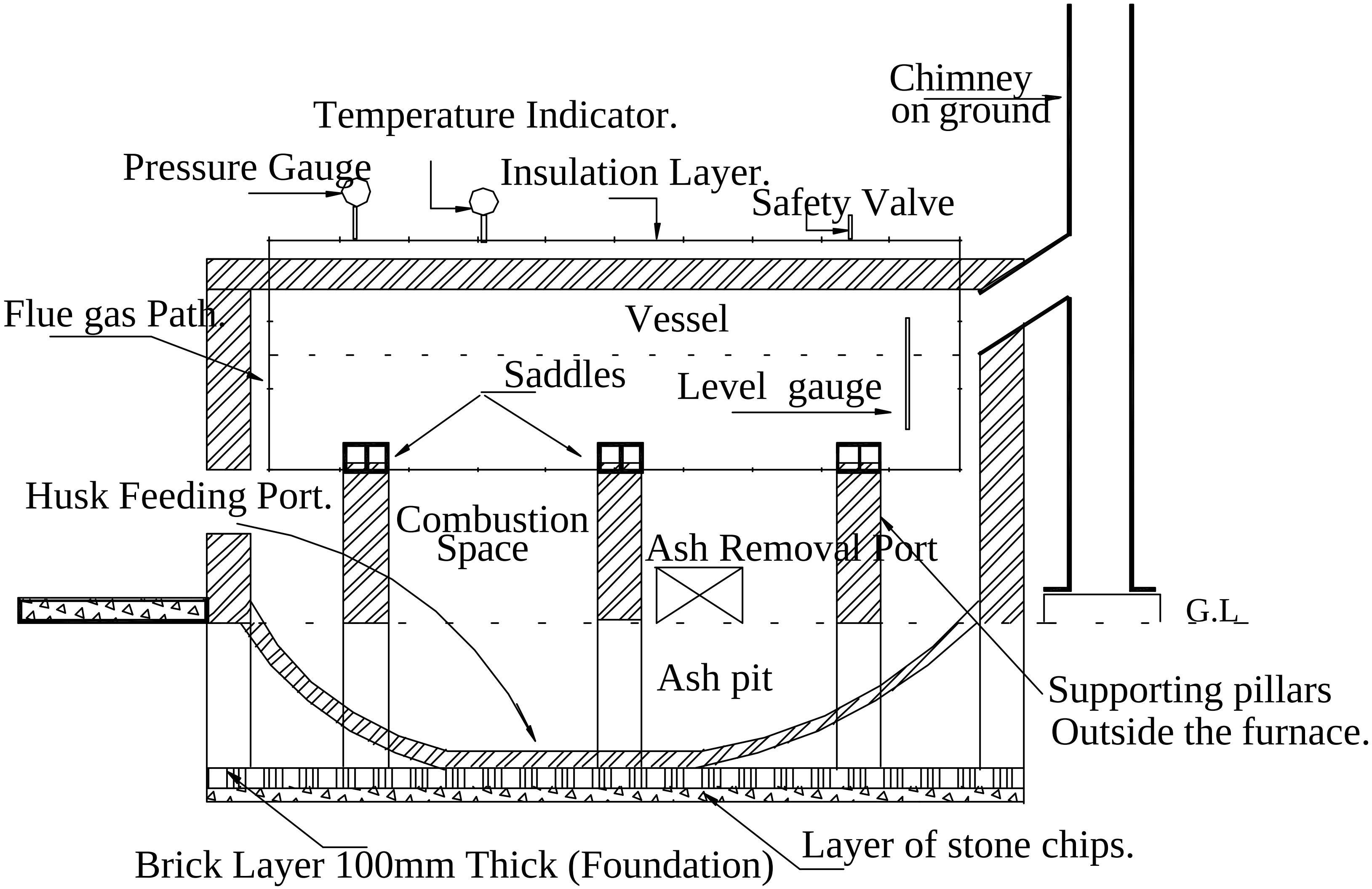
Sectional Drawing of the Vessel - Lengthwise

Appendix 3-C: Drawings and Performance of Mark 0



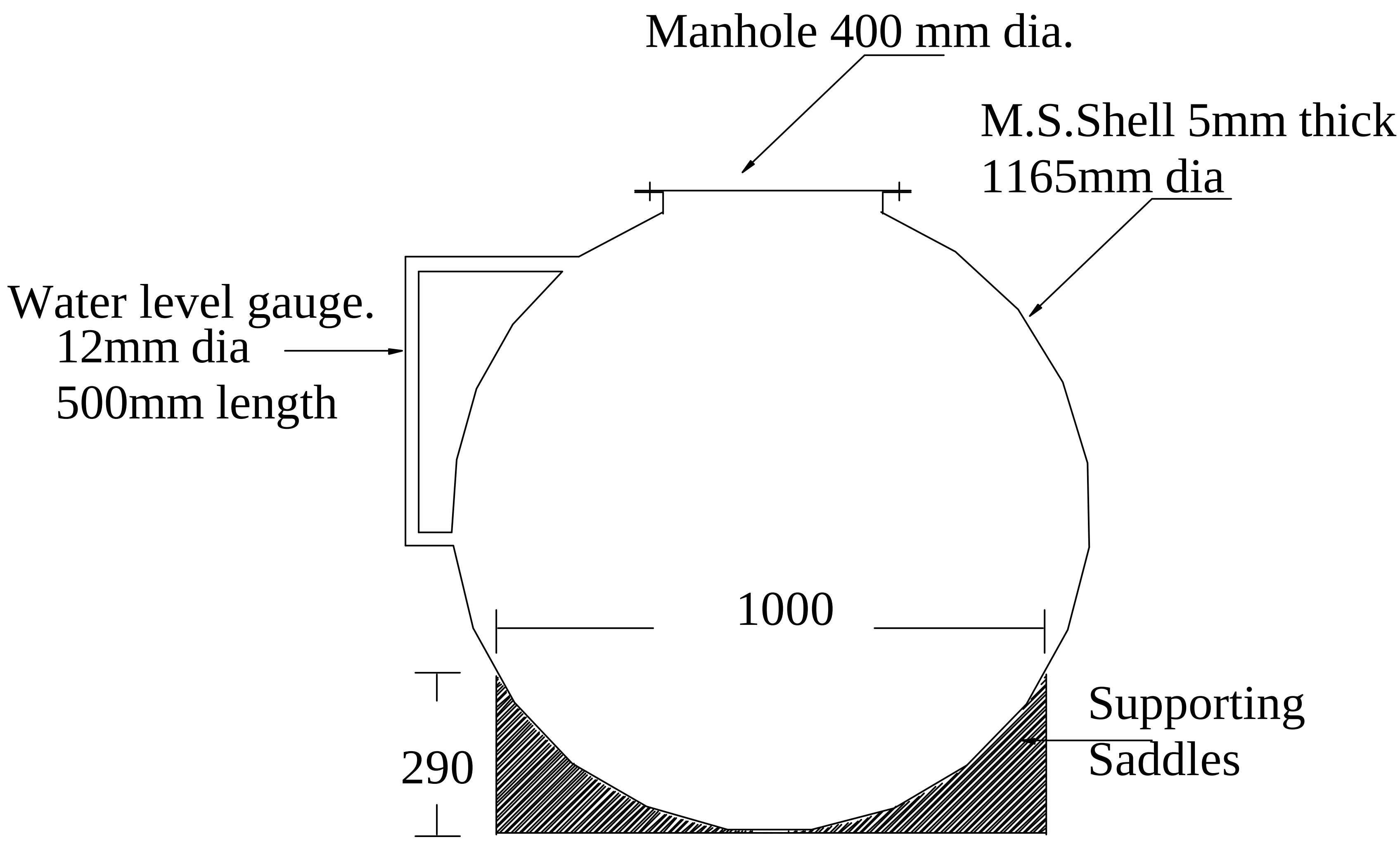
Cross-sectional View of the Furnace

Appendix 3-C: Drawings and Performance of Mark 0



Conceptual Diagram of the Improved Furnace with "chimney at the Ground level"

Appendix 3-C: Drawings and Performance of Mark 0

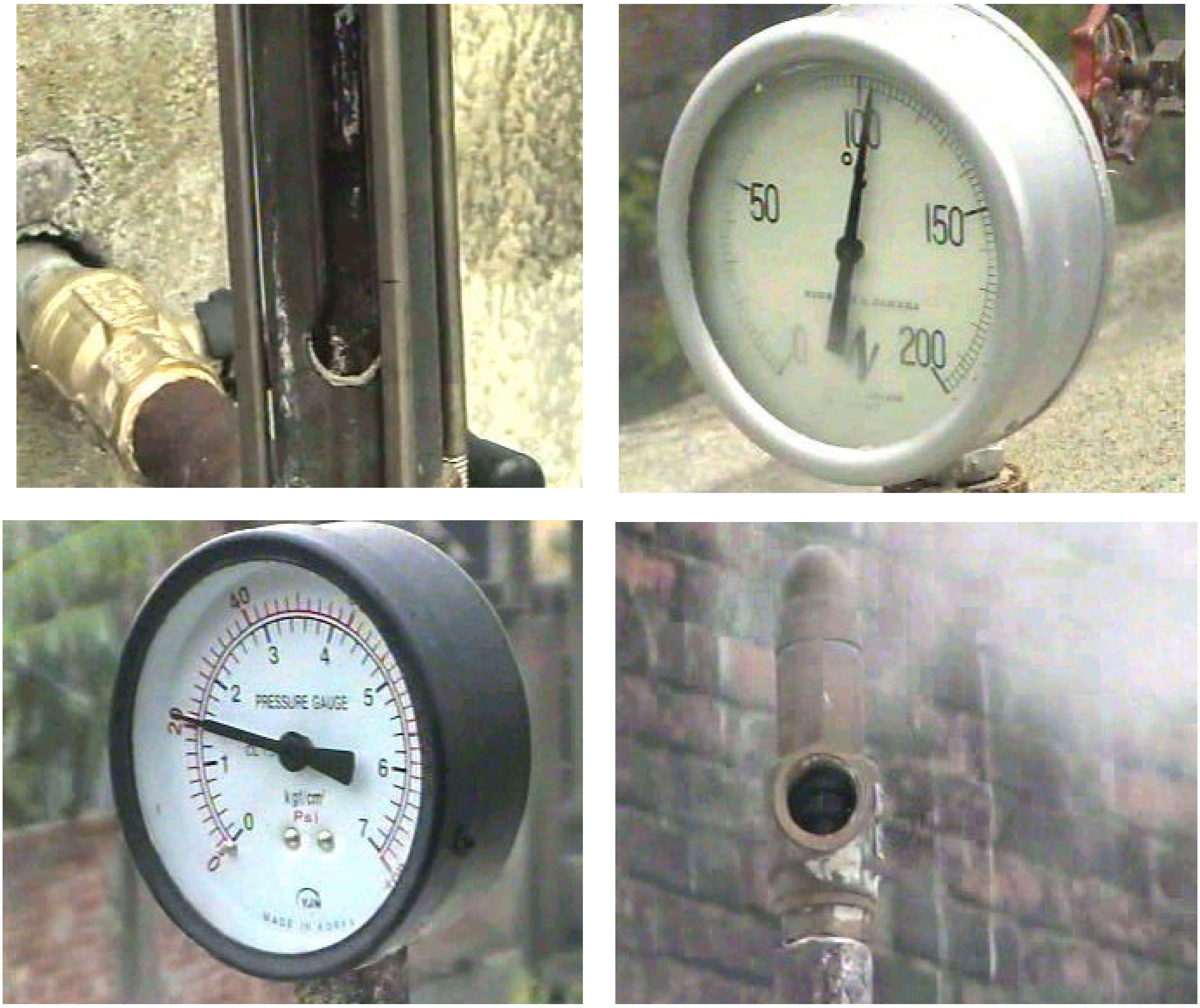


Appendix 3-C: Drawings and Performance of Mark 0

Complete combustion – improved furnace

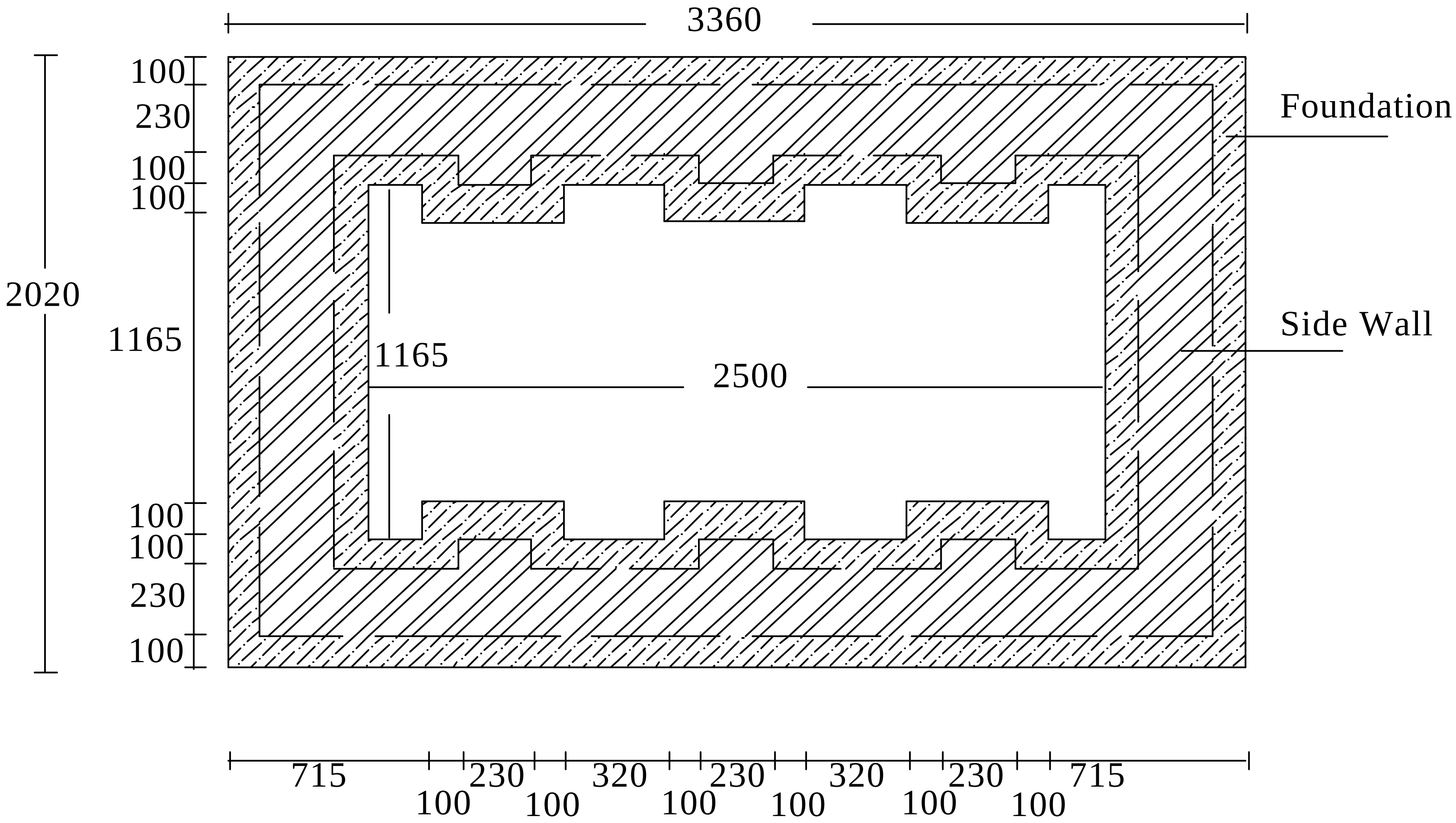
Less pollution from Improved Furnace

Appendix 3-C: Drawings and Performance of Mark 0

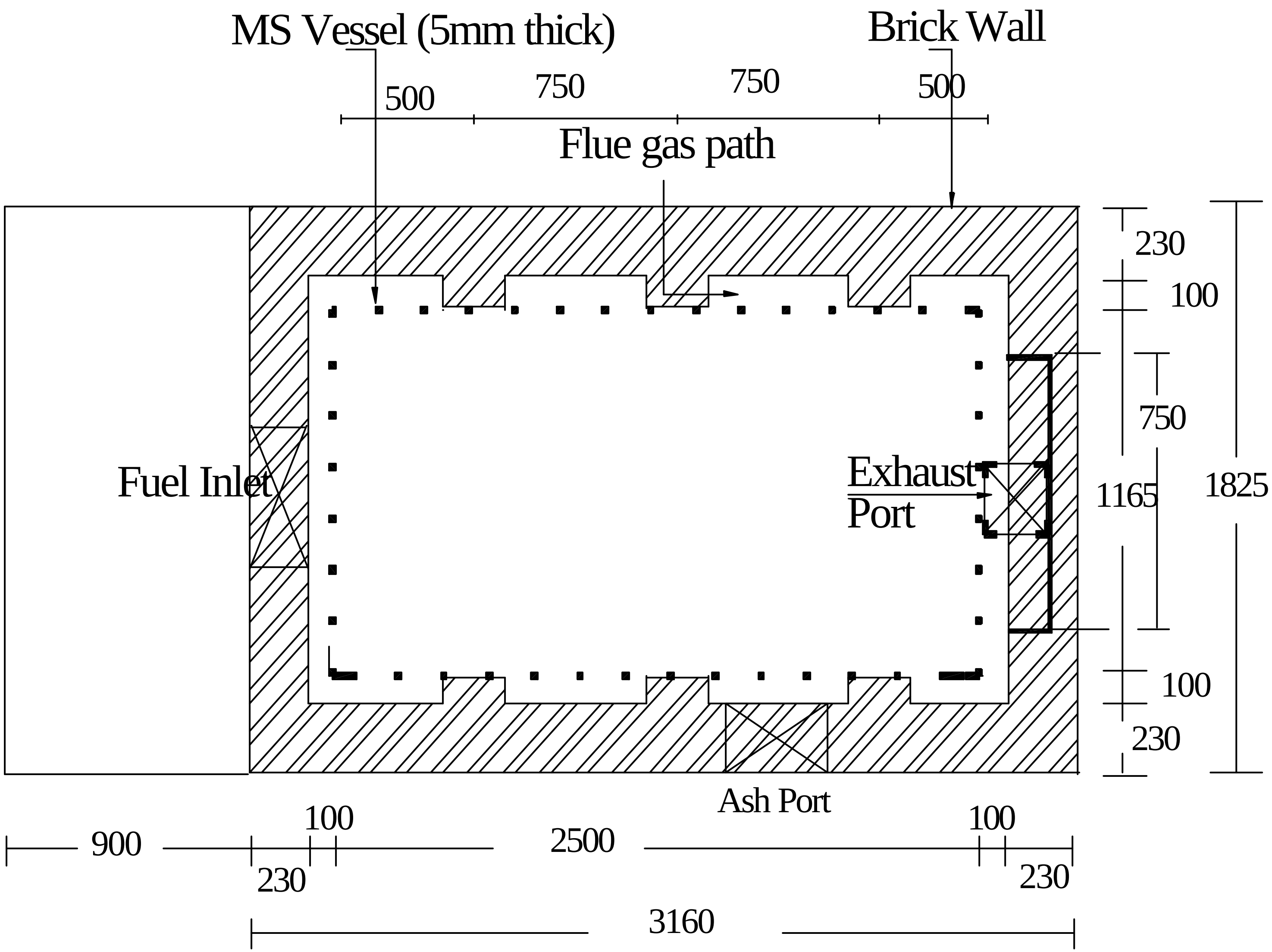


Instrumentation and Safety Valve installed in the New Boiler

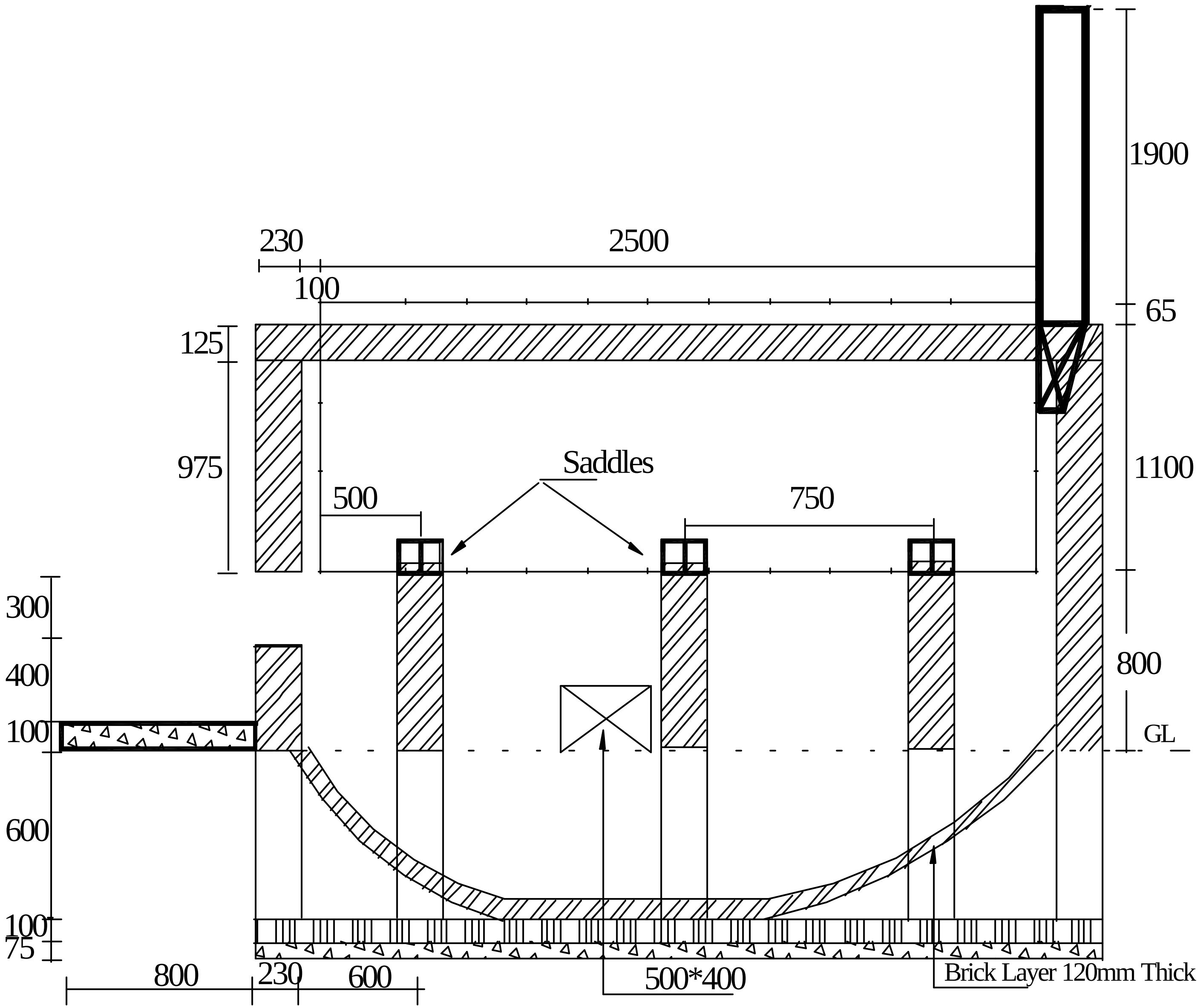
Appendix 3-D
Drawings for Furnace Model Mark 1



