Production of high quality rice husk ash

Title: Production of High Quality Rice Husk Ash

A C Hollingdale and U Kleih

Project A0155

STRUCTURE

INTRODUCTION

1. Rice husk can be utilised for a broad variety of actual and practical industrial purposes. When it is burnt, energy will be released, which may be recovered for heat and power. As the silica content of the husk is high (about 20%), combustion results in a high yield of rice husk ash (RHA) which contains around 95% silica. The objective of NRI's work will be to devise equipment and operational conditions for combustion of rice husks to supply energy for industrial processing but in such a manner as to provide a high grade rice husk ash by-product.

2. This by-product has many technical and commercial opportunities. A few examples are: insulation uses, refractories, reinforcing agents and fillers, fertilisers, filter mediums, silica source, and building material component. Commercial iniatives for use as a building material component are widespread and well documented. Whilst there is a potentially large market for such products they only attract a low market price. Other applications of RHA, many of proved commercial status, demand lower volumes but a tighter specification and therefore have the potential to attract a higher market value.

3. The success of any commercial venture rests largely on the control of the quality of ash produced. Lack of quality control is the main problem with existing combustion systems and even with RHA use in cement, probably the least sensitive to changes in quality, serious control problems exist. The silica is specified in terms of, *inter alia*: carbon content; content of amorphous against crystalline silica; and particle size. Greater control over the combustion process allows closer control over these properties.

4. Moreover, in rice producing countries, disposal of the rice husk is frequently a problem which is often addressed by indiscriminate dumping and pile burning. The full utilization of rice husks would have clear environmental benefits.

5. This report will outline the range of RHA uses. The various thermal processing routes for producing RHA will then be described with a resume of the physical chemistry aspects influencing the properties of the RHA product. Issues relating to the market potential for different applications will be examined and some cost models of selected process routes will be examined to quantify the prospects for commercial initiatives. Recommendations for further work will be made.

POTENTIAL USES OF RHA

6. It is possible to classify the potential uses of RHA in terms of its qualities as unmodified ash and as a silica source for cement, refractory and silica derived chemicals.

Some major potential uses are tabulated in table 1 together with some related direct uses of rice husk in which there is thermal processing or from which chemicals are derived.

Table 1: Potential uses of RHA

Form of Use	Use	Comments
As Ash	Fertilizer Organic use/filler pigment Insect Powder Oil Absorbent Insulant in steel production---->	(Average selling price ($270/tonne for (European market of (600-700 tonnes/yr
As Silica Source for Construction Material	Cement -------->	(Production costs ($30-40/tonne
	Refractory -------->	(> 20,000 tonnes/yrs (market for RHA
For Silica Chemicals	Soap Sodium silicate Active silica Silica sol Silicon tetrachloride Silicon Carbide Silicon nitride Semi-conductors/ metallurgical grade silicon Catalyst Supports	
Thermal Products of Rice Husk	Furfural, xylose Activated carbon	

7. There is need for an updated and more detailed technical study of the range of application for which rice husk can be utilized. However for present purposes the scope will be evident from the information in Annex I which is drawn from an FAO publication (Beagle 1975).

THERMAL PROCESSING ROUTES PRODUCING RHA

8. Techniques for thermal processing of rice husk to derive energy and provide RHA for subsequent use have been reported for many years. However often the need for RHA has not been linked to an energy requirement and various techniques are applied for simple incineration of rice husk to provide RHA. Some key systems described in the

literature are listed below in table 2 and then described in more detail.

Table 2: Thermal Processing Routes to RHA

System	Example (ref)	Capacity
1. Brick Incinerators	see figure 1 (a) Pakistan CSIR, Cement Research Institute of India (Cook 1985)	Batch - typically 1 tonne rice husk per unit/day
	(b) Guyana Institute of Applied Science & Technology, Building Research Establishment, UK (Smith 1989)	Batch - several units for 400kg rice husk per batch linked to give 1/2 ton/day output of RHA
2. Traditional Step Grate Furnaces	see figure 2 (Beagle 1978)	Continuous Range of capacities 0.2 -> 2.0 tonnes per hour of rice husks
3. Fluid Bed	(a) USA Mehta-Pitt (Cook 1985)	Continuous 7.5 tonne rice husk/hr
	(b) India/Australia (Cook 1985)	Continuous 2.0 tonnes rice husk/hr
4. Vortex Gasifier	Thailand Biomass Energy Service Technology (BEST) National Building Technology Centre (NBTC) (Hislop 1991)	Continuous 30 kg rice husk/hr
5. Pyrolysis/steam gasification	Indian Institute of Technology (Grover 1992)	Continuous 6 tonne rice husk/hr
6. Brick Suspension Burner	Sri Lanka/UK Natural Resources Institute (Robinson 1991)	Continuous 180kg rice husk/hr

Brick Incinerators

9. The status of these devices has been detailed through reports (Smith 1989 and Cook 1985). The attached figure 1 illustrates a typical design. Development of these low cost incineration systems has been limited to the use of RHA in

cement production. Through this work the importance of thermal processing techniques upon the physical properties of the ash has been established and although for this application there is some latitude on product quality it has been found necessary to draw-up a specification for RHA masonry cement (see Annex II). RHA for use in cement requires grinding in ball mills and the energy input for this operation is minimised with a high degree of amorphous silica in the ash. The time for milling may vary by a factor of seven and being an energy intensive operation it is a key consideration for process economics of rice husk ash cement production.

10. Incineration of rice husks in this way depends on there being no advantage in recovering energy and will continue to be relevant when rice husk also commands no value. It is known that in India rice husk is now being commercially produced for fuel brickettes (Hollingdale 1987). When there is a local energy demand, combustion processes are relevant and these should be specifically designed to provide ash as a saleable by-product.