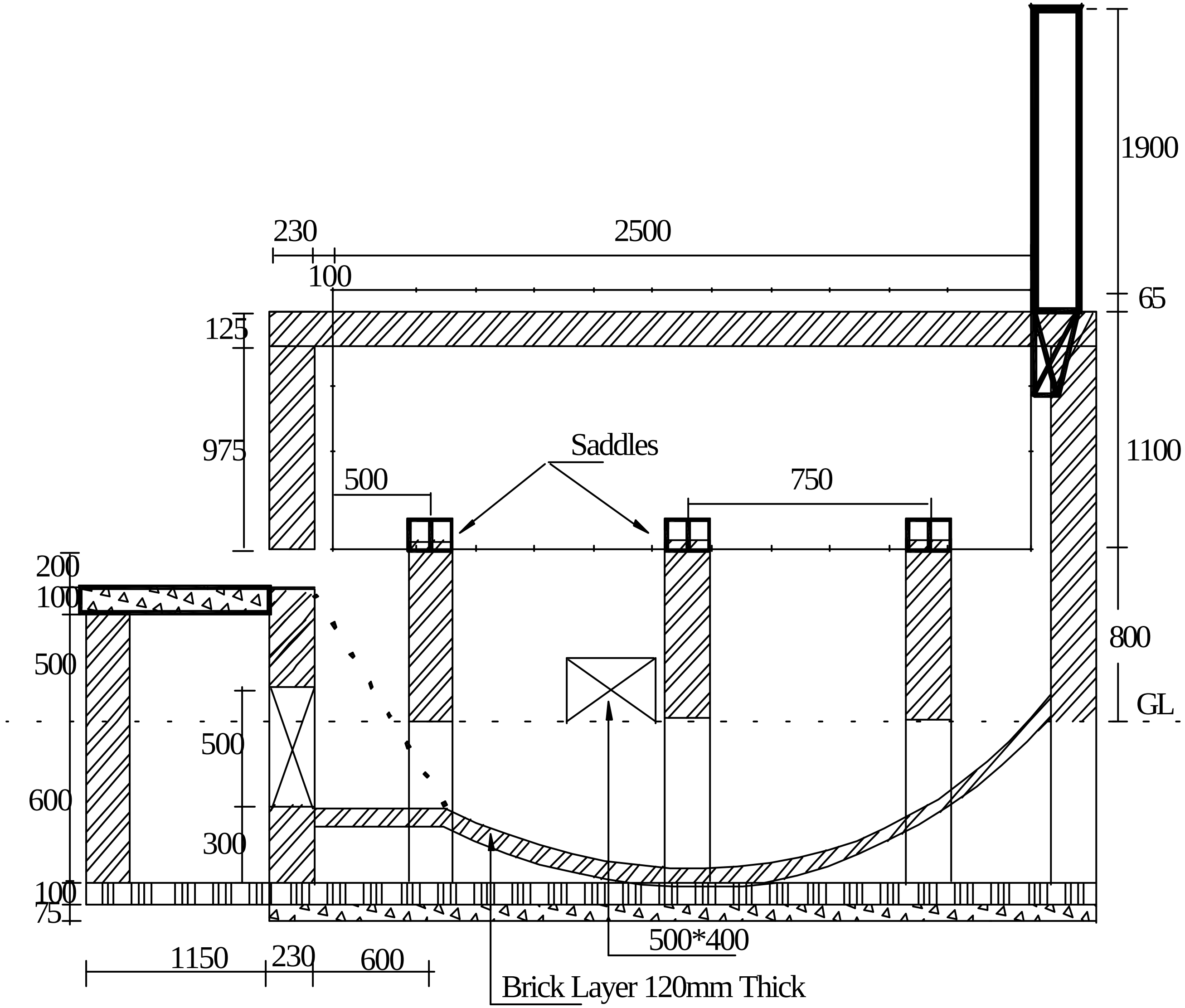
Foundation details



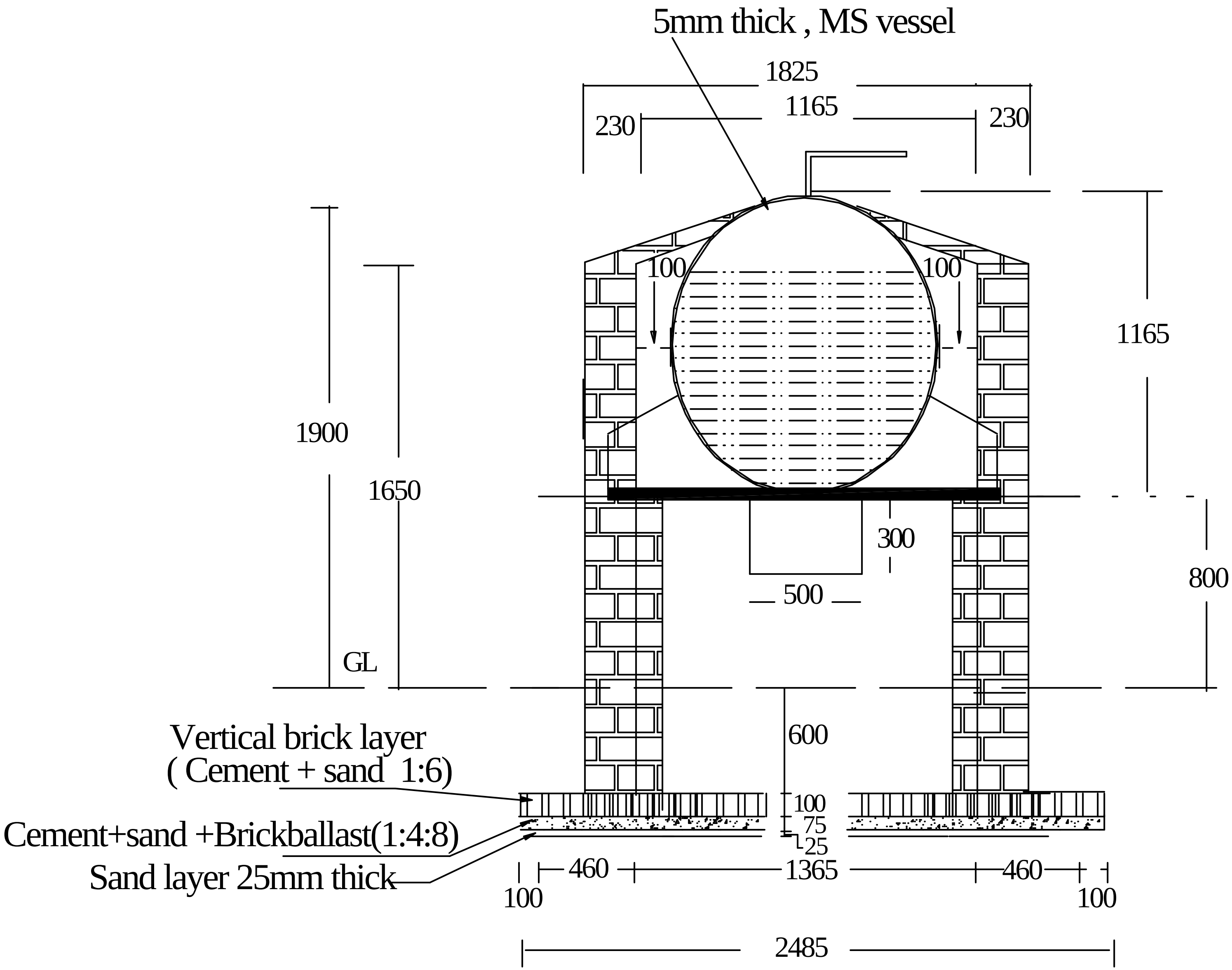
Plan of the furnace – sidewall details



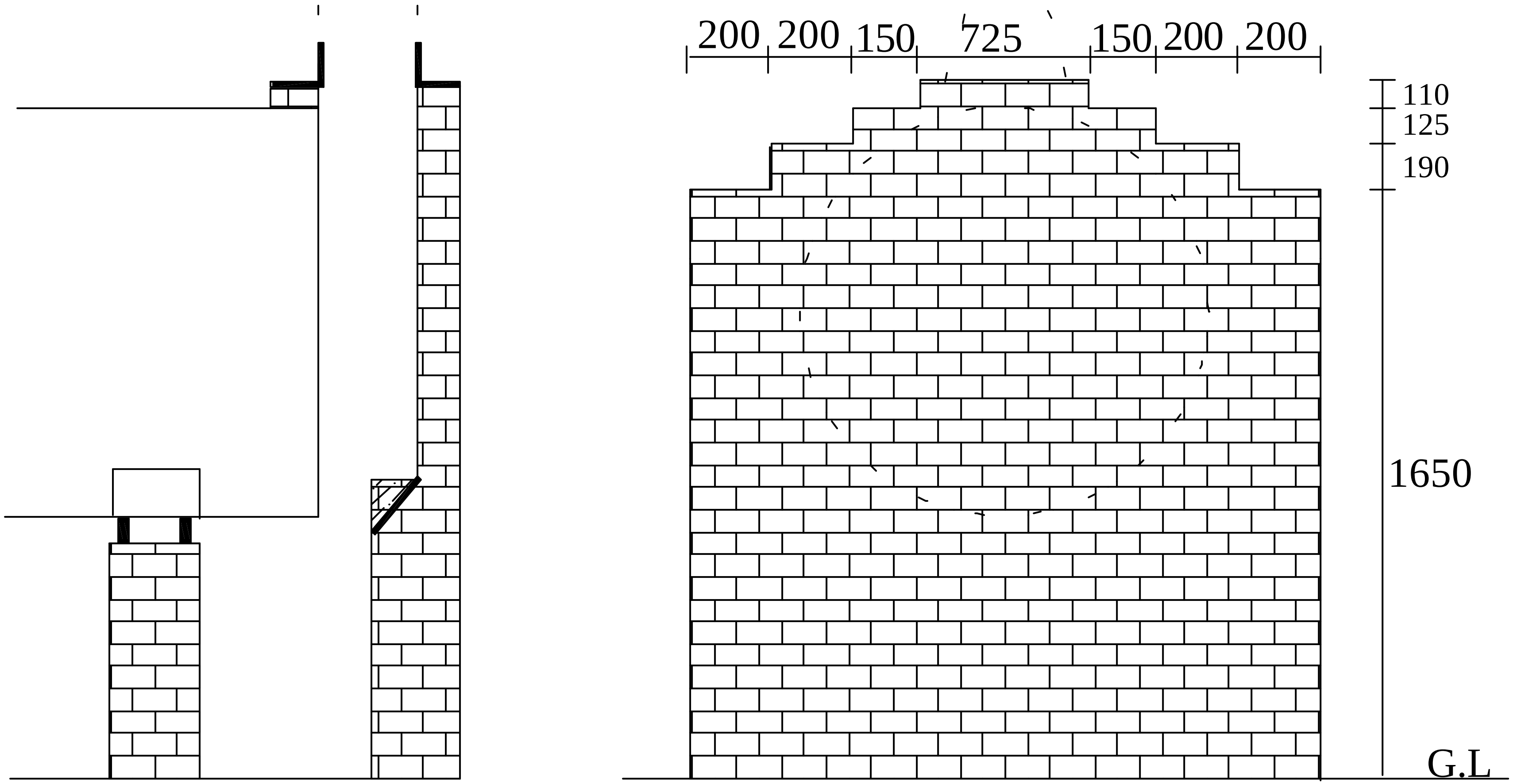
Sectional view of the furnace – lengthwise (without grate arrangement)



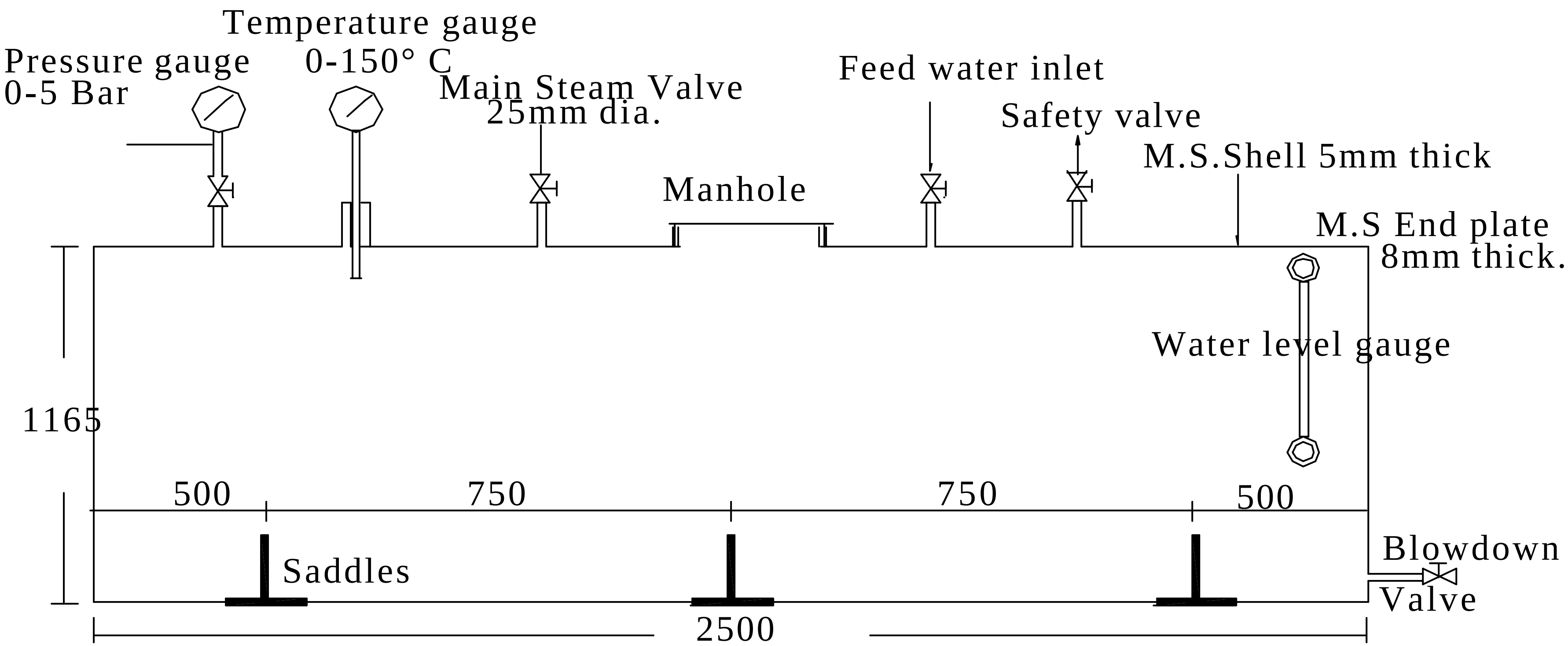
Sectional view of the furnace – lengthwise (with grate arrangement)



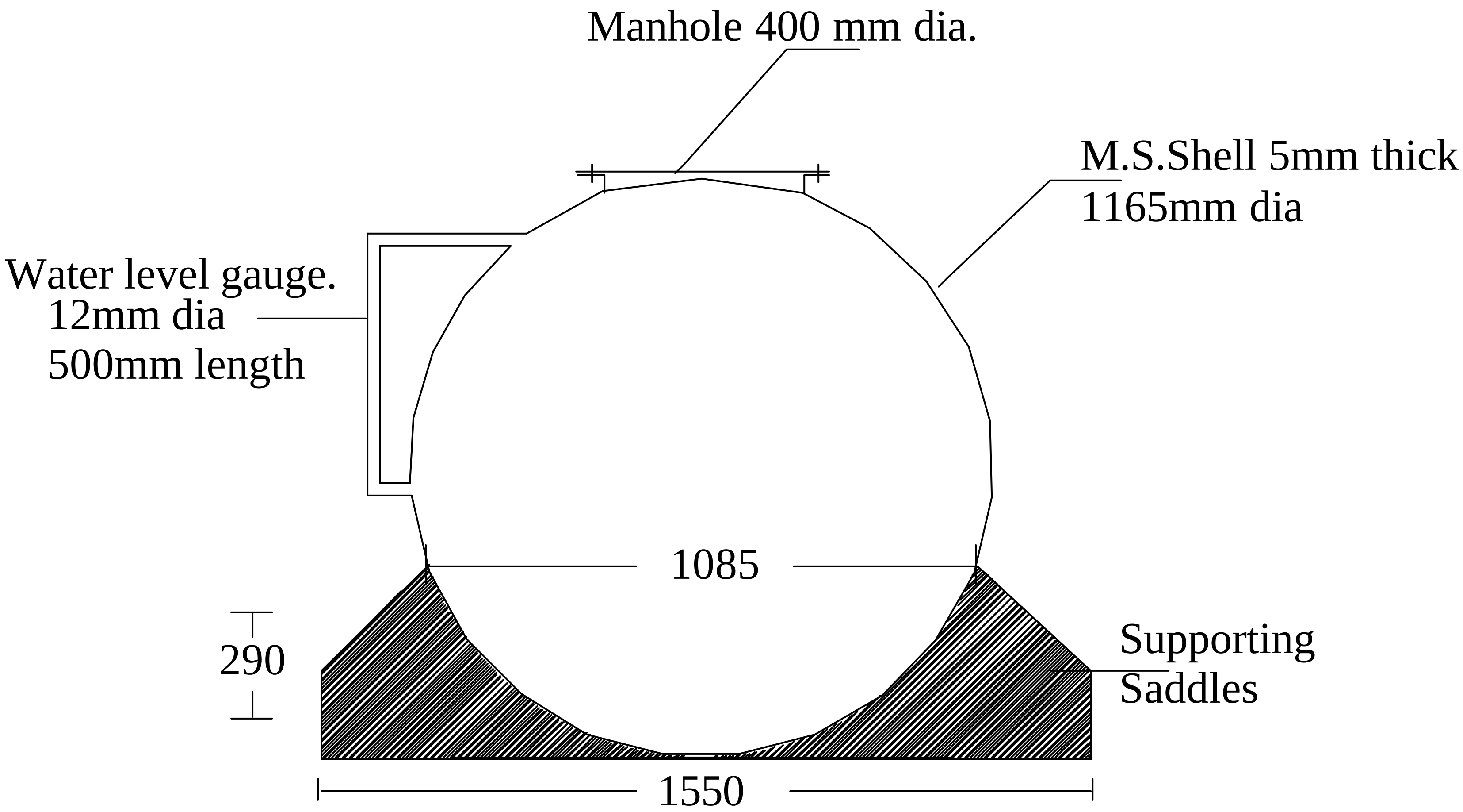
Sectional view - widthwise



Rear view of the furnace 9with chimney integrated)

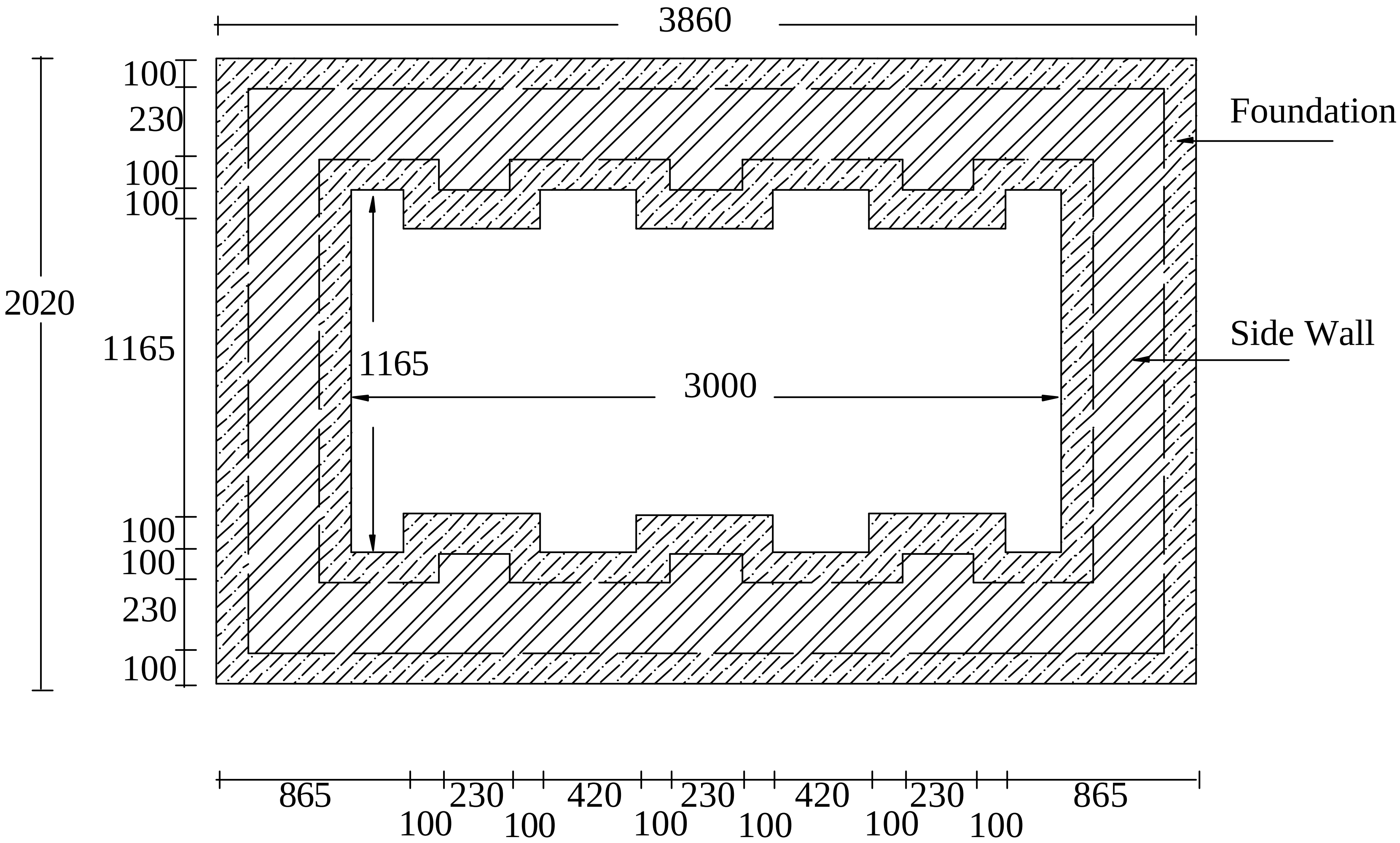


Vessel details – dimensions and components

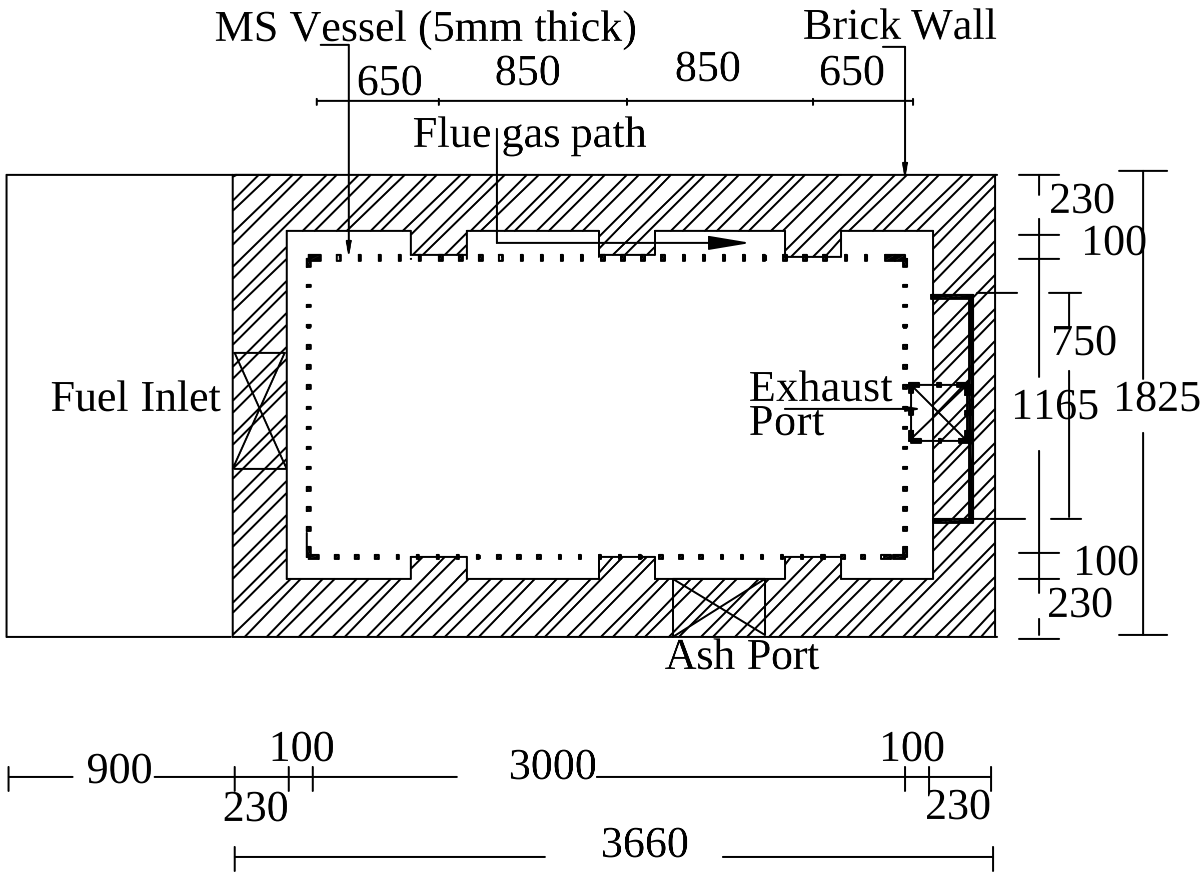


Sectional view of the vessel – width wise

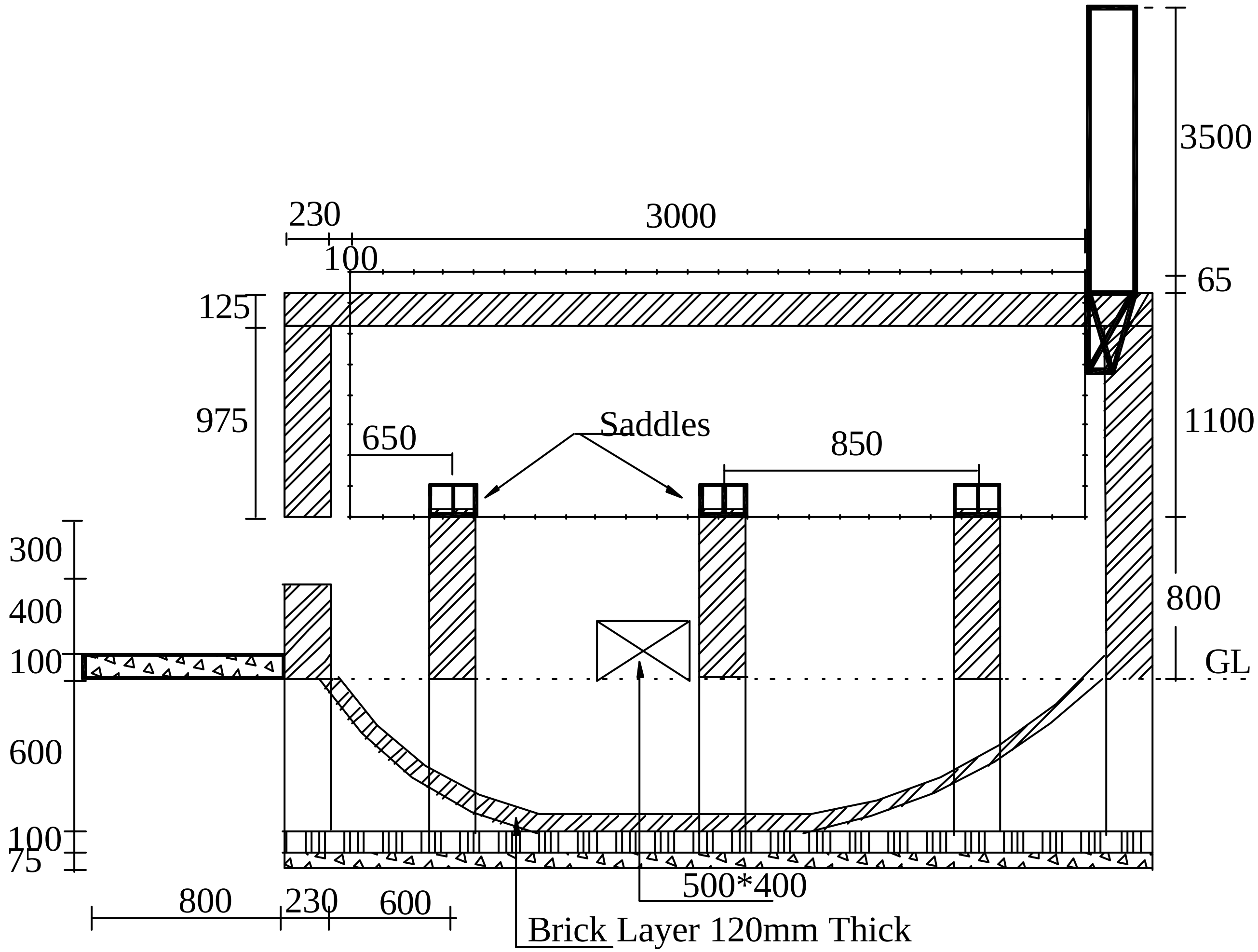
Appendix 3-E
Drawings of Furnace Model Mark 2



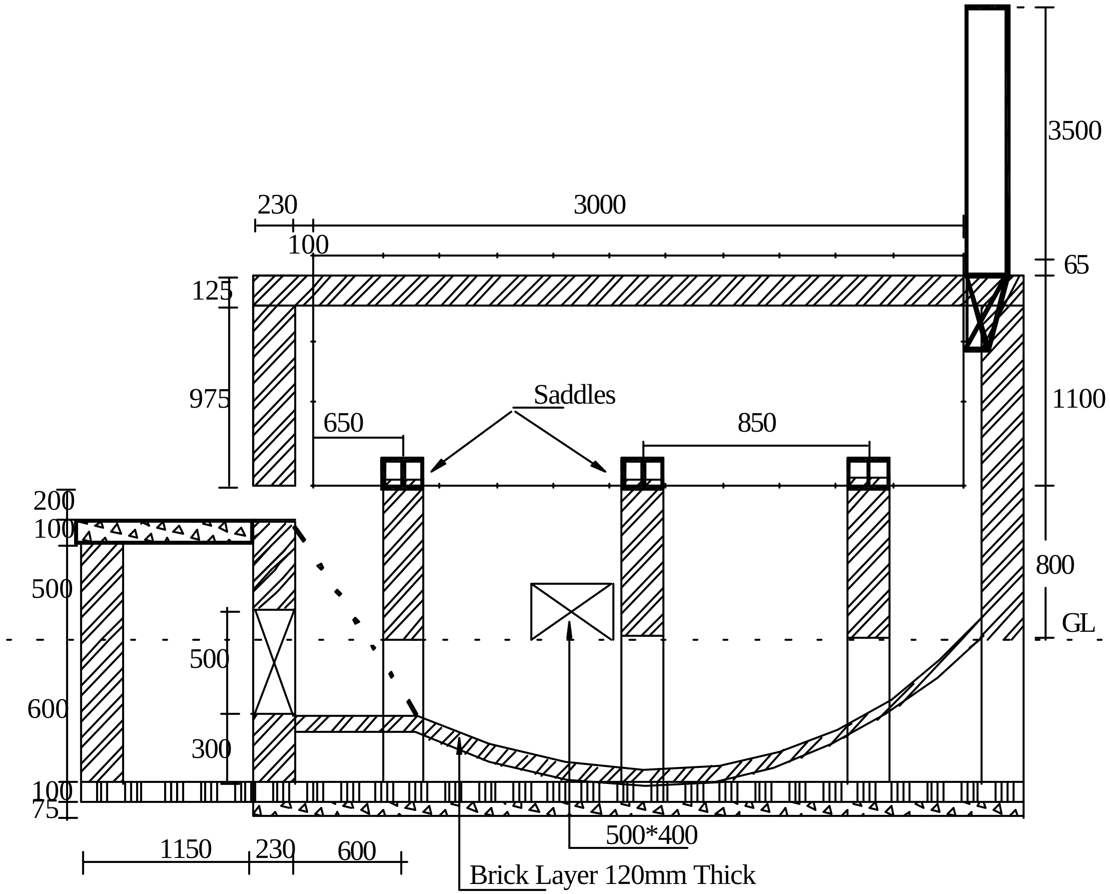
Foundation details



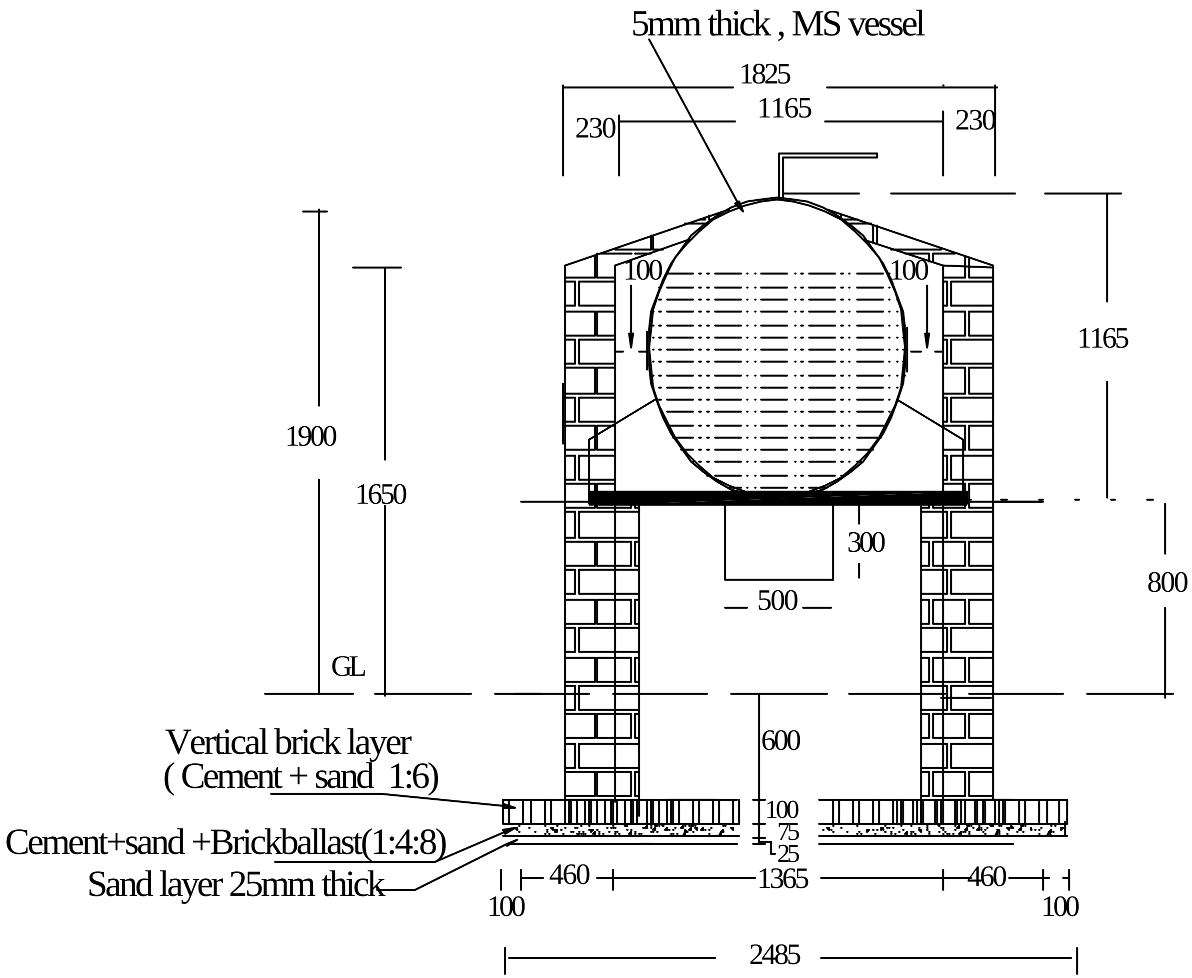
Plan of the furnace with sidewall details



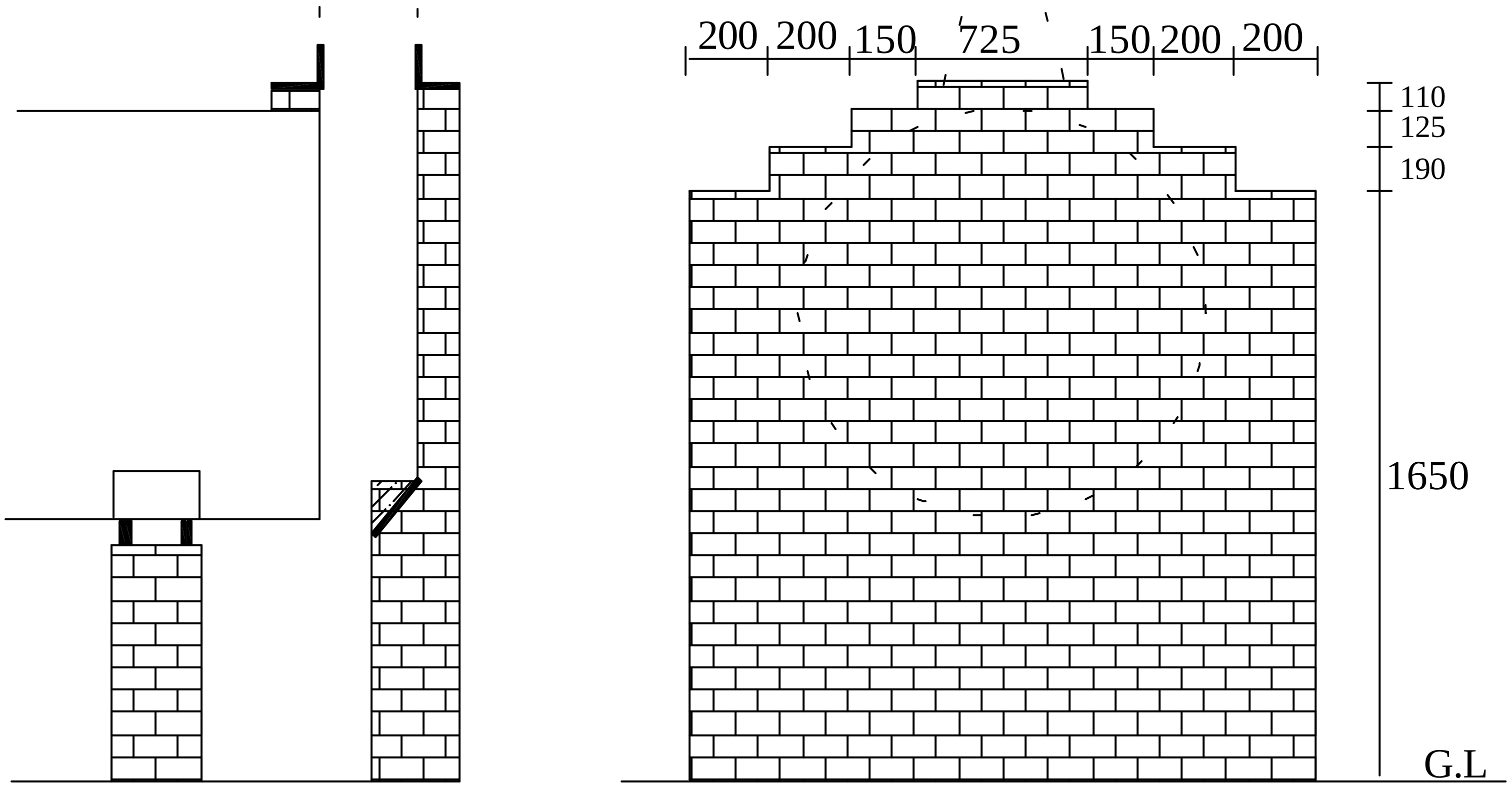
Sectional view of the furnace – lengthwise (without grate arrangement)



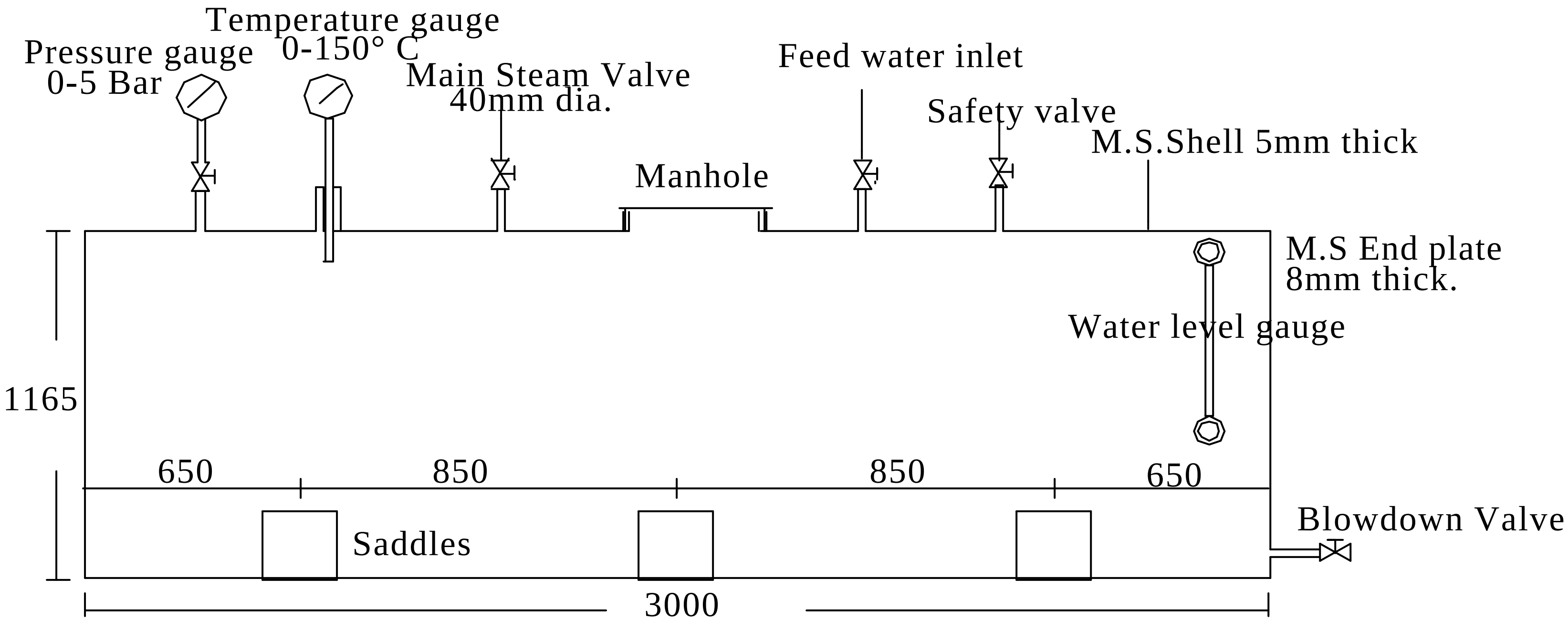
Sectional view of the furnace – lengthwise (with grate arrangement)