Traditional Step-grate boilers

11. Inclined-step grate boilers are the traditional design for rice husk burning. There are various configurations and the range has been fully described (Beagle, 1979). The attached figure 2 from this reference shows a typical installation. In normal use without close control of operation these units burn the husk at high temperature (above say 700°C) under conditions which result in the formation of crystalline ash. In general it appears that the ash from traditional step-grate furnaces does not retain an amorphous characteristic.

Fluid Bed Combustion

12. Fluid bed combustion of rice husk is a technique with intrinsic potential for producing amorphous ash since it enables low combustion temperatures. This route was applied for a large capacity application in USA in 1976 of 7.5 tonne rice husk/hr. Also work on 2 tonne/hr rice husk, fluidized bed, combustion units is reported to have been carried out in India and Australia (Cook 1985).

There may be scope for application of fluid bed combustion at smaller scale than was hitherto adopted. The NRI has been working on a fluid bed combustion and carbonisation test rig for particulate biomass at fuel rates of around 50kg/hr and it is known that large numbers of small fluid bed and combusters have been installed in China (Hollingdale 1990). NRI's work indicates a need to evaluate the scope for a fluid bed combustion system of 1/2 - 1 tonne/hr for application in developing countries. This could be relevant to rice husk combustion as ash of high quality should be produced through use of this technology.

Vortex Gasifiers

13. Renewed emphasis has been placed on biomass thermal gasification in recent years since it can provide a high conversion efficiency route to derive shaft power from the thermal energy of biomass. At lower capacities it can offer cost benefits compared to the traditional route of steam generation linked to steam engines or steam turbines. Technical difficulties in supply of clean gas have restricted the widespread adoption of such technology and where systems have operated, there has been a high level of engine maintenance.

14. In some preliminary collaborative work by Biomass Energy Services and Technology (BEST) and the National Building Technology Centre (NBTC) attempts have been made to generate a consistent amorphous ash from a 30 kg/hr feed rate vortex gasifier. This work has led to the design of a combined gasifier/boiler system which it is hoped will be followed up by pilot plant trials linked to more R & D (Hislop 1991).

Pyrolysis/steam gasification

15. The Indian Institute of Technology have advocated a thermal processing route for conversion of rice husk to process recovery of silica from the ash. The technique proposed is controlled pyrolysis followed by steam gasification of carbon present in char and it is said to be economically attractive at a system capacity of 6 tonne/day rice husk feed with output of 120 kw electrical power and 1 tonne/day silica (Grover 1992).

Brick Suspension Burner

16. The NRI have developed a low cost brick-built suspension burner for rice husks. This work has been carried out in collaboration with the Rice Processing Research and Development Centre, Sri Lanka in trials over the past two years. Two systems were installed; one for industrial application at a commercial rice mill; and another at the RPRDC establishment for R & D work. The rice mill unit operated at 180 kg/hr rice husk feed rate and produced 33 kg/hr of ash (see figure 3). Ash analysis by x-ray diffraction indicated it was amorphous in form though it is recognised that more work would be required to establish design and operation procedures which would ensure a constant ash quality to meet market specification. To date emphasis has been on energy production as there are very good environmental reasons to promote better use of biomass residues for energy. The financial argument for such work will be strengthened by availability of a marketable ash by-product (Robinson, *et al* 1991).

PHYSICAL CHEMISTRY OF RICE HUSK ASH

17. The crystalline properties of silica in rice husk ash are strongly influenced by the temperature of formation and

the duration of heating. There is also evidence that the level of impurities has a strong influence upon change of crystalline structure with temperature. This subject has been comprehensively reviewed in a recent article by James and Rao which is attached as Annex 2. (James J and Subba Roa 1992).

18. The particular amorphous crystalline characteristic of silica in rice husk which derives from its role in plant structure can only be maintained through the combustion process if the temperature of combustion is kept low. Precise temperatures vary but above 500°C it seems some significant degradation will commence. However it appears that even at temperatures of over 1000°C the amorphous structure will be retained provided the ash is quickly cooled. With increasing temperature the silica structure progressively changes into cristobelite, tridymite and quartz crystalline forms.

19. A high degree of amorphous structure of silica is known to give it a high reactivity in terms of its use for cement. The amorphous structure is very porous and has high surface area so this also gives a high activity for chemical treatment and in absorption. In general silica in this condition has far more potential for commercial utilization than mineral sources of silica which are characterised by higher temperature crystalline forms.

PROCESS AND MARKET INFORMATION

Ash Products

20. Some low cost disposal routes exist for ash which offer alternatives to dumping. These are grouped in table 1 and there is some market information available from Gariboldi which describes a commercial use as an insulant in the European Steel industry.

Increased use as an insecticide protectant may arise in view of the failure of contact insecticides. This would be more relevant for small scale and localised warehouses. In general such low value outlets are expected to be opportunistic and site specific and have not been pursued in this study.

Cement

21. Production cost models for lime/RHA cements have been published (Cook 1985). These are for a conceptual 2 tonnes/day system in India with alternative schemes for producing the RHA via (i) controlled pyroprocessing or (ii) from waste RHA derived from parboiling furnaces or heap burning.

At that time, production costs were competitive for cases (i) and (ii) above for standard cement at $60/tonne when the rice husk was costed at a nominal figure of $1/tonne. However it was projected that if the rice husk costs increased due to its use for fuel, as has now happened in some situations, then production costs for these processes would become too high for the product to compete.

Any process developments that might create a consistent high quality amorphous RHA would enhance its prospects for use as a substitute in cement. This market however is likely to remain only marginally attractive and this study has tried to examine the prospects for been higher value markets for RHA.

Refractories

Major Markets for Refractories

22 The following industries are the main end markets for refractories :

- Iron and Steel;
- Cement and other kiln products;
- Glass;
- Non-ferrous metals;
- Ceramics;
- Chemicals and petrochemicals;
- Minor other markets.