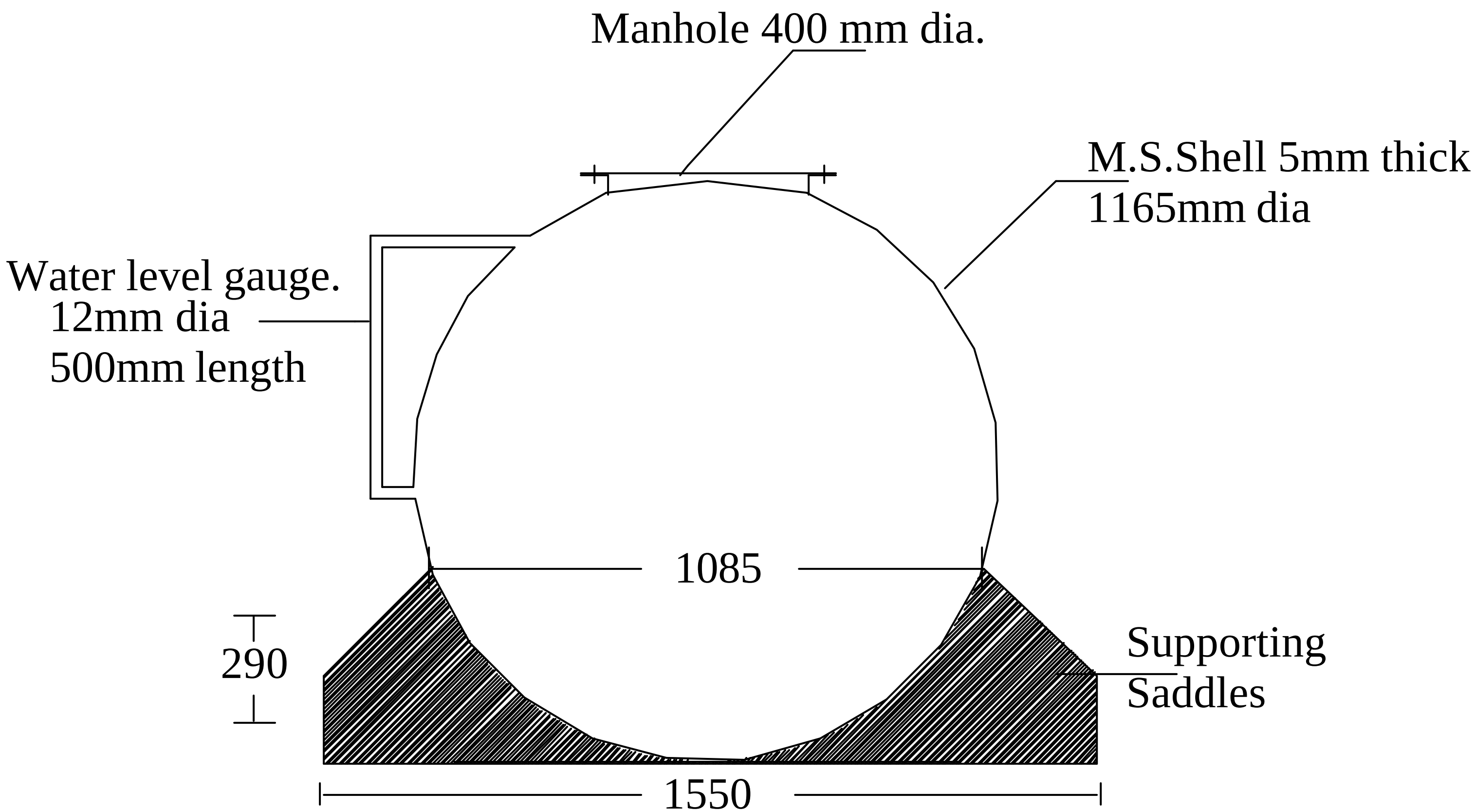
Sectional view of the furnace - widthwise



Rear view of the furnace (with chimney integrated)

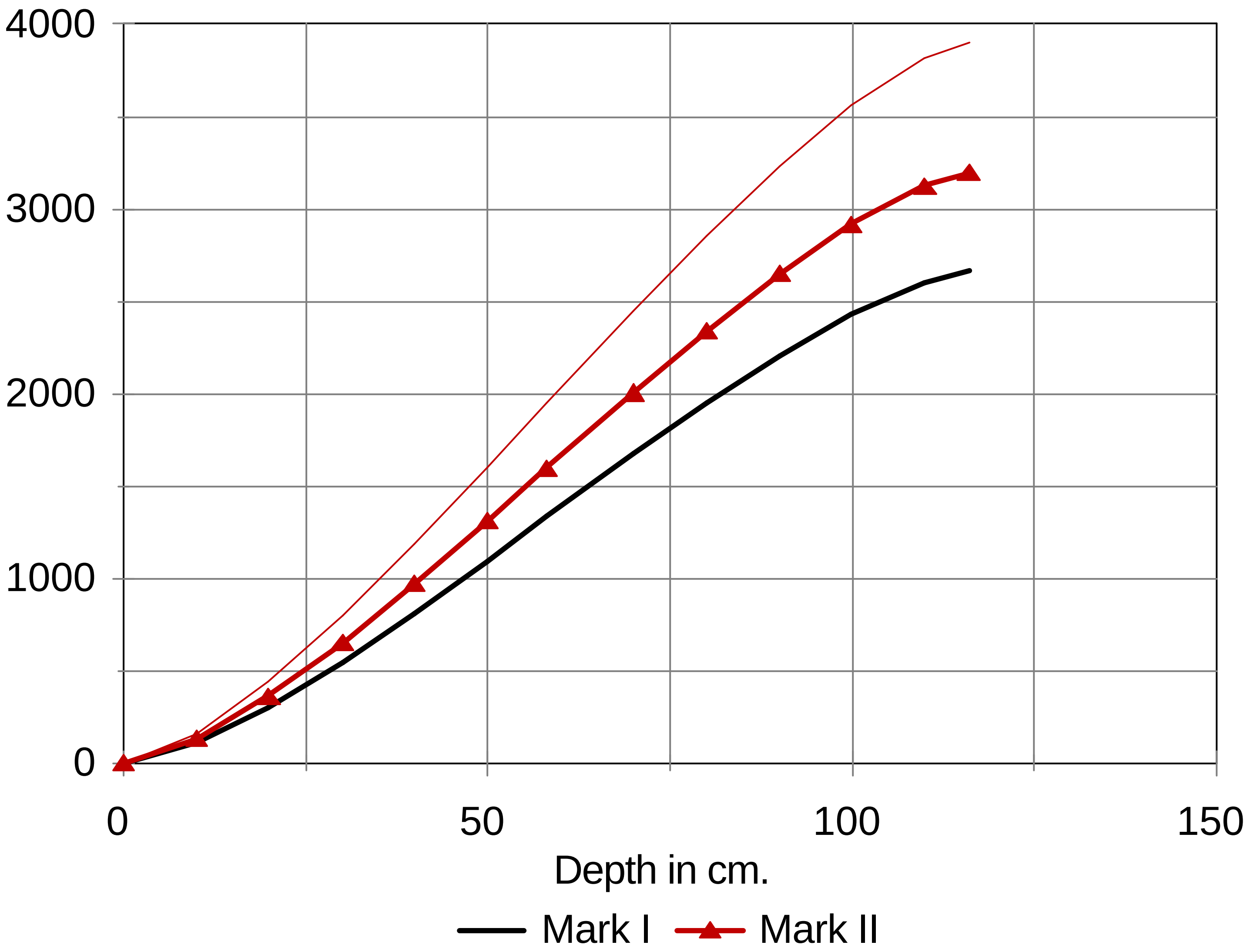


Vessel details – dimensions and components

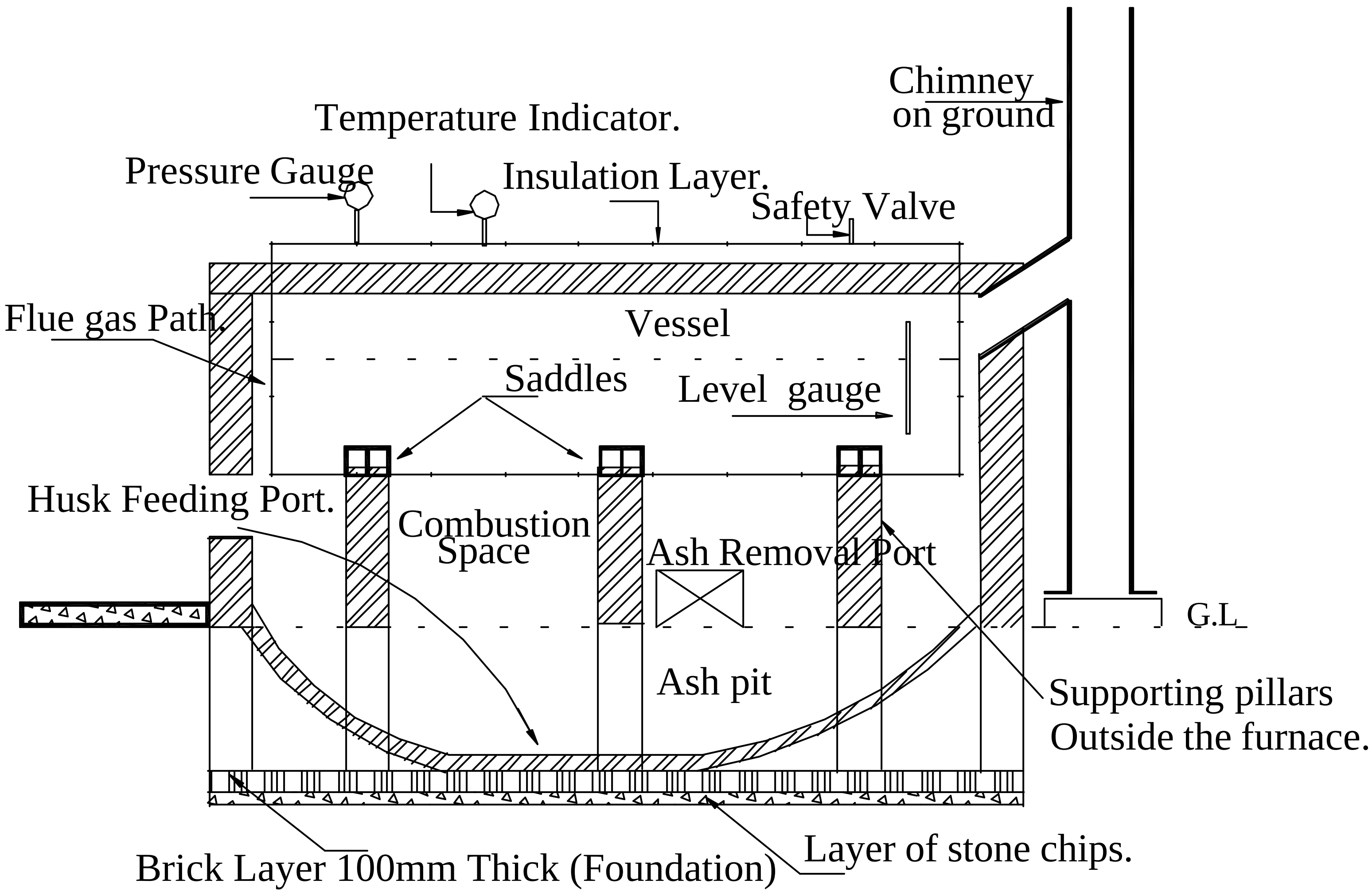


Sectional view of the vessel - widthwise

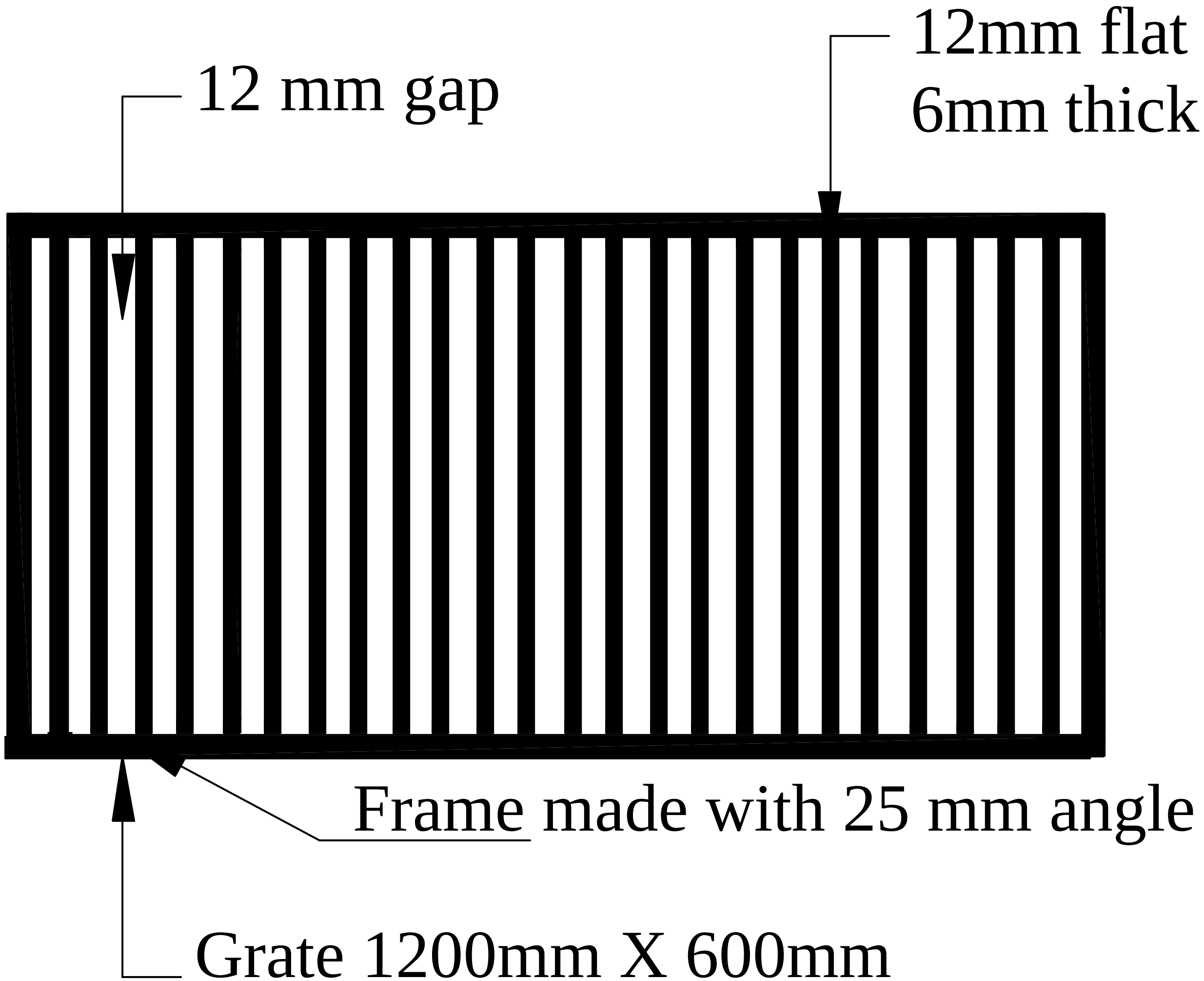
Appendix 3-F
Drawings of Furnace Components



Profile of depth versus volume (for Mark I and Mark II)



Conceptual diagram of the improved furnace with "chimney on the Ground level"



Details of the ash grate with dimensions

Appendix 3-G
Air Standards

Boiler of Industrial unit

Schedule I

Standards for Gaseous Emission

Parameters	**Presence of component mg/N m3**
1. Soot and particulate (Fuel based)	
coal	500
Gas	100
Oil	300
2. Oxides of Nitrogen	
Coal	600
Gas	150
Oil	300
Boiler using baggasse	
	Particulate, mg/Nm3
Step grate	250
Pulsating	500
Horse shoe spreader stoker	800
Brick kiln	1000

Schedule 2

Standards for Air

Density in microgram per cusec meter

	Categories of area	**Suspended particulate Matters (SPM)**	**Sulphur dioxide**	**Carbon Monoxide**	**Oxides of Nitrogen**
a	Industrial and mixed	500	120	5000	100
b	Commercial and mixed	400	100	5000	100
c	Residential and rural	200	80	2000	80
d	Sensitive Areas	100	30	1000	30

Notes:

(1) At national level sensitive areas includes monuments, health centres, hospitals, archaeological sites, educational institutions and Governemnt. designated areas

(2) Industrial units located in areas not designated as industrial areas shall not discharge pollutants which may contribute to exceeding the standard for air surrounding the areas specified in Nos. c and d above

(3) Suspended particulate matter means airborne particles of a diameter of 10 microns or less.

Appendix 4-A
Briquettes

Performance Tests of Improved Screw and Traditional Screw

Time, hr	Improved screw					Traditional practice		
	Briquette production, kg/hr	Power required, kW/hr	Energy required, kWh/ton	Density of briquette, g/cc	Crushing load, N/cm	Briquette production, kg/hr	Density of briquette, g/cc	Crushing load, N/cm
1	153.60	16.00	104.2	1.16	471	81.6	1.19	377
2	138.80	15.37	110.7	1.17	518	82.4	1.21	452
3	134.00	15.24	113.8	1.17	672	83.6	1.22	652
4	127.20	15.63	122.9	1.22	696	79.2	1.25	780
5	147.45	15.54	105.4	1.17	638	82.0	1.22	601
6	140.00	15.11	108.0	1.18	680	88.0	1.22	594
7	139.46	14.44	103.6	1.32	1333	88.0	1.20	436
8	145.16	13.65	94.1	1.33	1390	80.0	1.17	234
9	123.00	12.86	104.1	1.34	1540	72.0	1.19	377
10	110.12	12.18	110.6	1.34	1587			
11	109.92	11.72	106.7	1.29	1338			
12	108.40	11.61	107.1	1.26	1290			
13	102.76	11.95	116.3	1.27	1099			
14	100.92	12.86	127.5	1.26	875			
15	97.97	14.46	147.6	1.25	889			
16	96.04	16.86	175.5	1.25	805			
Av.	123.48	14.10	116.1	1.25	988	81.87	1.21	281

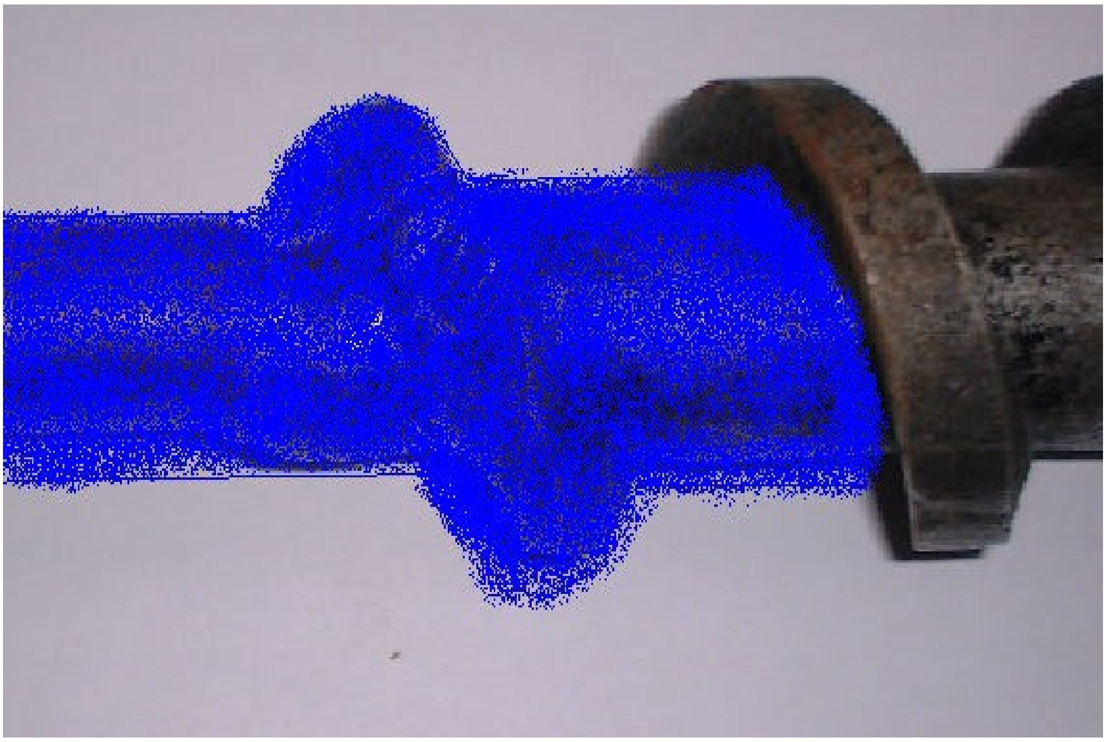
View of briquetting machine

Barrel heating with kerosene

Barrel heating with electricity

Worn out screw and barrel

Worn screw



Hardened surface coating

Briquettes in store

Briquettes ready to be transported to the market

Improved Screw, Cost break up, each hour

1.	Rice husk	=	150 Tk
2.	Diesel	=	51 tk (3 lit)
3.	Man power	=	10 Tk
4.	Electricity (2.30 Tk/kWh)	=	35 Tk (20 hp)
5.	Screw repair	=	7 Tk
6.	Screw barrel	=	3 Tk
7.	Weight loss	=	12 Tk (10% loss)
	Total	=	266 Tk
	Selling price	=	450 Tk
	Profit	=	180 Tk
	Monthly profit	=	54000

Payback less than a month

Appendix 5-A
Illustrations Relating to Chapter 5

Women Account for 50% of the Workers in Rice Mills

Chicks in a Medium Scale Broiler Farm

Appendices 6A – 6C

Data: Analysis of Rice Husk Ash

APPENDIX 6-A. METHODS OF CHARACTERISATION OF RICE HUSK AND RHA SAMPLES

Characterisation of Husk Samples

To characterise the moisture content of husk samples, volatile matter content and ash content were determined.

Determination of Moisture Content

The moisture content was determined by an oven-dry method at 105^{0}C and left overnight in the oven. The samples were removed from the oven when a constant weight was reached and then cooled in a desiccator. The moisture content was calculated by the following formula:

Moisture content (dry basis) = (Initial mass-Final mass ÷ Final mass) %

Determination of Ash and Volatile Matter Content

The thermogravimetric analysis (TGA) technique was applied to determine the ash and volatile matter content of the husk samples. Thermogravimetry is a technique where the weight loss of a substance in a closed environment is recorded as a function of time and temperature· On heating, many materials lose weight in specific temperature ranges, depending on the nature of the reactions causing the weight loss. These ranges were used to quantify the components within the husk under thermal degradation. Thermal husk degradation was conducted under static air and under nitrogen from ambient to 1000^{0}C.

Characterisation of RHA Samples

The following parameters were determined to characterise the ash samples:

Moisture Content of RHA Samples

Moisture content of RHA samples was determined by the oven-dry method similar to that of husk samples.

Determination of Particle Size Distribution of RHA Samples

Particle size distribution experiment was carried out by sieve analysis using BS sieves of 250,125 and 63 microns. This was done to determine whether there was any effect on the silica content in the ash samples due to their grain size or not. This was expressed as the percent weight of materials retained at each sieve after sieving. This was calculated by the following formula:

Percent particle size by weight = Weight of material retained on sieve after sieving /Total weight of material x 100

X-ray Diffraction Analysis of RHA Samples

The X-ray diffraction (X-RD) patterns were obtained using a Phillips diffractrometer (Figure 1) and nickel filtered Cu Kα radiation (λ = 0.1542 nm) at $2\theta = 5^0$-50^0. The objective of X-ray diffraction was to determine the crystallinity of ash samples. Six selected ash samples of particle size below 63 microns were used in the powder diffraction method of analysis.

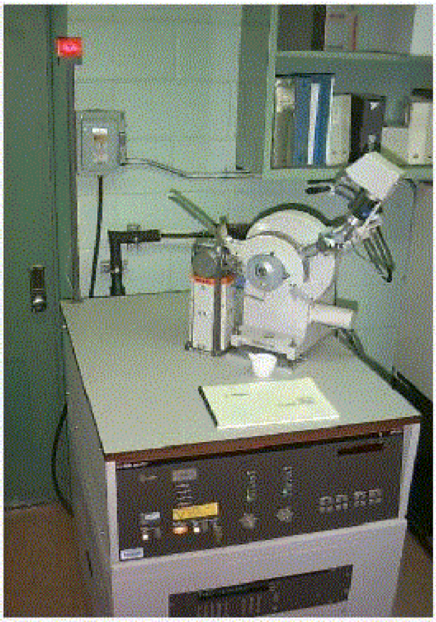


Figure 1 A Phillips Powder Diffractrometer

Determination of CHN of RHA samples

The percentage of element carbon, hydrogen and nitrogen were analysed using a Carlo-Erba analyser (Figure 2).

Figure 2 Carlo-Erba Analyser

SEM of RHA Samples

The application of scanning electron microscopy (SEM) is a valuable technique to characterise the morphological structure of RHA samples. Therefore, SEM analysis was conducted for the sample No. 1 and sample No. 10 by the JEOL JSM-5310 L.V. machine (Figure 3).

Figure 3 JEOL JSM-5310 L.V. Machine

Determination of Surface Area of RHA Particles

Surface area is one of the major indicators of determining pozzolanic reactivity of a material. The surface area was measured with a mercury absorption type surface area analyser (Gemini 2375 V4. 01) (Figure 4).

Figure 4 The Gemini 2375 V4. 01 Surface Area Analyser

FT-IR Spectroscopic Analysis of RHA Samples

Fourier transform infra-red (FT-IR) spectroscopy method occupies a special place in identification and characterisation of a material which enables us to examine the molecular structure of silica, the presence of functional groups and their chemical behaviour. Infrared spectra of all samples were obtained as KBr disks by Paragon, Perkin Elmar (Figure 5). The samples were scanned 10 times at the transmission mode in the region of 4000 – 450 cm^{-1} with a 2cm^{-1} resolution and averaged

Figure 5 A Paragon Elmar FT-IR Spectrometer

Determination of Compressive Strength of OPC-RHA Blended Cement Blocks

Blended cement blocks of 400g (dry wt.) were prepared by replacing 10% weight of OPC by RHA. For this 360 g of OPC plus a 10% addition of RHA (40 g) was placed in a Kenwood mixing bowl and 160 ml of water was added to give a water: solid ratio of 0.4. The paste was mixed for 4 minutes at the speed setting of 4 and then transferred into 2 disposable paper beakers at approximately equal quantity. Thus, twenty-eight of blocks were made taking ash for two blocks from each of 14 original RHA (without sieving) samples (Figure 6). In addition to this eight OPC-RHA blocks were prepared with the sieved ash of fractional particle sizes (250,125, 63 & < 63 microns) of selected RHA samples in the similar procedure mentioned above. However, this time a measured quantity of additional water was added to the mixture to bring the paste to workable condition. Another 8 blocks were prepared with the addition of increasing amount of RHA to OPC. However, two blocks with 100% OPC were prepared as a control. All the RHA–OPC cement blocks were left for moist curing at room temperature and were subsequently stored until required. The compressive strengths of samples were determined using a Dartec Universal Testing Machine (Figure 7) in the range of 100 kN at the speed of 0.15 mm/sec.

a. **b.**

Figure 6 Specimen Blocks made from a. Specimen Blocks made from 90% OPC+ 10% RHA, b. 100% OPC.

Figure 7 The Dartec Universal Testing Machine

APPENDIX 6-B

Table 1 Moisture Content of Husk Samples

Sample No.	Weight of original sample (gm)	Weight of oven dry Sample (gm)	Moisture content (%) dry basis
1	28.08	27.17	3.35
2	41.70	40.31	3.45
3	39.37	37.90	3.88
4	26.13	24.96	4.69
5	33.54	32.42	3.45
6	30.53	29.31	4.16
7	63.89	60.74	5.19
8	61.90	58.43	5.94

Table 2 Moisture Content of RHA Samples

Sample No.	Moisture content (dry basis) %
1	0.018
2	0.010
3	0.020
4	0.012
5	0.030
6	0.059
7	0.015
8	0.002
9	0.017
10	0.0015
11	0.0007
12	0.0061
13	0.0100
14	0.012

Appendix 6-B

Pores in silica 2-20 nm in diameter.

silica 10 iso

Page 1

Gemini 2375 V4.01
Instrument ID: 680
Setup Group: 9 - Jenny's Isotherm

Sample ID: sil10iso
ample Weight: 0.3234 g
vacuation Rate: 200.0 mmHg/min
No Free Space Correction Applied
Analysis Mode: Equilibration

Started: 25/06/02 12:05:59
Completed: 25/06/02 21:50:05
Evacuation Time: 1.0 min
Saturation Pressure: 760.00 mmHg
Equilibration Time: 5 sec

BET Multipoint Surface Area Report

Surface Area: 161.5155 sq. m/g
Slope: 0.026537
Y-Intercept: 0.000416
C: 64.849564
Vm: 37.102718
Correlation Coefficient: 9.9988e-001

BET Single Point Surface Area: 156.6667 sq. m/g

t-Method Micropore Report

Micropore Volume: -0.009319 cc/g
Micropore Area: -14.4848 sq. m/g
External Surface Area: 176.0003 sq. m/g
Slope: 11.378348
Y-Intercept: -6.025018
Correlation Coefficient: 9.9916e-001
Thickness Values Between: 3.500 and 5.000 A
Area Correction Factor: 1.000

0.5000
t = [13.9900/(0.0340 - log(P/Po))]

Adsorption Total Pore Volume at 0.9995 P/Po: 0.2291 cc/g

Analysis Log

Relative Pressure	Pressure (mmHg)	Vol. Adsorbed (cc/g STP)	Elapsed Time,(h:m)	Statistical Thickness,(A)	Surface Area Point
0.0101	7.64	23.393	0:16	2.624	
0.0258	19.59	27.568	0:20	2.936	
0.0415	31.54	30.104	0:23	3.143	*
0.0572	43.49	32.046	0:26	3.311	*
0.0730	55.44	33.668	0:29	3.457	*
0.0887	67.40	35.100	0:33	3.589	*
0.1044	79.37	36.410	0:36	3.712	*
0.1202	91.32	37.631	0:39	3.829	*
0.1359	103.27	38.801	0:42	3.941	*

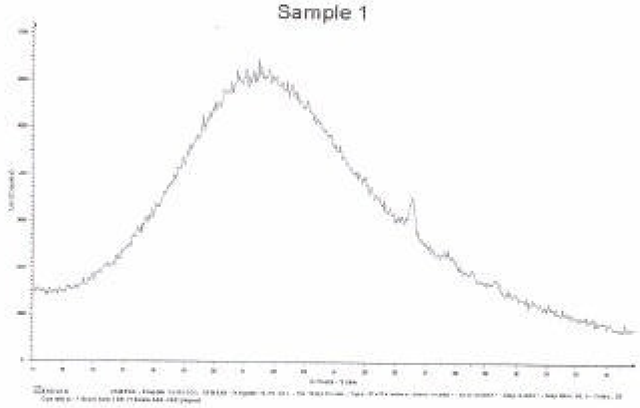
Table 3 BET Surface Area Analysis of RHA Particles of Sample No.10 Measured by the Gemini 2375 v4.01 Surface Area Analyser

Appendix 6-B

XRD analysis of Crystallinity Ian Slipper DEES

SAMPLE 1	Left Angle 2-Theta °	Right Angle 2-Theta °	Net Area Cps x 2-Theta °
total area	15.015	29.995	3265.70
peak areas	26.075	26.845	18.05
	27.475	28.175	5.67
	28.385	28.735	2.15
	29.05	29.68	4.64
	19.53	19.74	1.94
	20.615	21.175	5.36
total peak areas			37.81
% crystalline			**1.16**

Sample 1



SAMPLE 10	Left Angle 2-Theta °	Right Angle 2-Theta °	Net Area Cps x 2-Theta °
total area	15.015	29.995	3045.9
peak areas	20.545	21.35	7.965
	26.075	26.845	35.97
	27.475	28.175	0.66
	28.385	28.735	0.415
	29.05	29.68	4.622
total peak areas			49.63
% crystalline			**1.63**

Sample 10

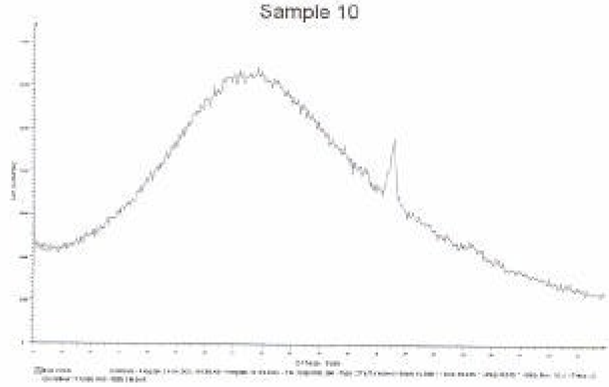


Table 4 XRD Analysis of Crystalline of RHA Sample No.1 and 10 by a Siemens Diffractometer

Appendix 6-B

Table 5 Test Results of Compressive Strength (N/Cm^2) of OPC- RHA Blocks After 28 Days of Curing

Observation	100% OPC	90% OPC + 10% RHA	80% OPC + 20% RHA	70% OPC + 30% RHA
1	1439.0	1338	809	546.0
2	1439.0	1315	881	663.0
3	1439.0	1292	977	624.0
Average	1439.0	1315	889	611.3

Table 6 Test Results of Compressive Strength (N/Cm^2) Of OPC- RHA Blocks After 28 Days of Curing (Ground RHA)

Observation	100% OPC	95% OPC + 5 % RHA	90% OPC + 10% RHA	85% OPC + 15 % RHA
1	1866.5	1812.25	1928.0	1847.5
2	1867.5	1812.35	1928.30	1847.25
3	1866.5	1812.25	1928.20	1847.30
Average	1866.83	1812.28	1928.17	1847.35

Table 7 Test of Compressive Strength (N/Cm^2) of OPC-RHA Block at Varying Water-Solid Ratio (Ground RHA)

Treat ment	Cement Part by Weight	Ash Part by Weight	Sand Part by Weight	Water Part by Weight	21 Days Average Strength (N/cm^2)	28 Days Average Strength (N/cm^2)	35 Days Average Strength (N/cm^2)
Control	0.09	0.10	2.75	0.485	1718	1820	1840
1	0.09	0.10	2.75	0.535	1524	1611	1710
2	0.09	0.10	2.75	0.435	1705	1909	1970
3	0.09	0.10	2.75	0.385	1978	2016	2309

Appendix 6-C

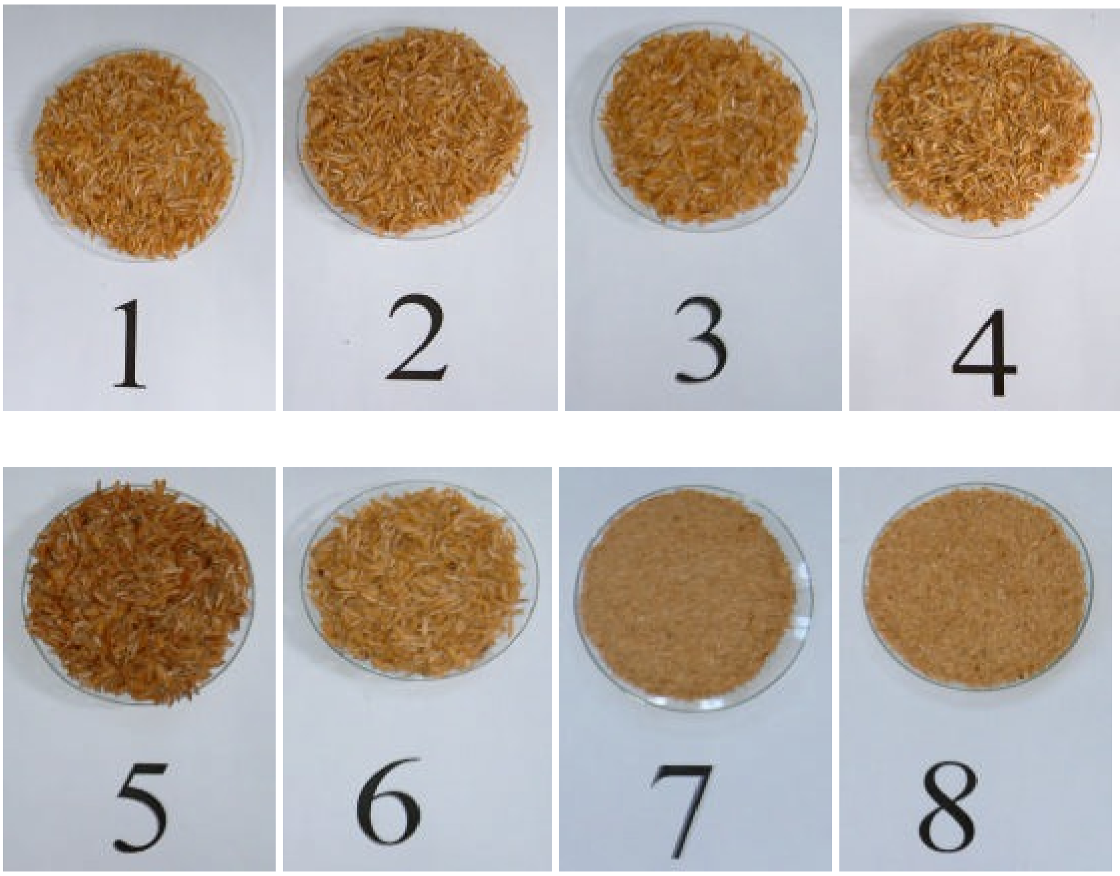


Figure 1. Photographs of Rice Husk Samples from Bangladesh

Appendix 6-C

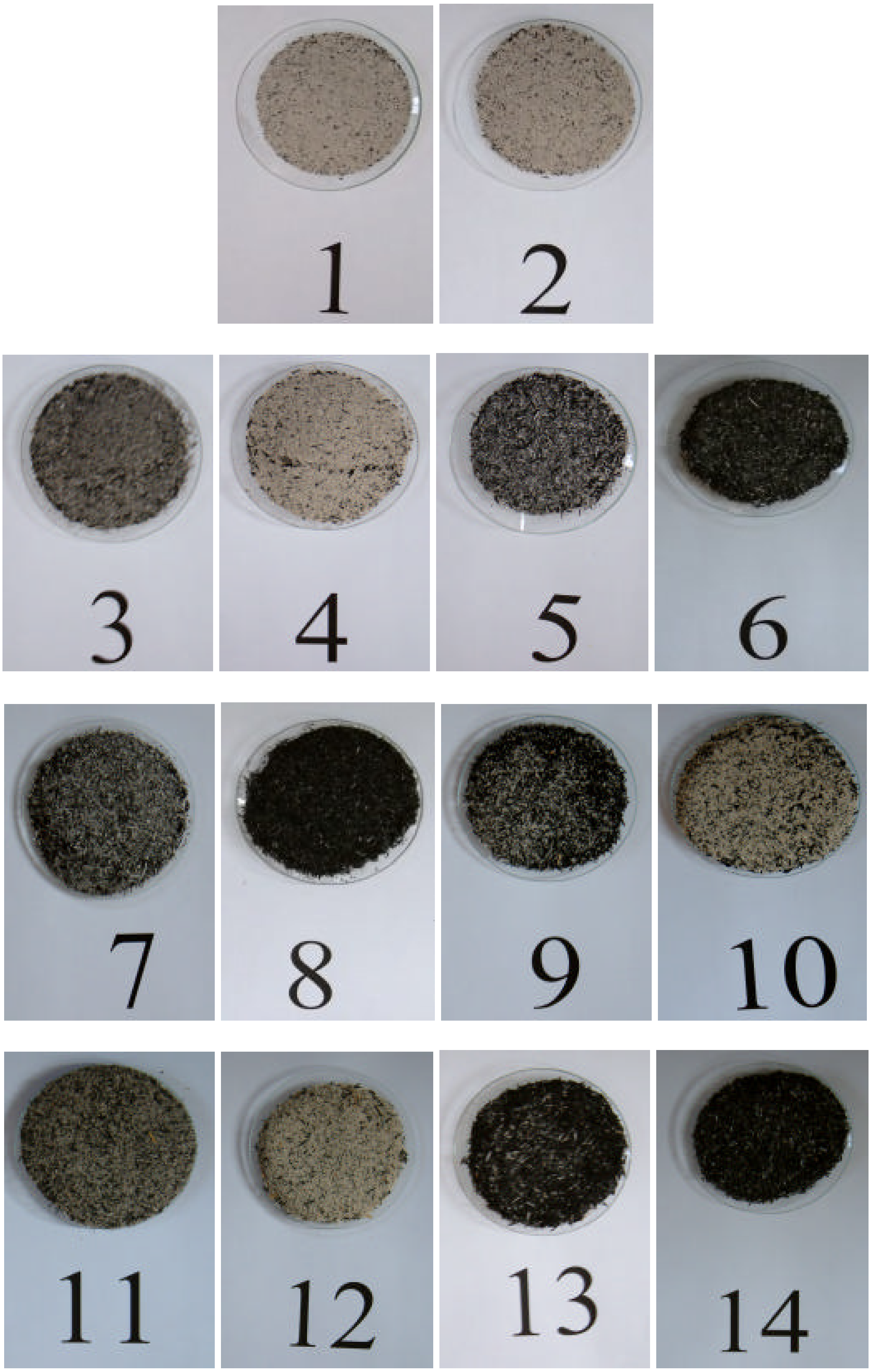


Figure 2. Photographs of Rice Husk Ash Samples from Bangladesh

Appendix 6-C

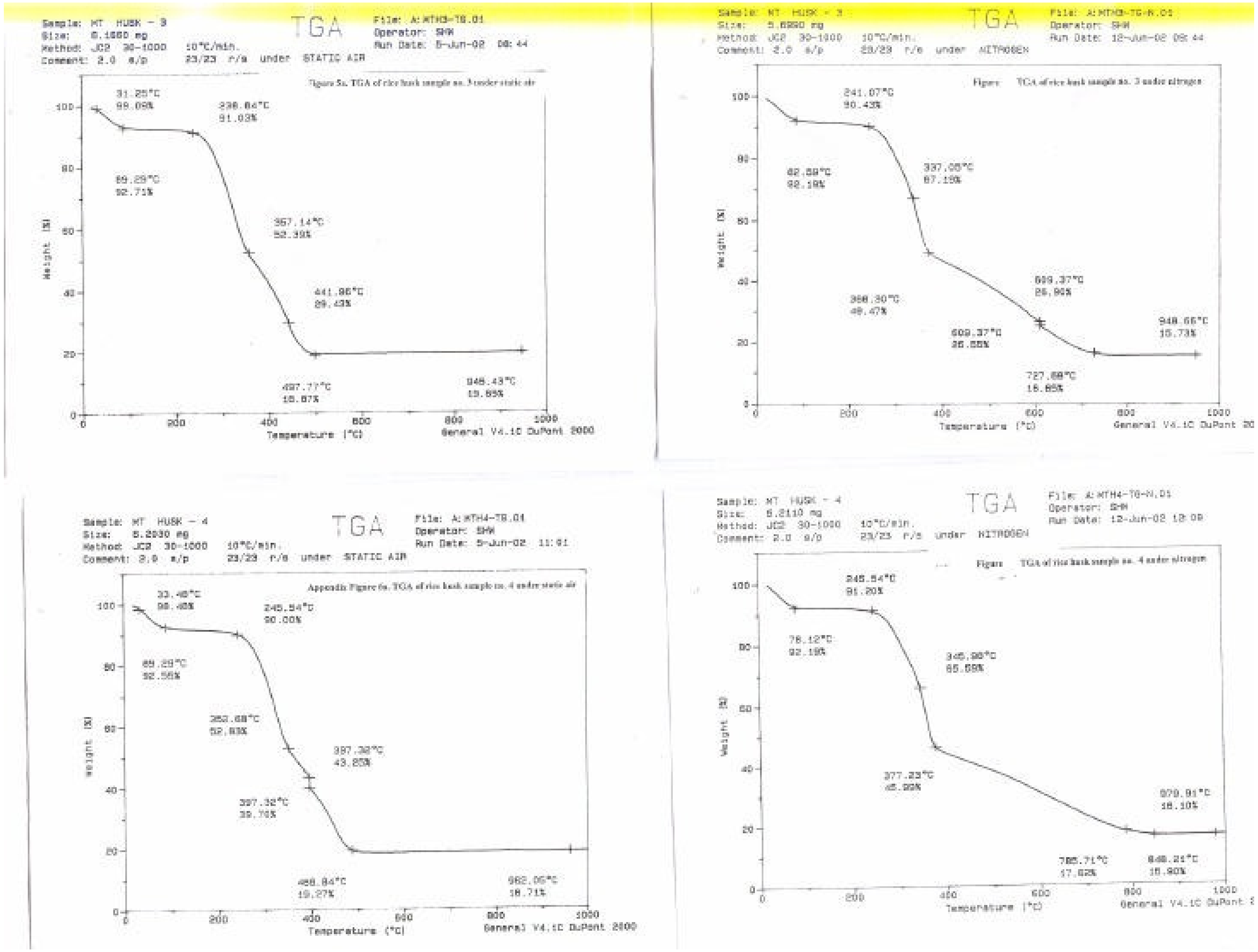


Figure 3. TGA Patterns of Husk Samples from Old Furnace

Appendix 6-C

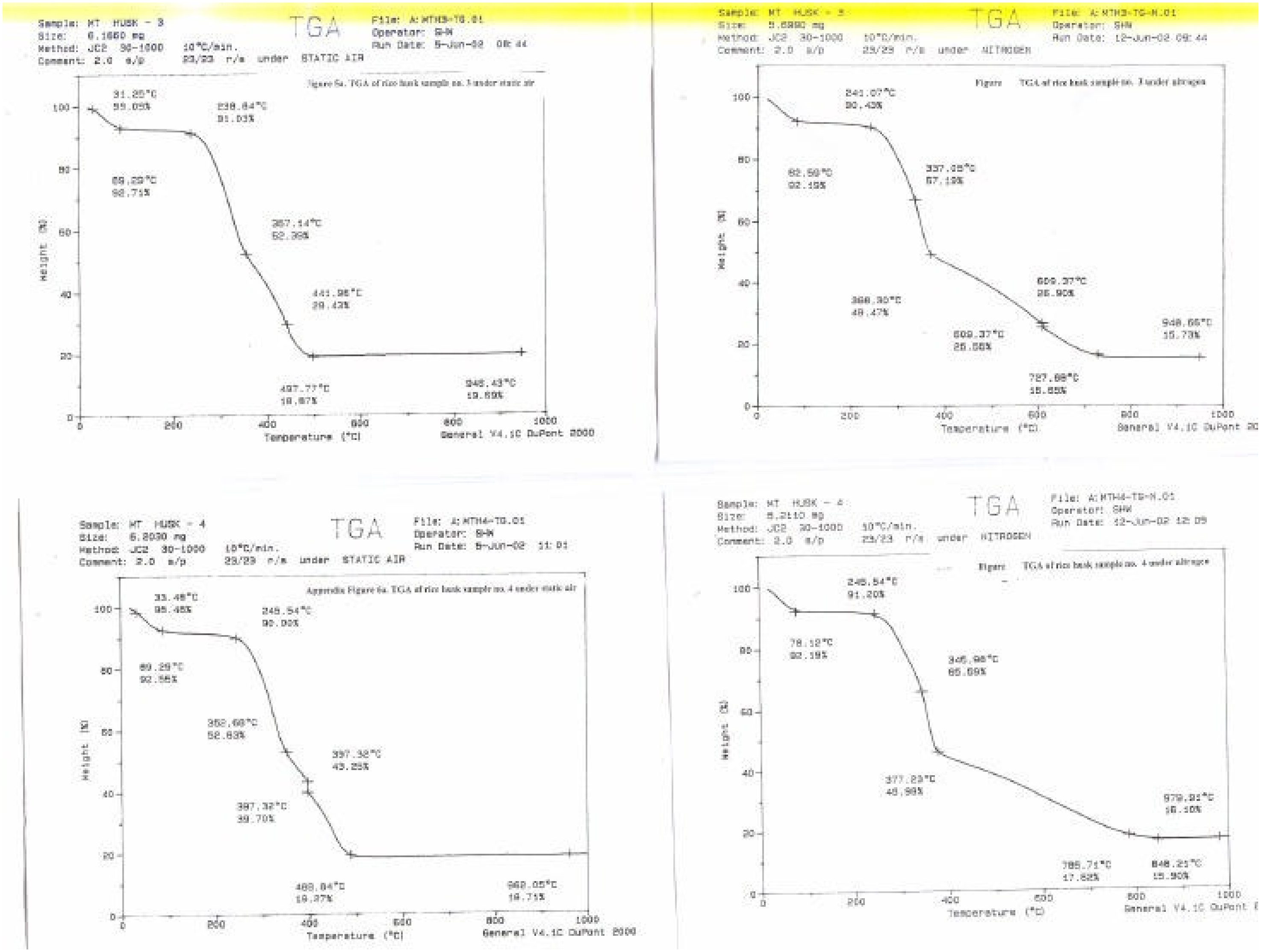


Figure 3. (continued)