By far the most important end market for refractories is the <u>iron and steel industry</u>, which accounted in 1981 for about three-quarters of the total physical consumption of refractory materials on a worldwide basis. The kiln products, glass, and non-ferrous metals industries represent most of the remaining demand for refractory products and will have a smaller but nonetheless important impact. There is a trend towards more advanced refractory products which are of higher quality and which have a longer life.

In the context of a developing country such as Sri Lanka it has to be examined which among the above industries are prevalent in the national economy. It can be assumed that there is a demand for refractory products from the cement, glass, and non-ferrous metals industries.

Commercial Activites

23. Trade information from one major company Refractechnik has indicated that their market is 20,000 t/year RHA for refractory bricks in the cement and steel industry. The process they have was under a patent which has expired. Refractechnik have indicated an interest in NRI's combustion technology. A link-up with an organisation like Refractechnik would be sought in future development work in order to access know-how on material properties, process techniques and applications. Efforts will be made to encourage other commercial interest in a developing country source of RHA.

Contact has been made with Unifurnaces Contracting Ltd., Stourbridge was in order to obtain some information on the production costs of refractory bricks. Mr. Shelton of Unifurnaces showed interest in the project and asked whether NRI could send him a copy of the expired patent of Refratechnik GmbH on which the future production technique might be based. Further discussions are planned.

Sodium Silicate

Market for Sodium Silicate

24. Sodium silicate solutions (water glass) have strong adhesive properties similar to those of organic colloids like gums and resins. The silicate has the advantage of being colourless, odourless, heat resistant and of becoming insoluble. The major uses of sodium silicate are connected with its adhesive, wetting, binding and detergent properties.

Sodium silicate is widely used in the washing soap industry to improve the quality of foaming capacity of soap. It replaces fat and acts as a detergent and decolourising agent. It softens the water by precipitating calcium and magnesium from hard water. Thus, silicate improves the cleaning property of the soap. As long as there is a soap industry, sodium silicate has a market.

In addition, water glass is used to putty glass and china, to conserve foodstuffs such as eggs, to impregnate paper and as a fire resistant paint.

Prices of sodium silicate

25. The following price details are taken from the "Chemical Marketing Reporter" of 9 November 1992:

- Sodium silicate, solid or glass, 3.22 - 3.25 ratio, car or truck load, works, 100lbs., bulk : US$ 20.65 and if in bags : US$ 30.75;

- or with 1.95 - 2.00 ratio, car or truck load, works, 100lbs., bulk : US$ 26.70 and if in bags : US$ 44.30.

- or solution, 41.0 deg. solid, 3.22 - 3.25 ratio, bulk, car or truckload, frt. equald. 100 lbs.: US$ 8.25.

"Ratio" indicates percentage by weight of SiO_2 divided by percentage by weight of Na_2O (see also annex).

Fumed Silica/Precipitated Silicates

26. A number of silica chemical suppliers have been contacted and their trade literature reviewed. Three major traders are:

Company	Product
Degussa	Aerosil (fumed silica) Precipitated silica/silicates
Crosfields	Precipitated silicates
Cabot	CAB O SIL (fumed silica)

A variety of overlapping uses exist for fumed silica and silica/silicate products. An indication of the range of products is given by the information in Annex III. Production of these sophisticated range of products is linked to a detailed technical and market know-how beyond the scope of this exercise. Raw material routes for such products have however been identified and these are silicon tetrachloride which is used for fumed silica and sodium silicate or water glass for precipitated silicates.

The major supplier of sodium silicate to Degussa in Germany is Henkel but prices are not known. Indian workers have analysed low cost routes to sodium silicate from RHA (Andiappan 1981 & Iengar 1981). These schemes relate to low outputs in the region of 1 to 3 tonne/day and it is not clear that they could meet raw material specifications for major users of sodium silicate but the route involved does benefit from the use of amorphous silica. It is therefore of interest in the context of this exercise. A specification for sodium silicate is being sought from Degussa and Henkel.

Other products

27. Other silicon products that have been identified and which could be derived from amorphous rice husk ash are silicon carbide, silicon tetrachloride, silicone nitride, silane, semi-conductor/metallurgical grade silicon and catalyst supports. Each involves particular production techniques which have been ascertained to varying degrees. The use of a high quality amorphous silica is generally advantageous. Detail knowledge of markets or production techniques has not been obtained.

SELECTED OPTIONS/COST MODELS

28. In order to develop an understanding of the benefits that would accrue from a burner that provided a high grade amorphous rice husk ash a series of sample cost models has been examined. The costings all derive from a cost estimate for a 160kg/hr furnace to produce heat and ash. This gives a production cost-base for the RHA.

Production Costs of Rice Husk Ash

30. Tables 1A and 1B in Appendix 1 show detailed production costs of RHA in Sri Lanka. All the information is taken

from "Report on a visit to Sri Lanka to carry out a Techno-economic appraisal of the NRI rice burner in collaboration with the Rice Processing Research and Development Centre. 11 March to 1 April 1991" (Robinson et al,1991).

The results show that the production costs of rice husk ash are considerably lower if a heat production component is included into the project. Without heat production the cost of producing one tonne of ash is S.L. Rupees 1,389 (US$ 31.56) compared to S.L.Rupees 799 (US$ 18.15) if heat production is included.

However, a project which focuses on rice husk ash should not rely on the production of heat. If the ash production depends heavily on the by-product heat the sustainability of the project will not be guarrantied since changes in the demand for the by-product might lead to future management decisions which could stop the ash production.

The price of rice husk ash on the European market is US$ 270 per MT ex mill in 10kg bags and the quantities required by European industry is estimated at 600 to 700 tonnes per month (Garibaldi, August 1991). Thus, the production cost of RHA in Sri Lanka is only about one eighth of the price ex factory in Europe without considering the value of the by-product heat. Clearly quality specification should be examined to establish a full comparison.

Production Costs of Cement

30. The cost estimates in tables 2A,2B and 2C in Appendix 1 for cement production are based on data from "Rice-Husk Ash Cements : their development and applications, UNIDO, Vienna, 1985" (Cook, 1985). The original figures were given in US Dollars which were based on costs in India. The US Dollar figures were converted into Sri Lankan Rupees at the exchange rate of October 1992 which was: US$ 1 = 44.02 S.L Rupees.

The results show that a change in the lime-ash-ratio does not influence the production costs very heavily. The production costs based on a lime-ash-ratio of 1:1 are only 20% higher than the costs based on a ratio of 1:3.

The production cost of one tonne of cement is between US$ 37 and US$ 45 depending on the quality.

In December 1992, one tonne of cement produced in the United Kingdom costs about £ 70 (US$ 108) ex factory. Bags of Indian cement are currently being sold in Sri Lanka at a price equivalent/tonne of £68 (US$ 106).

However, at this point it is difficult to compare prices of European cement to the one produced in Sri Lanka or India since the differences in quality are not known.

Production Costs of Refractory Bricks

32. Only a preliminary assessment of potential cost savings from use of RHA in refractory bricks has been possible. Lanka Refractories have advised that for bricks requiring an imported raw material (typically magnesite) raw material costs would come to around 30% of production costs. The trade list price for magnesite ex-works and supplied bulk in bags is around $400/tonne. This may be compared to the local cost of RHA which is less than one tenth. This suggests that use of local RHA as a substitute for an imported raw material could reduce production costs by 25-30%. Lanka Refractories also advised that they had in fact once made 8000 insulation bricks from local RHA for a contract order.

Further cost models would be developed once necessary information was available.

Production Costs of Sodium Silicate

31. The production costs of sodium silicate shown in table 3 in Appendix 1 are based on data taken from "Manufacture of Sodium Silicate, in: Proceedings of the National Seminar on Utilisation of By-products from Rice Milling Industry, New Delhi 1980" (Andiappan,1981). The method of production described is first of all intended for sodium silicate used for soap making. The 1980 cost details were converted into US-Dollars at the exchange rate of that time and reconverted into Indian Rupees at the rate of mid-1992.

Thus, one tonne of sodium silicate produced in India would cost 3,844 Rupees or US$ 148. According to information taken from "Chemical Marketing Reporter" of November 1992, the price of one tonne of sodium silicate on the international market is between US$ 456 and US$ 589 for product in bulk and US$ 679 and US$ 978 for bagged product depending on the quality. The international price for sodium silicate solution is US$ 182 per tonne.

PROSPECTS FOR PROJECT DEVELOPMENT

Techno-economic Criteria

33. On the basis of this review of the application of RHA it has become evident that the ability to generate RHA with a high level of amorphous structure offers benefits for its use as a raw material in various derived products. The process requirements for such products have been examined and certain products have been identified with potential for production in developing countries. RHA cement, sodium silicate and RHA refractory brick are three such products.

RHA cement does not offer a high value-added use of RHA since the price must be competative with standard cement products. Previous studies on RHA cement have been re-examined and it is concluded that this product is only likely to be profitable at larger scale operations than would apply with the application of the NRI rice husk furnace.

Sodium silicate and RHA refractory bricks are two products to which more attention should be applied. These would sell at higher cost than RHA cement and might be produced more cheaply than comparable products not using RHA as a raw material. Reduced production costs would arise partly from the fact that RHA is an intrinsically cheap material but also from the technical benefits stemming from the amorphous structure.

Opportunities for Collaborative Work

34. Interest has been expressed by the following organisation in some form of collaborative work in this field:

- Rice Processing Research and Development Centre (RPRDC), Sri Lanka
- Indian Institute of Technology, New Delhi
- Forestry Research Institute of Malaysia
- Lanka Refactories, Padukka, Sri Lanka

Contacts have also been established with two European companies with particular interest in RHA refractory brick production. These are :

- Refratechnik Gmbh, Gottingen, Germany
- Unifurnaces Contracting Ltd., Stourbridge, UK

From the study it would appear feasible to propose that RHA derived from the NRI furnace could be the basis for process operations in developing countries to produce sodium silicate and/or RHA refractory bricks. In this situation one attractive route forward would be to seek collaborative funding to examine this prospect further through, for example, the CEC Science and Technology Development Programme.

Funding Proposal for Future Work

A scheme of work has been broadly outlined and costed which would enable the opportunities identified in this desk study to be examined in more depth. This is attached to this report as Appendix 2.

CONCLUSIONS/RECOMMENDATIONS

In view of the market potential for commercial products from RHA there should be further development of a furnace/ combuster that provides energy in association with a high grade RHA.

Experimental work would be focussed on existing design of the brick suspension burner in view of the relative low cost and simple designs which makes it directly applicable to LDCs.

In further financial modelling consideration should be given to (a) the brick suspension burner and (b) the NRI fluid bed combuster in a scaled up design of 1/2 -1 tonne/hr RHA.

Market evaluation for silica production derived from RHA should be extended and commercial collaborative links established with a view to encouraging joint venture operations in LDC's where a degree of added-value production can be anticipated.

Funding requirements for such future work have been outlined. Consideration will be given to integration of this work with the proposals that have been derived for further work on rice husk combustion for combined heat and power systems through Project A0154.