Appendix 6-C

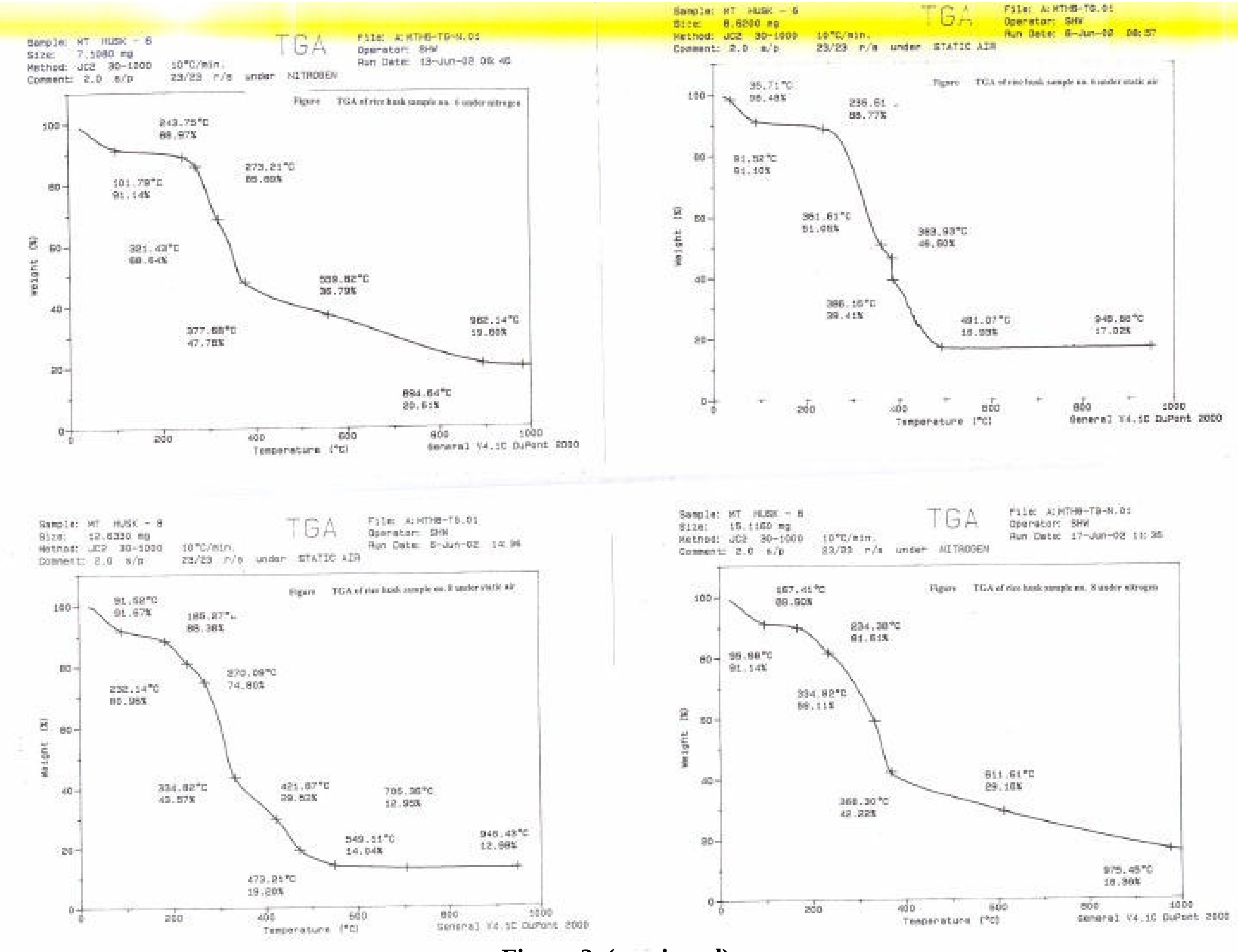


Figure 3. (continued)

Appendix 6-C

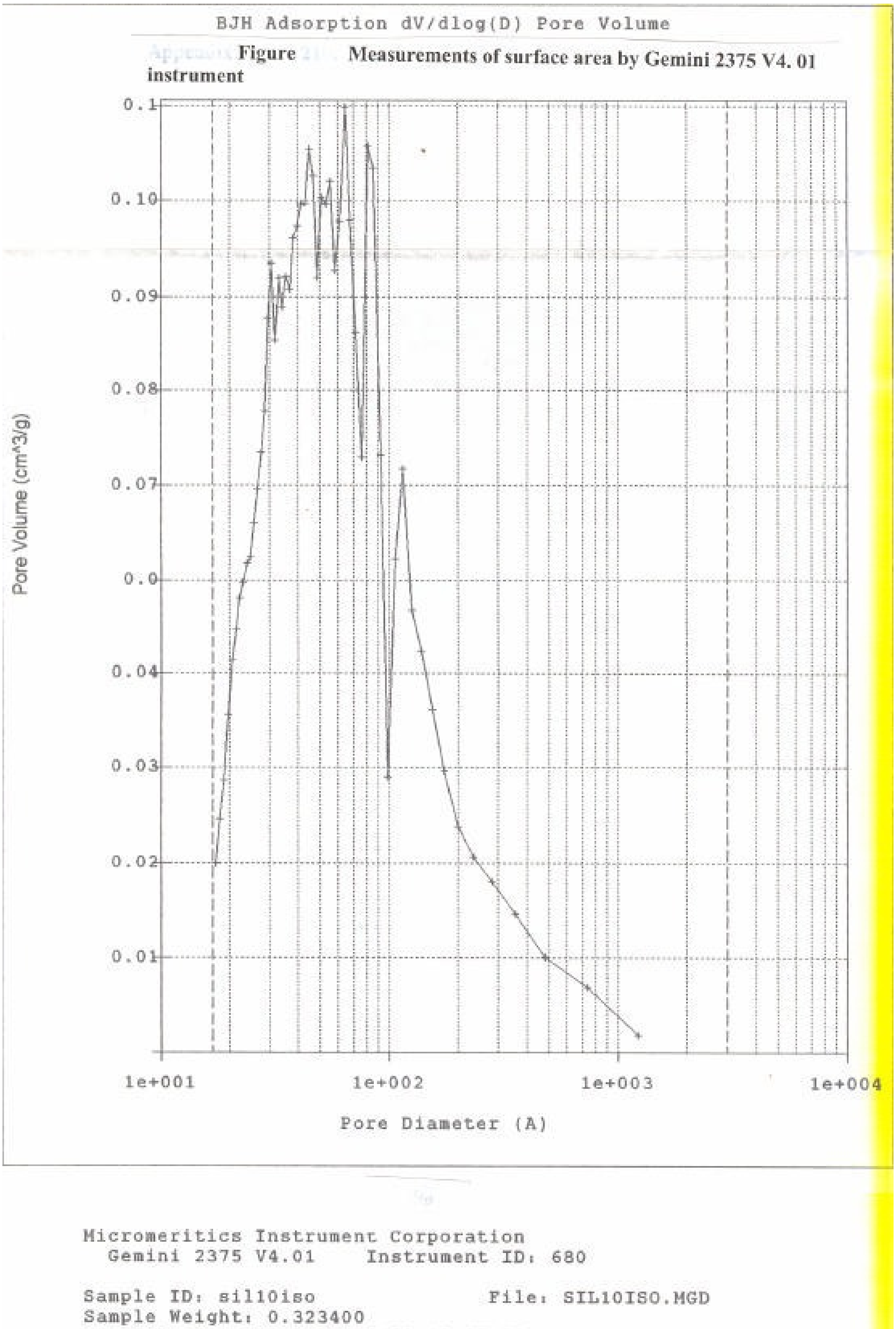


Figure 4. Surface Area Measurement of RHA Sample from Old Furnace

Appendix 6-C

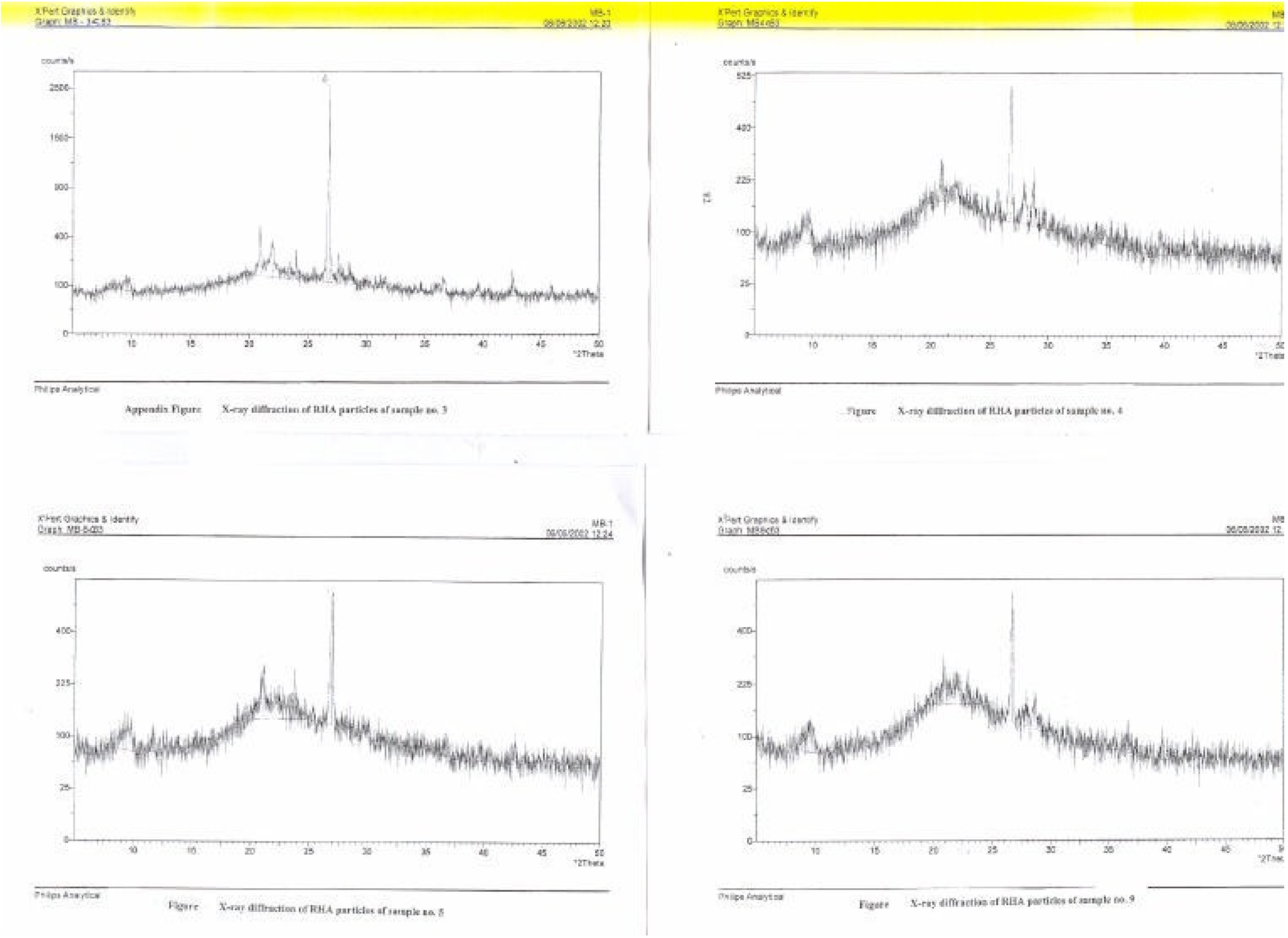
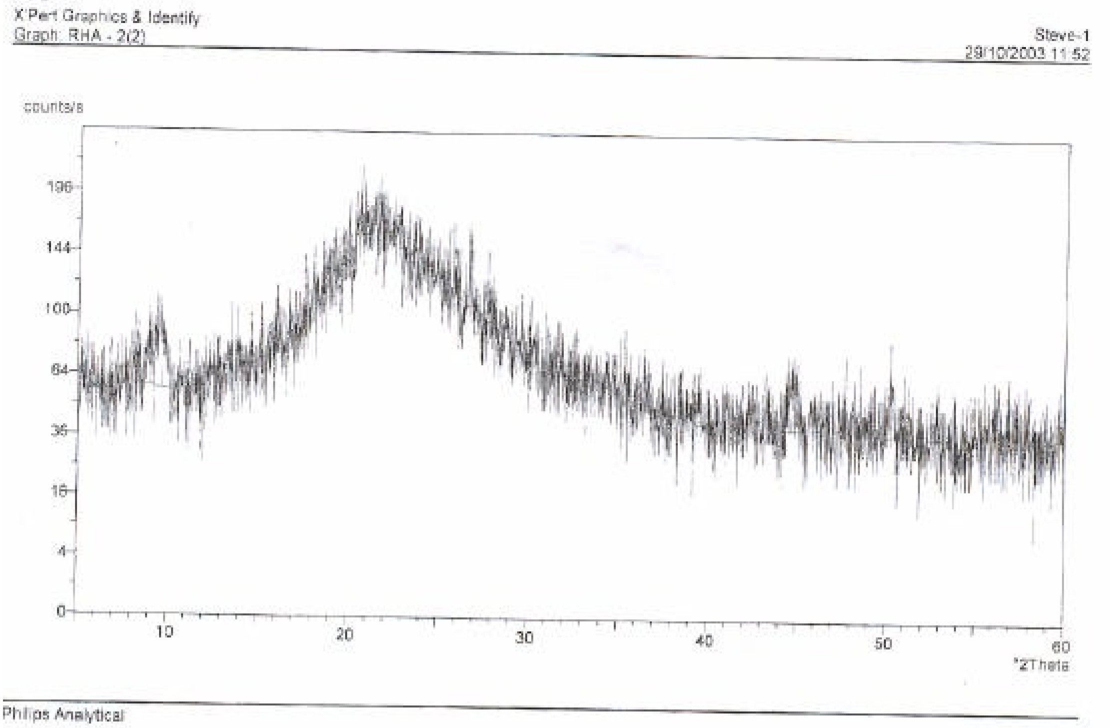


Figure 5. X-ray Diffraction Patterns of RHA from Old Furnace

Appendix 6-C



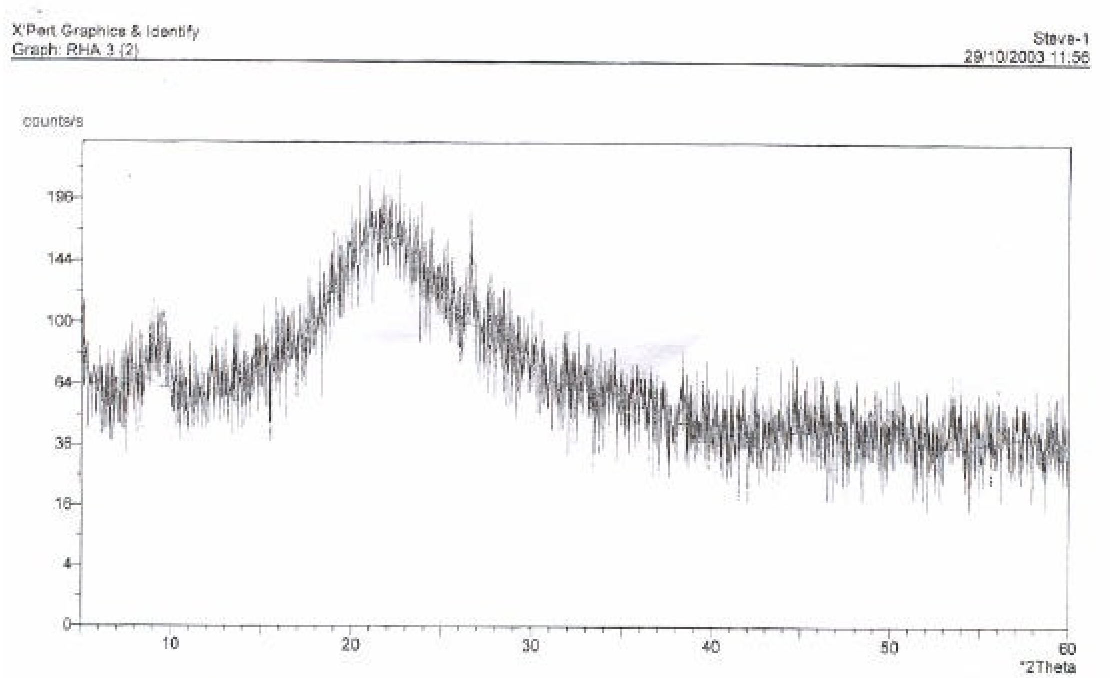
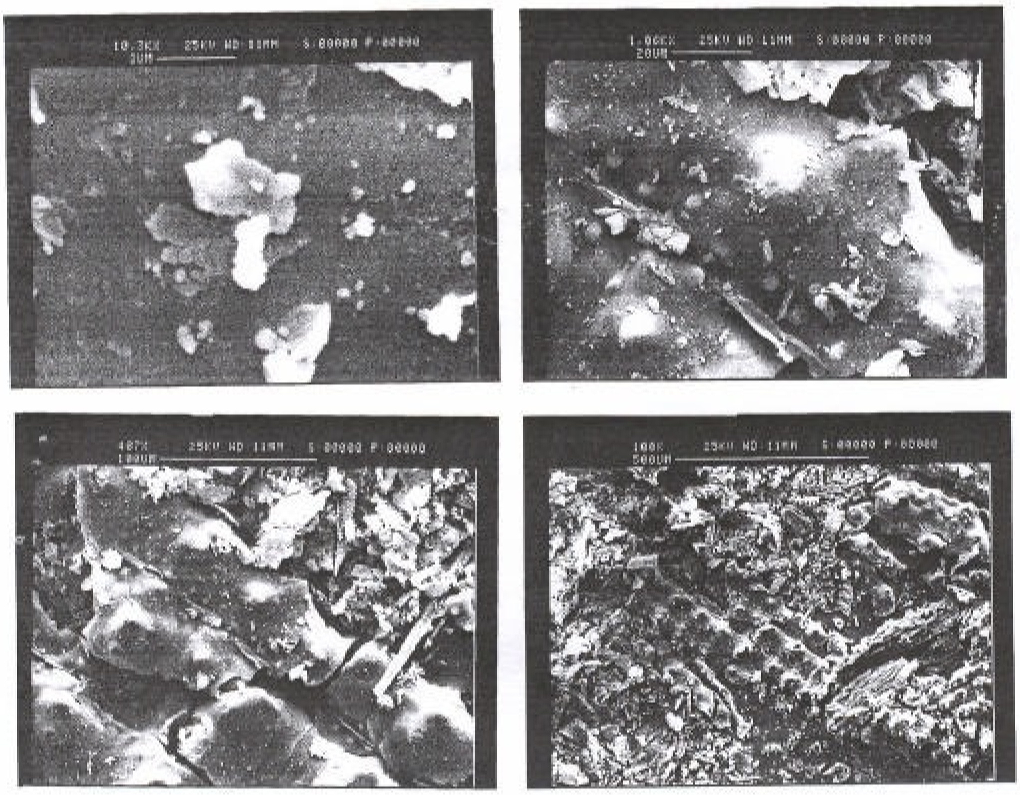
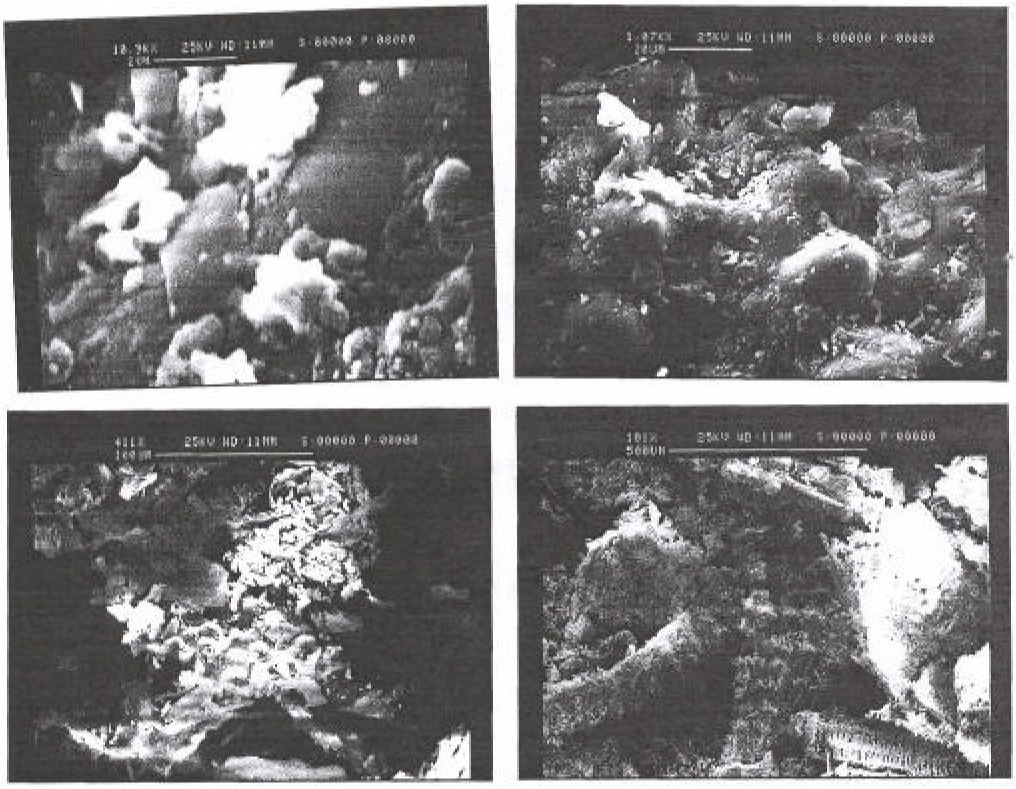