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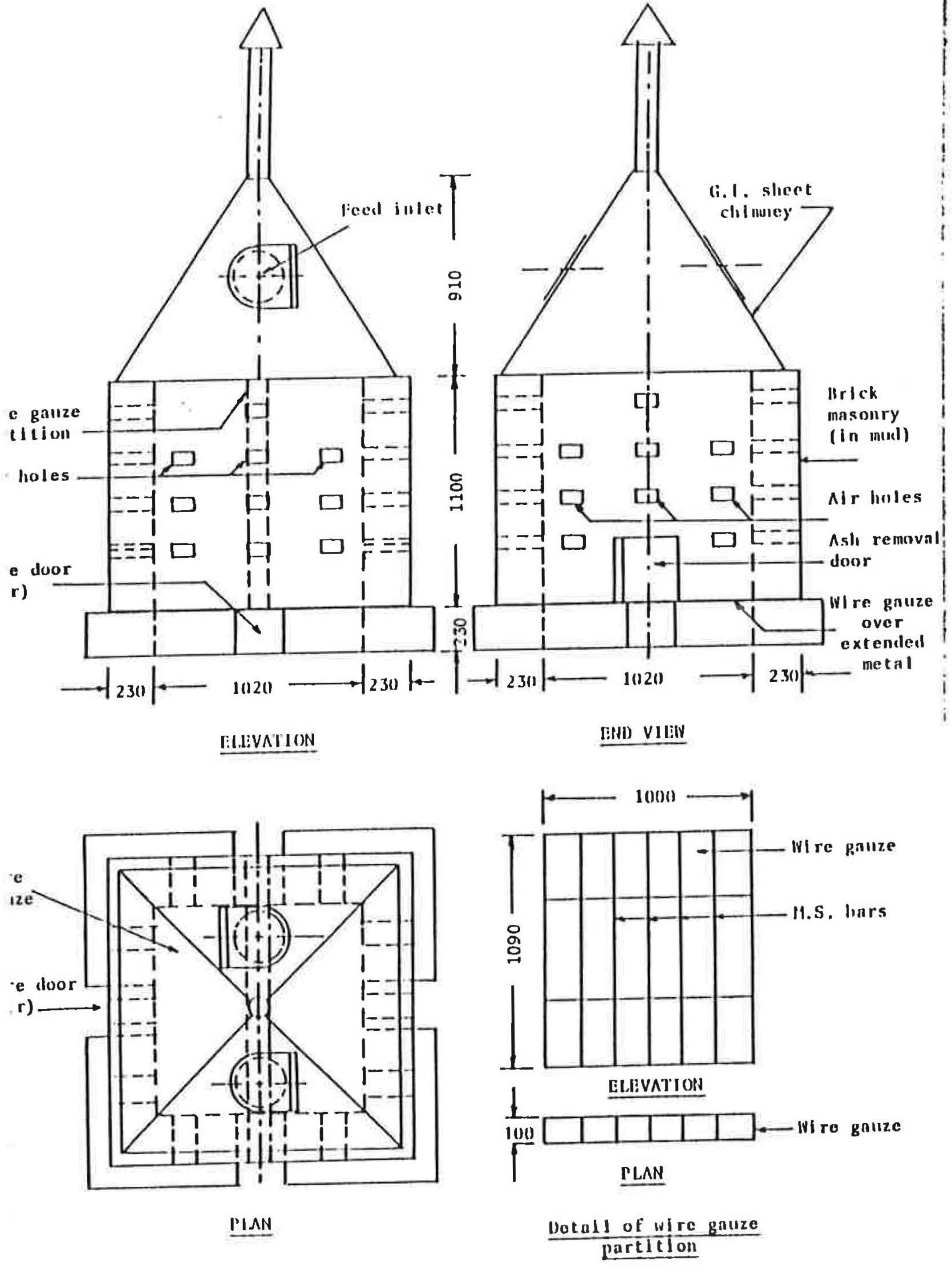
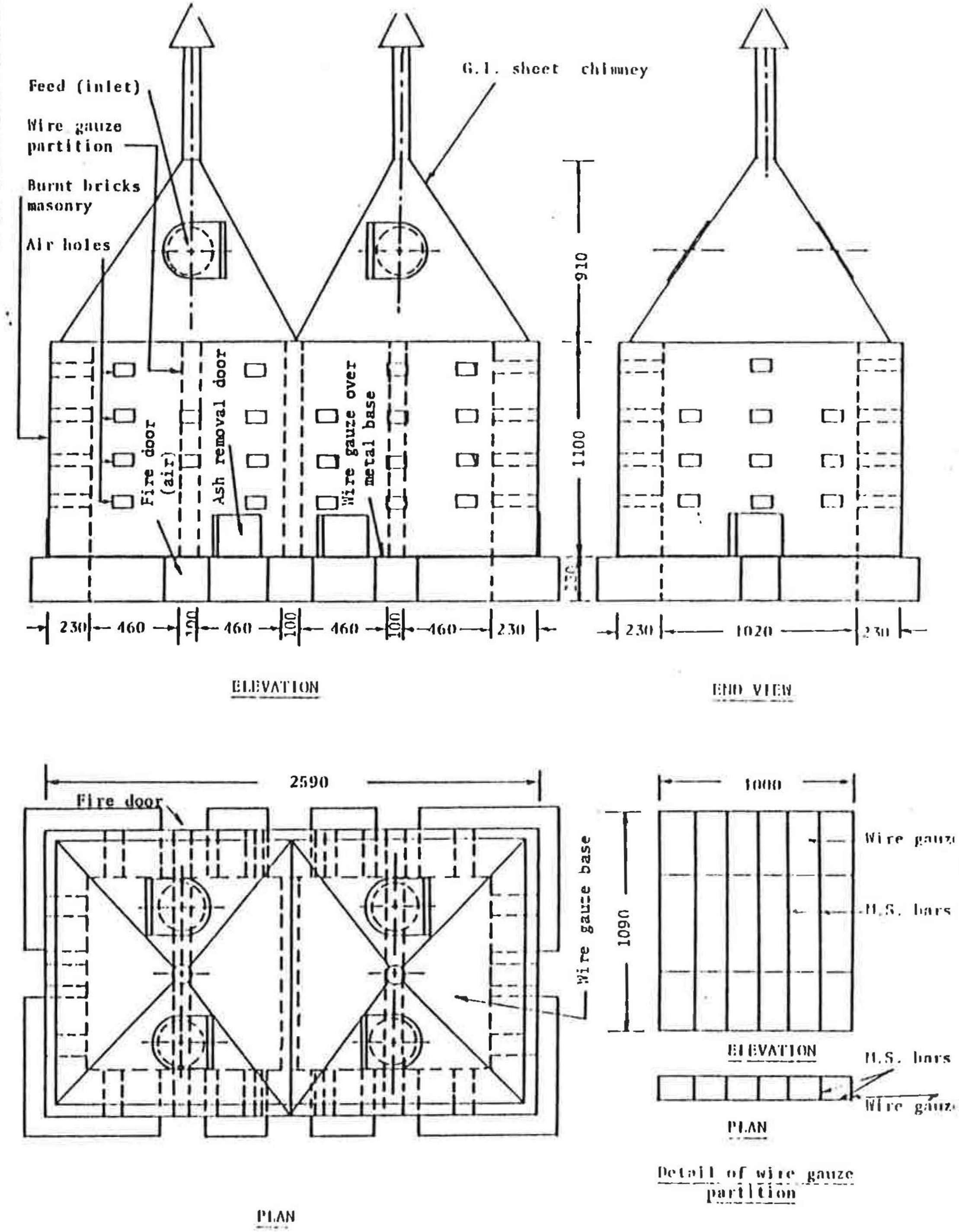


Source: PCSIR (28).

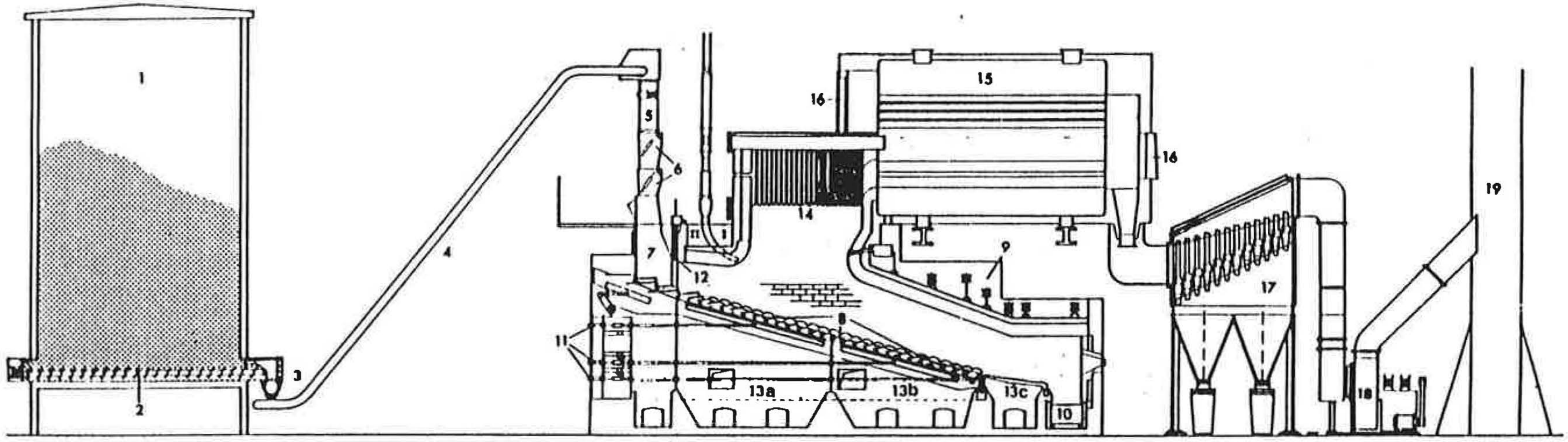


Source: PCSIR (28).