Figure 6. X-ray Diffraction Patterns of RHA Samples from New Furnace

Appendix 6-C



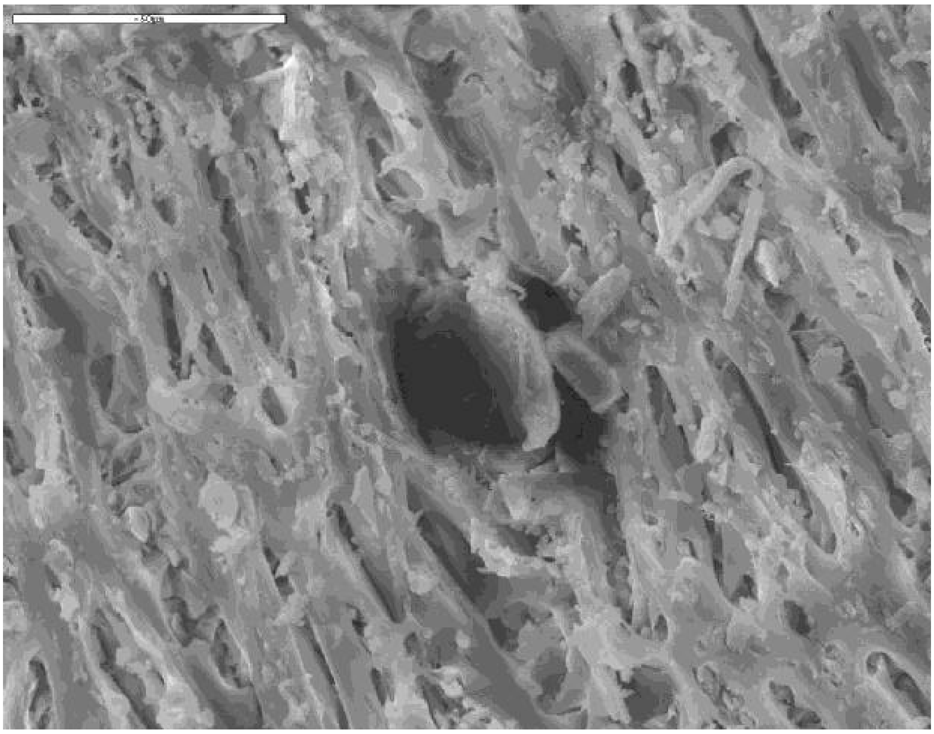
Sample No. 2



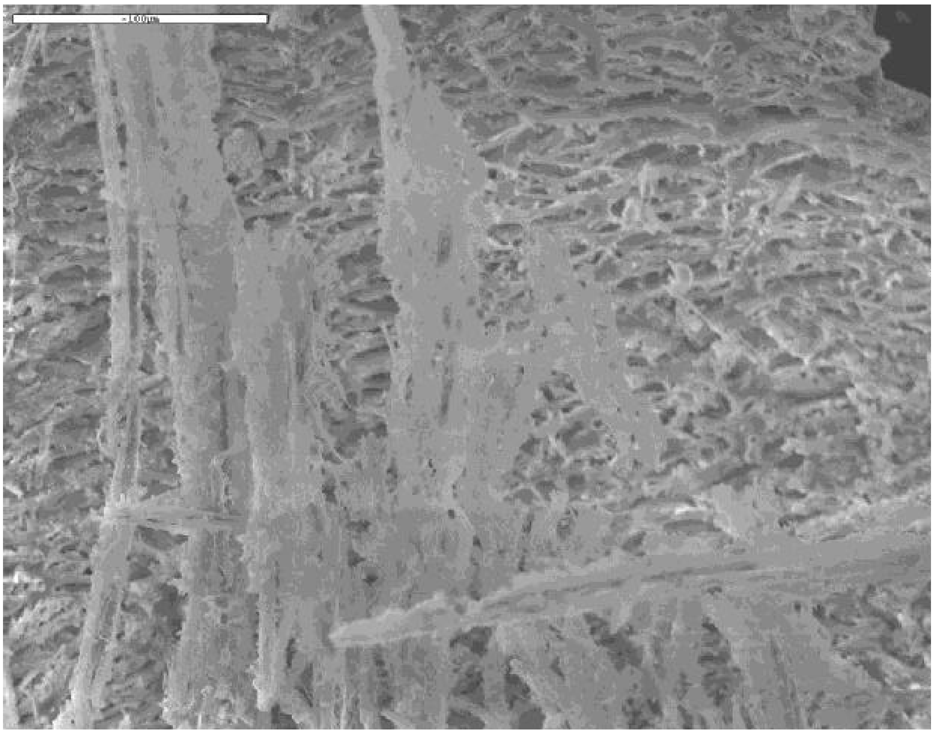
Sample No. 3

Figure 7. SEM Pictures of RHA Samples from New Furnace (showing less porous structure)

Appendix 6-C



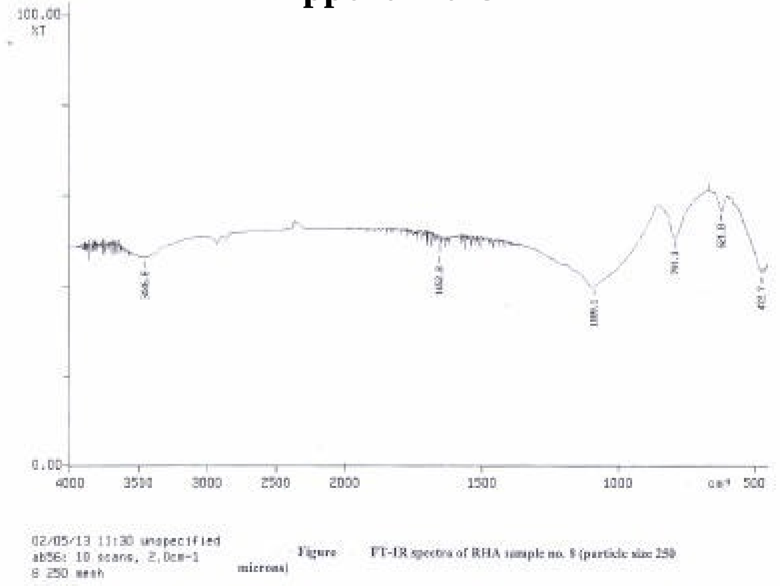
a.

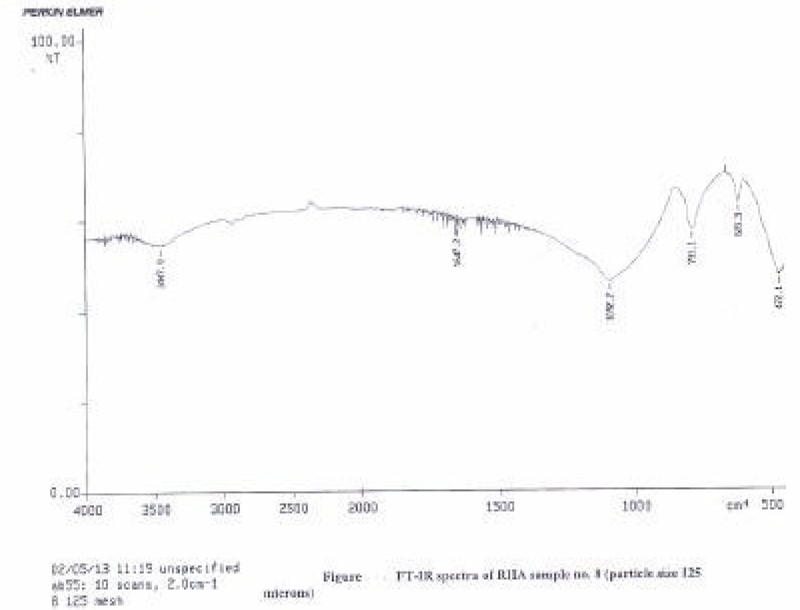


b.

Figure 8. SEM Pictures of RHA Particles of Samples from Old Furnace (a. Sample No. 1; b. Sample No. 10) (showing porous structure)

Appendix 6-C





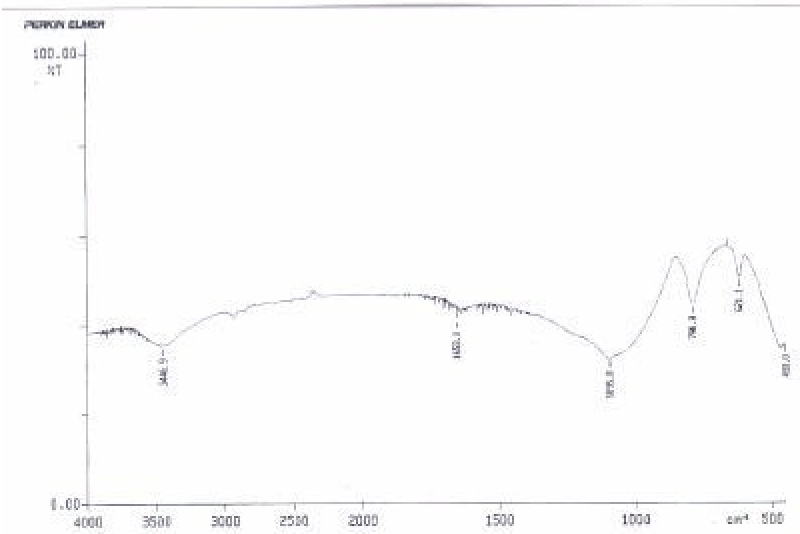
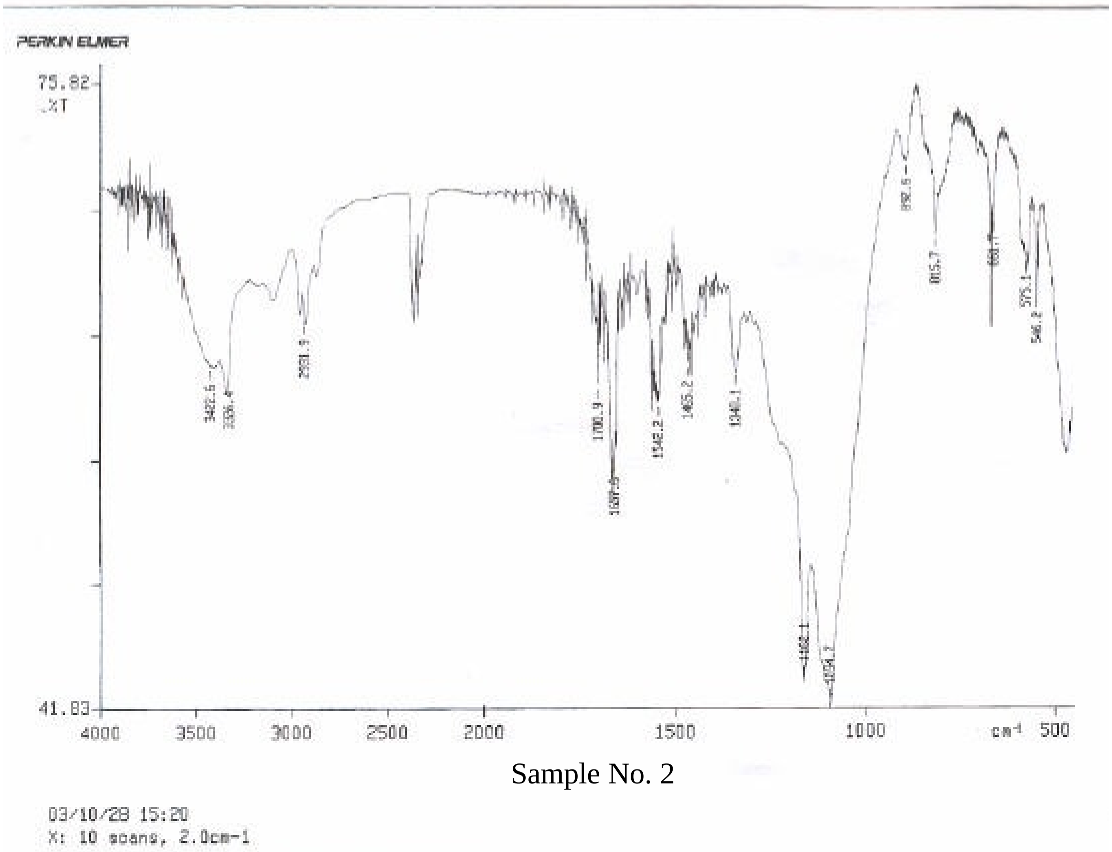
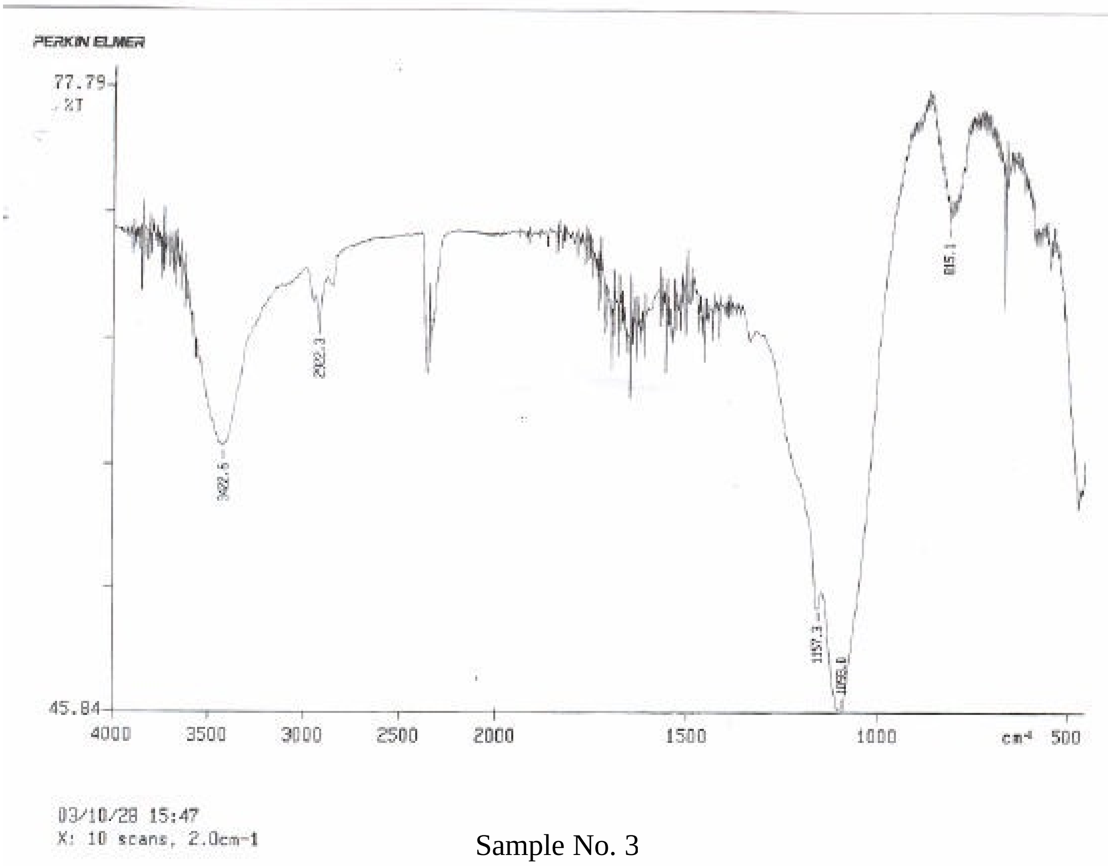


Figure 9. RHA Sample no. 8 from Old Furnace Showing Spectra at 3400, 1600, 1100, 800, 600 and 450cm^{-1}

Appendix 6-C



Sample No. 2



Sample No. 3

Figure 10. RHA Samples from New Furnace Showing Spectra at 3400, 1600, 1100 and 800cm^{-1}

Appendix 7A-7D
Information on Dissemination Activities in Bangladesh

Appendix 7-A

Natural Resources Institute

Dissemination Workshop For Rice Mill Owners and Technicians
Benefits of Improved Rice Husk Combustion Efficiency

teri

25 June 2003

Programme

BRRI

Venue : BRRI Conference Room, Gazipur

Time	Description
9.00	Registration
	Opening Session
9.30	Recitation from the holy Qu'ran
9.35	Welcome address by Dr. M. A. Baqui, Principal Investigator
9.45	Address by Project Leader: Dr. Nandini Dasgupta
10.00	Address by Special Guest: Director Administration, BRRI
10.10	Inaugural address by Chief Guest: Director General, BRRI,
10.20	Address by Chairman: Director Research, BRRI
10.30	**Tea Break**
	Technical Session
	Chairman : Prof. Dr. M Akhteruzzaman
10.50	Video presentation with explanations?
	Mr. P Raman "Comparative Performance of Improve and Conversional Rice Parboiling System".
12.00	Site Visit
	Guide: Mr. M Ahiduzzaman and Mr Raman
13.00	**Lunch and Prayer**
14.00	Dr. M A Baqui "Benefits and dissemination of new improve furnace and steam vessel".
14.30	**Discussions**
15.00	Summing up and recommendations from the industry.
15.30	**Tea**

Appendix 7-A

Natural Resources Institute

teri

National Seminar on

Benefits of Improved Rice Husk Combustion Efficiency”

26 June 2003

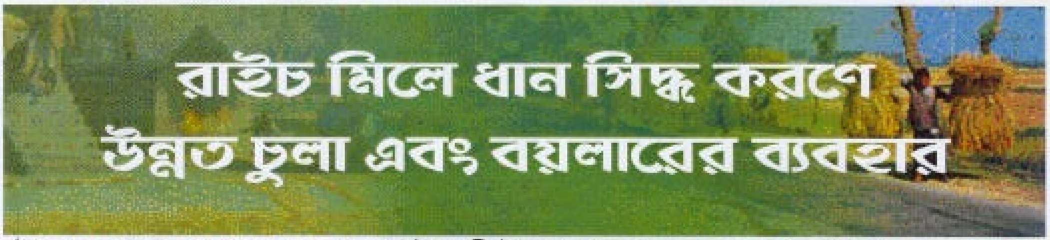
Programme

BRRI

Venue : Conference Room BRRI, Gazipur

Time	Description
9.00	Registration **Opening Session**
9.30	Recitation from the holy Qu’ran
9.35	Address by Chairman: Director Research, BRRI
9.40	Dr. Nandini Dasgupta, Project Leader: Background to Project and Methodology
9.55	Keynote paper by Dr. M A Baqui, Principal Investigator “Benefits of Improved Rice Processing Technologies”
10.30	**Discussions** Led by Prof. Dr. R. I. Sarker and Prof Dr. M A Rashid Sarker
11:00	**Tea Break**
	Technical Session
	Chairman : Prof. Dr. S. M. Farouk, Former Vice Chancellor, BAU
	Presentations
11.20 11.35	“Present status of Conventional Rice Parboiling Units of Bangladesh” by- Mr. M Ahiduzzaman "Concept, Design and Performance of an Improved Furnace and Steam Vessel" by - Mr. P Raman
11.55	“Efficient Biomass Conversion Technologies and Briquetting” by- Mr. Sunil Dhingra.
12.10	“Characterisation of Rice Husk Ash (RHA) for alternate uses” by- Dr. M. A. Baqui
12.30	Discussion
13.00	**Lunch and Prayer**
14.00	Chairman: Dr. M A Mazed, Member Director, BARC
	Project Conclusions and Recommendtions: Dr. Nandini Dasgupta
14.30	Summing Up by Dr M. A. Mazed
15.30	**Tea**

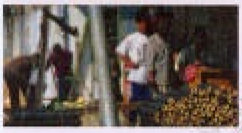
Appendix 7-B



উন্নত চুলা এবং বয়লারের বৈশিষ্ট্য সমূহঃ

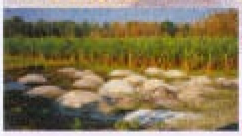
- জ্বালানী দক্ষতা বেশী এবং দূষণের মাত্রা কম।
- প্রচলিত চুলার মতই এ চুলা জ্বালিয়ে এক ঘন্টার মধ্যে বয়লারে বাষ্প তৈরী করা যায়।

- এ চুলা ব্যবহার করলে পরিস্কার এবং বিপদমুক্ত পরিবেশে আরামে কাজ করা যায়।
- সমপরিমাণ বাষ্প তৈরী করতে প্রচলিত চুলার চেয়ে এ চুলায় প্রায় অর্ধেক তুষ লাগে এবং এ চুলা ব্যবহার করে প্রচলিত পদ্ধতির চেয়ে প্রায় অর্ধেক সময়ে ধান সিদ্ধ করা যায়।



- কুড়া বিহীন তুষ দিয়েও এ চুলা জ্বালানো যায়।

- এ চুলা ব্যবহারের ফলে জ্বালানী তুষ সাশ্রয় হবে এবং সাশ্রয়কৃত তুষ দিয়ে তুষের লাকড়ী (চারকোল) তৈরী করা যাবে, যা জ্বালানী কাঠের পরিবর্তে ব্যবহার করা যায়। এ ছাড়া গ্যাসিফিকেশনের কাজেও তুষের লাকড়ী ব্যবহার করা যাবে।
- স্থানীয় মিস্ত্রিগণ প্রশিক্ষণের মাধ্যমে সহজেই এ চুলা তৈরী করতে পারবেন।
- প্রচলিত পদ্ধতির চেয়ে এ চুলায় জ্বালানী নিক্ষেপের হার কম বিধায় চুলা জ্বালানো আরামদায়ক।



- কোন কারণে বাষ্পের উচ্চচাপ সৃষ্টি হলে বয়লারের সেফটি ভাল্ব স্বয়ংক্রিয় ভাবে খুলে যায় বিধায় এটা চালানো নিরাপদ।
- এ উন্নত চুলা একটি বাস্তব সম্মত এবং অর্থনৈতিকভাবে লাভজনক প্রযুক্তি।

প্রকল্পের নামঃ ধানের তুষের জ্বালানী দক্ষতা উন্নয়নে সুবিধা

অর্থায়নে	ঃ ডিএফআইডি, যুক্তরাজ্য
বাস্তবায়নে	ঃ বাংলাদেশ ধান গবেষণা ইনস্টিটিউট ন্যাচারাল রিসোর্সেস ইনস্টিটিউট, যুক্তরাজ্য
প্রকল্প মেয়াদ	ঃ ২০০১-২০০৩

Natural Resource Institute

BENEFITS OF IMPROVED RICE HUSK COMBUSTION

Funded by DFID's Knowledge and Research Programme
Project Duration: October 2000 to December 2003
Programme Managed by NRI, UK, in Collaboration with BRRI and The Energy & Research Institute, (TERI) India.