Brick double incinerator developed by PCSIR

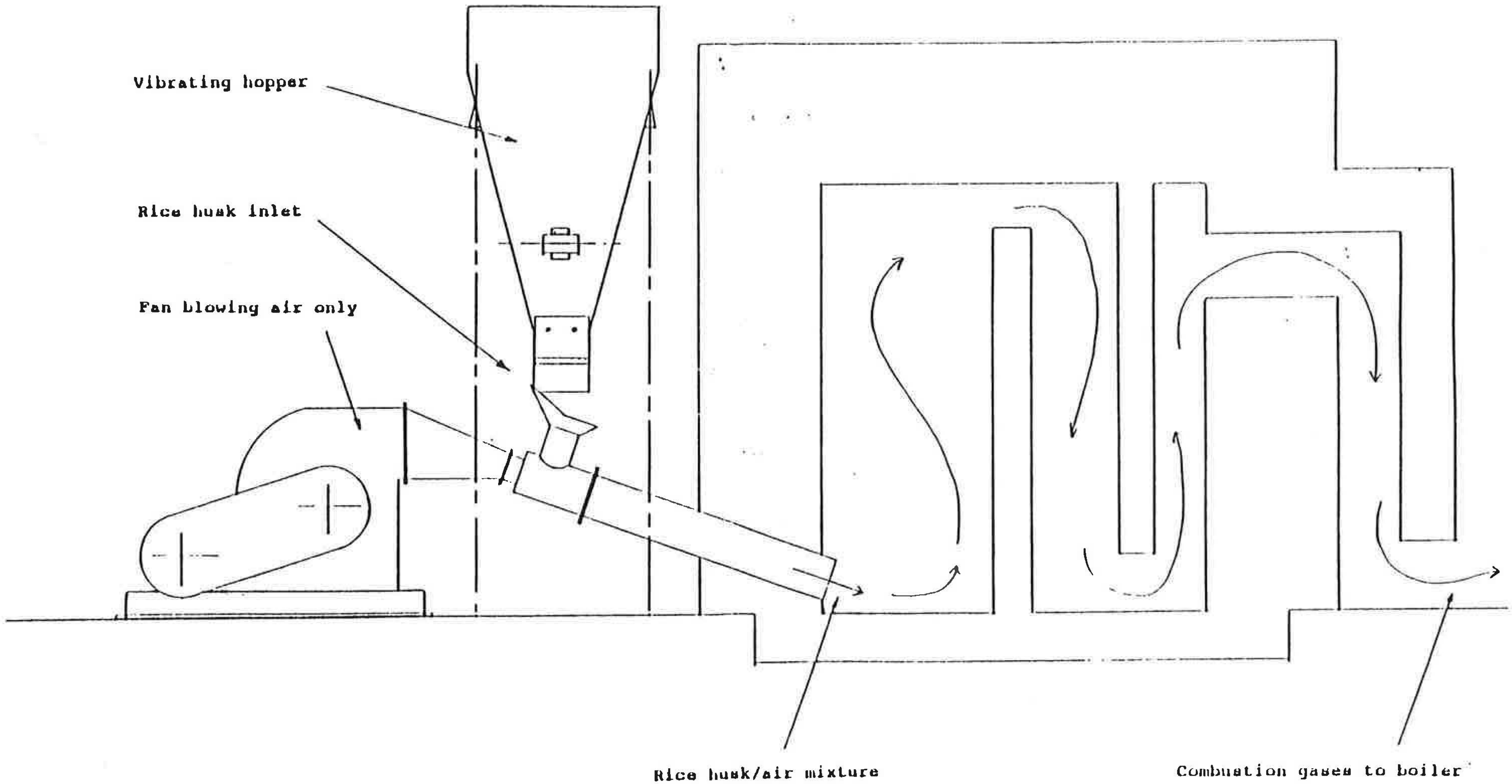
Figure 1 - Designs for Brick Incinerators

Figure 2 - Typical Step-grate Furnace



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

Movable inclined step-grate furnace



General Arrangement of 180 kg/h Furnace

Richard Pieris Rice Mill

Figure 3 - NRI Brick Suspension Burner

Table 1A
PRODUCTION COSTS OF RICE HUSK ASH
Model 1: Heat production not considered

Capital costs in 1990 terms:	
Furnace:	135,455 S.L. Rs
Ash collector:	35,000 S.L. Rs
Building:	17,046 S.L. Rs
Total	187,501 S.L. Rs
Asssumed inflation rate for two-year period 1990/91:	15.0%
Capital costs in 1992 terms:	215,626 S.L. Rs
Life of structure :	5 years
Interest rate:	20.0%
Annualised capital cost:	72,101 S.L. Rs
Operating and Maintenance Costs per Year:	
Maintenance:	21,563 S.L. Rs
Management:	20,000 S.L. Rs
Labour:	12,500 S.L. Rs
Power:	15,000 S.L. Rs
Raw material:	0 S.L. Rs
Other Material:	120 S.L. Rs
Insurance:	2,156 S.L. Rs
Interest on working capital:	2,854 S.L. Rs
Contingencies (5%):	3,710 S.L. Rs
Total:	77,902 S.L. Rs
Total production costs/year:	150,003 S.L. Rs
RHA output per year:	108.0 tonnes
Production cost/tonne of RHA:	1,388.9 S.L. Rs

MODEL 1 : VARIABLES

Prices for inputs:	
Labour:	50.0 Rs/day
Power:	5.0 Rs/KW
Rice husk:	.0 Rs/tonne
Raw material requirements:	180 kgs/hour
Operating time per year:	250 days
Operating time per day:	12 hours
Output:	20.0% of raw mat. input
Insurance:	1% of total capital costs
Interest on working capital:	based on 50 working days

Table 1B

PRODUCTION COSTS OF RICE HUSK ASH

Model 2: Heat production considered

Capital costs in 1990 terms:	
Furnace:	135,455 S.L. Rs
Ash collector:	35,000 S.L. Rs
Heat Exchanger:	50,000 S.L. Rs
Building:	8,500 S.L. Rs
Total	228,955 S.L. Rs
Asssumed inflation rate for two-year period 1990/91:	15.0%
Capital costs in 1992 terms:	263,298 S.L. Rs
Life of structure :	5 years
Interest rate:	20.0%
Annualised capital cost:	88,042 S.L. Rs
Operating and Maintenance Costs per Year:	
Maintenance:	26,330 S.L. Rs
Management:	20,000 S.L. Rs
Labour:	12,500 S.L. Rs
Power:	15,000 S.L. Rs
Raw material:	0 S.L. Rs
Other material:	2,500 S.L. Rs
Insurance:	2,633 S.L. Rs
Interest on working capital:	3,159 S.L. Rs
Contingencies (5%):	4,106 S.L. Rs
Total:	86,227 S.L. Rs
Total production costs/year:	174,269 S.L. Rs
RHA output per year:	108.0 tonnes
Production cost/tonne of RHA:	1,614 S.L. Rs
Value of heat (in 1992 terms):	87,975 S.L. Rs
Value of heat/tonne of RHA:	815 S.L. Rs
Net Cost/tonne of RHA:	799 S.L. Rs

MODEL 2: VARIABLES

Prices for inputs:	
Labour:	50.0 Rs/day
Power:	5.0 Rs/KW
Rice husk:	.0 Rs/tonne
Heat value:	1.0 Rs/KW
Raw material requirements:	180 kgs/hour
Operating time per year:	250 days
Operating time per day:	12 hours
Output:	20.0% of raw mat. input
Furnace heat rating:	750 KW
Fuel savings (1990 prices):	76,500 S.L.Rupees