Background

90% of the rice produced in Bangladesh is parboiled. The small rice parboiling and milling units produce a vast amount of rice-husk and bran mixture as a by-product and rice-husk ash as a waste product. There is very inefficient use and disposal of these materials. This project aimed to increase the efficiency of use of these products. There are three components to this project.

I Improving the rice-husk combustion efficiency

A majority of mills use the rice-husk and bran mixture as fuel to generate steam to parboil rice. The combustion efficiency of the furnace is very low leading to wastage of rice-husk and bran mixture. The mixture is used as animal feed. The growth in the poultry industry and the rising price of this mixture is making it difficult for poor households to afford it.

The First objective

of the project is to improve the furnace design and increase the efficiency by at least 15% to save the rice-husk and bran mixture. To enhance the scope of uptake, the project aimed to keep the costs low and affordable. Increasing the combustion efficiency would increase the profitability of the mills, improve the working conditions for workers and increase the supply of animal feed for poor households.

II Reducing the cost of making briquettes from husk of parboiled rice.

Paddy in Sylhet and Chittagong is dry hulled and the husk made into briquettes, which is a clean and efficient fuel. Poor household and small, street-food retailing units in these districts have shifted to briquettes from firewood. Only a small amount of rice husk from parboiled rice is used for briquetting, This is primarily because the wear and tear of the screw used in the extrusion process is high, giving a screw life of about three hours, which is not cost effective.

The Second Objective

of this project is to improve the screw life so that it is economically feasible to make briquettes with rice-husk from parboiled rice. This would make a clean and affordable fuel more accessible for the poor.

III Assessing alternative uses of Rice Husk Ash (RHA) in low strength construction

Rice mills through out Bangladesh dump the ash on surrounding agricultural land. RHA is being used with Portland cement in many countries. However, the ratio of the mix and the strength will vary with the specific characteristics of the RHA.

The Third Objective

is to assess alternative uses of Rice Husk Ash in construction.

THE PROJECT OUTCOMES ARE PRESENTED ON REVERSE PAGE

DFID Department for International Development

teri

Project Team:
Project Leader: Dr. Nandini Dasgupta, Natural Resources Institute, University of Greenwich
Bangladesh Rice Research Institute: Dr. Abdul Baqui and Mr Ahiduzzaman
The Energy and Research Institute: Mr Sunil Dhingra and Mr P. Raman

Output 1

Conventional and Improved Furnace – A comparison

S.No	Component	Unit	Conventional Furnace	Improved Furnace
1.	Ambient	°C	27	26
2.	Flue gas temperature	°C	720	440
3.	0_2 content	%	Nil	4.5
4.	CO content	ppm	>10000	3300
5.	Steam pressure	Kg/Cm²	0.5	1.0
6.	Efficiency	%	20	42*
7.	Processing duration	Minutes	13	6
8.	Cost	Tk	95,000	64,000

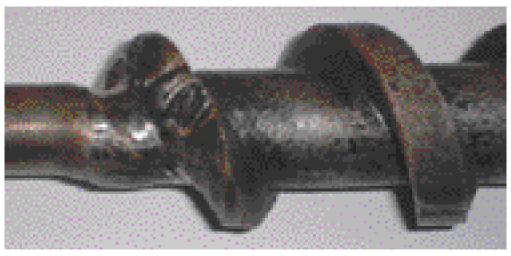
***Project aim was to increase efficiency by 15%.**

Salient Features of the Improved Furnace

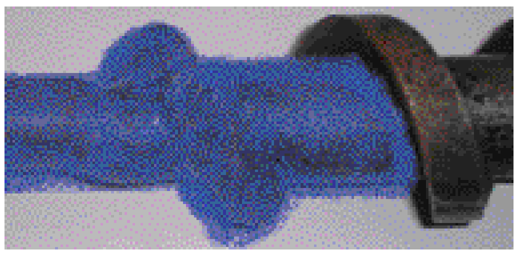
* Higher efficiency and low pollution
* 50% saving in Rice Husk
* Saved rice husk can be made into briquettes
* Cheaper and more efficient
* Local *mistries* can be trained
* Clean and safe working conditions
* Furnace operated with husk only
* Briquettes can replace fuel wood
* 50% reduction in processing time
* Lower feed rate reduces pressure on furnace operator

Output 2

Different screw materials are being used to reduce screw wear. These are (i) die steel with satellite coating; and (ii) material EN9 hardened and tempered with Titanium carbide.



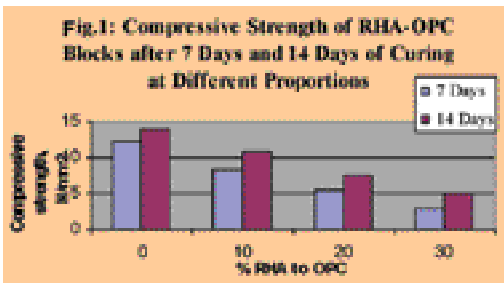
Deteriorated part of the screw

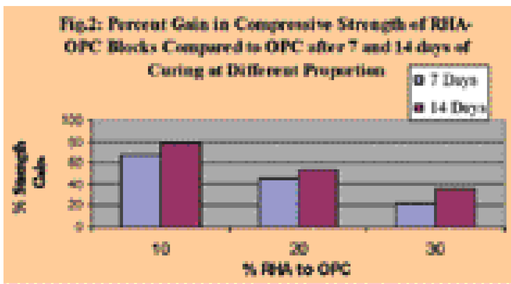


EN9 Hardened and tempered with Titanium carbide

Output 3

Test Results of Rice Husk Ash (RHA) in Combination with Ordinary Portland Cement (OPC)





The tests in this study indicate that a proportion of 10% RHA to 90% OPC, cured for 14 days gives sufficient compressive strength for it to be used in low strength construction.

THE QUEEN'S ANNIVERSARY PRIZES
2000 & 2002

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Appendix 7-D

Bangladesh
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	20,821,010	22,556,290	26,777,900	26,398,500	28,182,800
Harvested area (ha)	10,308,930	10,398,170	10,435,340	9,951,700	10,000,000
IRR (%)	12.2	15.5	22	27.1	-
RFL (%)	66.9	57.5	47	49.2	-
UPL (%)	8.7	8.7	8	8.4	-
Others (%)	11.2	18.3	23	15.3	-
Yield (kg/ha)	2019.7	2169.3	2566.1	2652.7	2790.3
Import (tons)	548,090	677,323	380,062	1,566,000	-
Export (tons)	0	0	0	84	-
Consumption (kg/per/yr)	202.2	-	233.6	219.4	-
OTHERS					
Population (1000)	88,221	99,310	109,765	118,229	-
Arable Land (1000Ha)	8,892	8,860	9,486	8,480	-
Irrigated Land (1000Ha)	1,569	2,073	2,936	3,305	-
Agricultural tractors (No.)	4,200	4,900	5,200	5,300	-

Bhutan
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	56,600	62,000	43,000	50,000	50,000
Harvested area (ha)	28,300	32,000	26,000	30,000	30,000
IRR (%)	49.5	50	50	50	-
RFL (%)	3.5	4.7	3.8	5	-
UPL (%)	4.6	4.7	3.8	5	-
Others (%)	42.4	40.6	42.3	40	-
Yield (kg/ha)	2000	1937.5	1653.8	1666.7	1666.7
Import (tons)	2500	10,000	19,433	26,973	-
Export (tons)	0	0	0	5	-
OTHERS					
Population (1000)	1,292	1,451	1,645	1,770	-
Arable Land (1000Ha)	104	110	113	130	-
Irrigated Land (1000Ha)	26	30	39	39	-

Appendix 7-D

Cambodia
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	1,717,000	1,812,000	2,500,000	3,300,000	3,414,917
Harvested area (ha)	1,346,000	1,345,000	1,740,000	1,924,040	1,950,000
IRR (%)	3.4	8	8	8	-
RFL (%)	54.2	58.8	48	58.4	-
UPL (%)	2.1	2.2	2	1.7	-
Others (%)	11.2	18.3	23	31.9	-
Yield (kg/ha)	1275.6	1347.2	1436.8	1715.1	1738.6
Import (tons)	138,500	55,000	25,800	81,000	-
Export (tons)	0	3,935	0	0	-
Consumption (kg/per/yr)	209.3	-	249.2	244.6	-
OTHERS					
Population (1000)	6,498	7,422	8,695	10,024	-
Arable Land (1000Ha)	2,000	2,300	3,700	3,719	-
Irrigated Land (1000Ha)	100	130	160	173	-
Agricultural tractors (No.)	1,233	1,233	1,200	1,190	-
Harvesters (No.)	20	20	20	20	-

China PR
Basic Statistics

	1980	**1985**	**1990**	**1995**	**1997**
RICE					
Production (tons)	139,910,000	168,596,000	189,331,000	185,226,000	202,701,300
Harvested area (ha)	33,845,010	32,070,000	33,064,700	30,744,000	31,000,000
IRR (%)	92.7	93	93.2	92.5	-
RFL (%)	5	5	5	5.4	-
UPL (%)	2.3	2	1.8	2.1	-
Others (%)	0	0	0	0	-
Yield (kg/ha)	4133.8	5256.3	5726.1	6024.8	6290.3
Import (tons)	131,000	213,218	62,530	1,645,837	-
Export (tons)	1,376,616	1,045,848	405,381	235,934	-
Consumption (kg/per/yr)	126.1	-	140.4	137.2	-
OTHERS					
Population (1000)	998,877	1,070,175	1,155,305	1,220,224	-
Arable Land (1000Ha)	96,937	120,828	123,678	124,061	-
Irrigated Land (1000Ha)	45,467	44,581	47,965	49,857	-
Agricultural tractors (No.)	747,893	861,357	824,106	685,198	-
Harvesters (No.)	27,045	34,573	38,719	90,000	-

Appendix 7-D

India
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	80,312,000	95,817,700	111,517,400	119,442,000	125,263,000
Harvested area (ha)	40,151,500	41,137,200	42,686,610	42,910,000	42,800,000
IRR (%)	40.7	43	45	46	-
RFL (%)	38.9	36.7	34.1	32.6	-
UPL (%)	14.9	14.8	14.7	14.7	-
Others (%)	5.5	5.6	6.2	6.7	-
Yield (kg/ha)	2000.2	2329.2	2612.5	2783.5	2839.1
Import (tons)	4,179	61,100	66,038	52	-
Export (tons)	483,162	315,070	505,027	4,913,156	-
Consumption (kg/per/yr)	89.8	-	114.6	113.6	-
OTHERS					
Population (1000)	688,856	767,940	850,793	929,005	-
Arable Land (1000Ha)	162,955	163,215	163,138	162,500	-
Irrigated Land (1000Ha)	38,478	41,779	45,144	54,000	-
Agricultural tractors (No.)	382,869	607,773	988,070	1,354,864	-
Harvesters (No.)	1,557	2,960	2,950	3,550	-

Indonesia
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	29,651,900	39,032,940	45,178,750	49,744,140	49,253,800
Harvested area (ha)	9,005,065	9,902,293	10,502,360	11,438,760	11,600,000
IRR (%)	58.8	57.6	56.3	53.8	-
RFL (%)	13.4	27.5	29.1	35.1	-
UPL (%)	13.4	27.5	29.1	35.1	-
Others (%)	7.8	7.1	9.9	0.2	-
Yield (kg/ha)	3292.8	3941.8	4301.8	4348.7	4396.6
Import (tons)	2,011,713	33,853	49,577	3,157,700	-
Export (tons)	10,003	258,712	1,911	5	-
Consumption (kg/per/yr)	181.6	-	221	218.8	-
OTHERS					
Population (1000)	150,958	167,332	182,812	197,460	-
Arable Land (1000Ha)	18,000	19,500	20,253	17,130	-
Irrigated Land (1000Ha)	4,301	4,300	4,410	4,580	-
Agricultural tractors (No.)	9,240	12,033	27,955	59,991	-
Harvesters (No.)	14,000	65,524	127,509	300,141	-

Appendix 7-D

LAOS PDR
Basic Statistics

	1980	**1985**	**1990**	**1995**	**1997**
RICE					
Production (tons)	1,053,097	1,395,177	1,491,495	1,417,829	1,660,000
Harvested area (ha)	732,050	663,487	650,300	559,900	553,741
IRR (%)	0.7	0.9	2	7.2	-
RFL (%)	58.3	63.4	56.1	56.9	-
UPL (%)	41	37.2	41.9	35.9	-
Others (%)	0	0	0	0	-
Yield (kg/ha)	1438.6	2102.8	2293.5	2532.3	2552.6
Import (tons)	1,000	6,800	4,240	15,939	-
Export (tons)	0	0	0	0	-
Consumption (kg/per/yr)	263.4	-	253.6	259.2	-
OTHERS					
Population (1000)	3,205	3,594	4,202	4,882	-
Agric. Population (% Population)	-	-	-	-	-
Arable Land (1000Ha)	670	835	810	805	-
Irrigated Land (1000Ha)	115	119	130	177	-
Agricultural tractors (No.)	464	780	870	890	-

Malaysia
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	2,044,604	1,849,003	1,960,000	2,126,000	1,970,000
Harvested area (ha)	716,800	665,000	678,000	681,000	660,000
IRR (%)	58.1	58.2	65.9	65.4	-
RFL (%)	27.9	27.8	20.9	22.3	-
UPL (%)	14	14	12.1	12.3	-
Others (%)	0	0	1	0	-
Yield (kg/ha)	2852.4	2780.5	2890.9	3121.9	3128.8
Import (tons)	167,593	428,017	330,336	427,556	-
Export (tons)	200	2,002	111	2,430	-
Consumption (kg/per/yr)	163.6	-	131.9	132.6	-
OTHERS					
Population (1000)	13,763	15,677	17,891	20,140	-
Arable Land (1000Ha)	1,000	1,280	1,700	1,820	-
Irrigated Land (1000Ha)	320	334	335	340	-
Agricultural tractors (No.)	7,340	12,000	26,000	43,295	-

Appendix 7-D

Myanmar
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	13,317,400	14,317,050	13,969,000	19,568,450	17,673,100
Harvested area (ha)	4,800,900	4,660,800	4,760,000	6,144,400	6,600,000
IRR (%)	18.2	18.4	18.6	18.3	-
RFL (%)	63.1	66.3	70.1	67.8	-
UPL (%)	14.6	11	7	4.1	-
Others (%)	4.2	4.3	4.3	9.8	-
Yield (kg/ha)	2773	3071	2934	3184	3212
Import (tons)	0	0	0	0	-
Export (tons)	653,100	581,500	213,600	353,800	-
Consumption (kg/per/yr)	274.4	-	308.6	314.3	-
OTHERS					
Population (1000)	33,821	37,544	41,354	45,106	-
Arable Land (1000Ha)	9,573	9,593	9,567	9,540	-
Irrigated Land (1000Ha)	999	1,085	1,005	1,555	-
Agricultural tractors (No.)	9,273	10,026	13,000	7,818	-
Harvesters (No.)	2,000	2,500	3,500	7,158	-

Nepal
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	2,464,310	2,804,490	3,502,160	3,578,830	3,640,860
Harvested area (ha)	1,275,520	1,391,040	1,455,170	1,496,790	1,511,000
IRR (%)	15.5	20.9	22.4	22.3	-
RFL (%)	76.6	72.4	71.2	71.1	-
UPL (%)	3.9	3.2	3	3	-
Others (%)	3.9	3.5	3.4	3.6	-
Yield (kg/ha)	1932	2016.1	2406.7	2391	2456
Import (tons)	0	7,412	11,594	42,124	-
Export (tons)	7,315	59,077	0	0	-
Consumption (kg/per/yr)	130.3	-	159.1	117.8	-
OTHERS					
Population (1000)	14,498	16,503	18,772	21,456	-
Arable Land (1000Ha)	2,290	2,289	2,308	2,914	-
Irrigated Land (1000Ha)	520	760	900	885	-
Agricultural tractors (No.)	2,514	2,783	4,400	4,600	-

Appendix 7-D

Pakistan
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	4,684,800	4,378,400	4,891,200	5,920,000	6,546,450
Harvested area (ha)	1,933,100	1,863,200	2,112,700	2,161,800	2,232,000
IRR (%)	100	100	100	100	-
RFL (%)	0	0	0	0	-
UPL (%)	0	0	0	0	-
Others (%)	0	0	0	0	-
Yield (kg/ha)	2423	2349	2315	2738	2880
Import (tons)	3	7	25	68	-
Export (tons)	1,086,641	718,686	743,889	1,852,267	-
Consumption (kg/per/yr)	32	-	28.8	20.5	-
OTHERS					
Population (1000)	85,299	101,196	119,141	136,257	-
Arable Land (1000Ha)	19,994	20,202	20,484	21,034	-
Irrigated Land (1000Ha)	14,680	15,760	16,940	17,200	-
Agricultural tractors (No.)	97,373	156,633	265,728	304,992	-
Harvesters (No.)	500	800	1,500	1,600	-

Philippines
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	7,646,490	8,805,600	9,885,000	10,540,650	11,269,000
Harvested area (ha)	3,459,130	3,402,610	3,318,720	3,758,691	4,035,000
IRR (%)	46.5	54	60.6	62.1	-
RFL (%)	43.4	34.5	35.1	34.7	-
UPL (%)	10.1	11.5	4.4	3.2	-
Others (%)	0	0	0	0	-
Yield (kg/ha)	2210	2587	2978	2804	2891
Import (tons)	3	538,150	592,727	263,275	-
Export (tons)	260,927	58	2	0	-
Consumption (kg/per/yr)	142.5	-	150	135.6	-
OTHERS					
Population (1000)	48,317	54,668	60,779	67,839	-
Arable Land (1000Ha)	4,317	4,550	4,830	5,220	-
Irrigated Land (1000Ha)	1,219	1,440	1,560	1,580	-
Agricultural tractors (No.)	10,533	8,050	10,700	11,500	-
Harvesters (No.)	440	570	660	700	-

Appendix 7-D

Sri Lanka
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	2,133,199	2,661,211	2,538,000	2,809,890	2,239,370
Harvested area (ha)	823,734	864,677	828,246	889,586	660,079
IRR (%)		69.1	57.5	73	-
RFL (%)		24	35.3	27	-
UPL (%)		6.9	7.3	0	-
Others (%)		0	0	0	-
Yield (kg/ha)	2589.7	3077.7	3064.3	3158.6	3953.7
Import (tons)	168,322	176,863	131,771	9,106	-
Export (tons)	15	5	246	43,832	-
Consumption (kg/per/yr)	138.9	-	145.8	130.5	-
OTHERS					
Population (1000)	14,819	16,060	17,057	17,928	-
Arable Land (1000Ha)	855	866	890	886	-
Irrigated Land (1000Ha)	525	583	520	550	-

Thailand
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	17,368,100	20,263,870	17,193,220	21,130,000	22,431,600
Harvested area (ha)	9,200,080	9,833,074	8,791,885	9,019,708	9,175,000
IRR (%)	21.8	24.2	23.5	23	-
RFL (%)	63	58.5	68	75.3	-
UPL (%)	10.9	6.2	0.6	0.4	-
Others (%)	4.3	11.1	7.9	1.3	-
Yield (kg/ha)	1887	2060	1955	2342	2256
Import (tons)	0	0	0	68	-
Export (tons)	2,796,964	4,061,715	4,017,079	6,197,990	-
Consumption (kg/per/yr)	215	-	183.1	175.1	-
OTHERS					
Population (1000)	46,718	51,128	55,580	58,242	-
Arable Land (1000Ha)	16,515	17,693	17,494	17,085	-
Irrigated Land (1000Ha)	3,015	3,822	4,238	4,642	-
Agricultural tractors (No.)	18,000	31,415	57,739	148,841	-
Harvesters (No.)	18,394	29,735	41,876	68,527	-

Appendix 7-D

Vietnam
Basic Statistics

	1980	1985	1990	1995	1997
RICE					
Production (tons)	11,647,400	15,874,800	19,225,100	24,963,700	27,645,800
Harvested area (ha)	5,600,200	5,703,900	6,027,700	6,765,600	7,020,700
IRR (%)	40.2	44	53	54.5	-
RFL (%)	41.1	34.3	28.9	28.9	-
UPL (%)	11.6	8.4	6.6	5.1	-
Others (%)	7.1	13.3	11.5	11.5	-
Yield (kg/ha)	2079	2783	3189	3689	3759
Import (tons)	201,400	336,100	1,900	11,000	-
Export (tons)	33,300	59,400	1,624,000	1,988,000	-
Consumption (kg/per/yr)	198.2	-	230.7	246.6	-
OTHERS					
Population (1000)	53,711	59,898	66,689	73,793	-
Arable Land (1000Ha)	5,940	5,616	5,339	5,509	-
Irrigated Land (1000Ha)	1,542	1,770	1,840	2,000	-
Agricultural tractors (No.)	24,105	31,620	25,086	97,817	-

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