Table 2A

COST ANALYSIS FOR CEMENT PRODUCTION (CONTROLLED PYROPROCESSING)

Case 1: Lime ash ratio (1:1); Exch. rate: 44.02 S.L. Rupees = 1$

Capital costs:				
Buildings:	6,050	US$	266,321	Rs
Plant:	12,650	US$	556,853	Rs
Life of Buildings:	40	years		
Life of plant:	10	years		
Interest rate:	20.00%			
Annualised cost for buildings:	1,211	US$	53,300	Rs
Annualised costs for plant:	3,017	US$	132,822	Rs
Total annualised capital costs:	4,228	US$	186,123	Rs
Operating and maintenance costs per year:				
Maintenance:	910	US$	40,069	Rs
Limestone:	6,000	US$	264,120	Rs
Coal:	3,600	US$	158,472	Rs
Rice husk:	1,305	US$	57,446	Rs
Power:	1,073	US$	47,225	Rs
Salaries and wages:	3,900	US$	171,678	Rs
Other consumables:	300	US$	13,206	Rs
Packaging:	3,000	US$	132,060	Rs
Quality control:	600	US$	26,412	Rs
Insurance:	187	US$	8,232	Rs
Interest on working capital:	835	US$	36,757	Rs
Contingencies (5%):	1,086	US$	47,784	Rs
Total:	22,796	US$	1,003,460	Rs
Total production costs per year:	27,024	US$	1,189,583	Rs
Cement output per year:	600	tonnes		
Production cost/tonne of cement:	45.04	US$	1,983	Rs
Prod. cost/40kg bag of cement:	1.80	US$	79	Rs

VARIABLES

Prices for inputs:		Units:
Limestone:	10	US$/tonne
Coal:	30	US$/tonne
Rice husk:	1	US$/tonne
Power:	.04	US$/kwh
Supervisor:	100	US$/month
Skilled labour:	75	US$/month
Unskilled labour:	1	US$/day
Empty 40kg bags:	.20	US$/bag

Quantities:		
Limestone:	600	tonnes
Coal:	120	tonnes
Rice husk:	1,305	tonnes
Power:	26,820	kwh
Empty 40kg bags:	15,000	bags
Output of cement:	600	tonnes
Operating time per year:	250	days

Table 2B

COST ANALYSIS FOR CEMENT PRODUCTION (CONTROLLED PYROPROCESSING)

Case 2: Lime ash ratio (1:2); Exch. rate: 44.02 S.L. Rupees = 1$

Capital costs:				
Buildings:	6,050	US$	266,321	Rps
Plant:	12,650	US$	556,853	Rps
Life of Buildings:	40	years		
Life of plant:	10	years		
Interest rate:	20.00%			
Annualised cost for buildings:	1,211	US$	53,300	Rs
Annualised costs for plant:	3,017	US$	132,822	Rs
Total annualised capital costs:	4,228	US$	186,123	Rs
Operating and maintenance costs per year:				
Maintenance:	910	US$	40,069	Rs
Limestone:	4,000	US$	176,080	Rs
Coal:	2,400	US$	105,648	Rs
Rice husk:	1,740	US$	76,595	Rs
Power:	1,073	US$	47,225	Rs
Salaries and wages:	3,900	US$	171,678	Rs
Other consumables:	300	US$	13,206	Rs
Packaging:	3,000	US$	132,060	Rs
Quality control:	600	US$	26,412	Rs
Insurance:	187	US$	8,232	Rs
Interest on working capital:	724	US$	31,888	Rs
Contingencies (5%):	942	US$	41,455	Rs
Total:	19,776	US$	870,547	Rs
Total production costs per year:	24,004	US$	1,056,670	Rs
Cement output per year:	600	tonnes		
Production cost/tonne of cement:	40.01	US$	1,761	Rs
Prod. cost/40kg bag of cement:	1.60	US$	70	Rs

VARIABLES

Quantities:		
Limestone:	400	tonnes
Coal:	80	tonnes
Rice husk:	1,740	tonnes
Power:	26,820	kwh
Empty 40kg bags:	15,000	bags

The data concerning prices and output are the same as in table 2A

Table 2C
COST ANALYSIS FOR CEMENT PRODUCTION (CONTROLLED PYROPROCESSING)
Case 3: Lime ash ratio (1:3); Exch. rate: 44.02 S.L. Rupees = 1$

Capital costs:				
Buildings:	6,050	US$	266,321	Rs
Plant:	12,650	US$	556,853	Rs
Life of Buildings:	40	years		
Life of plant:	10	years		
Interest rate:	20.00%			
Annualised cost for buildings:	1,211	US$	53,300	Rs
Annualised costs for plant:	3,017	US$	132,822	Rs
Total annualised capital costs:	4,228	US$	186,123	Rs
Operating and maintenance costs per year:				
Maintenance:	910	US$	40,069	Rs
Limestone:	3,000	US$	132,060	Rs
Coal:	1,800	US$	79,236	Rs
Rice husk:	1,950	US$	85,839	Rs
Power:	1,073	US$	47,225	Rs
Salaries and wages:	3,900	US$	171,678	Rs
Other consumables:	300	US$	13,206	Rs
Packaging:	3,000	US$	132,060	Rs
Quality control:	600	US$	26,412	Rs
Insurance:	187	US$	8,232	Rs
Interest on working capital:	669	US$	29,441	Rs
Contingencies (5%):	869	US$	38,273	Rs
Total:	18,258	US$	803,730	Rs
Total production costs per year:	22,486	US$	989,853	Rs
Cement output per year:	600	tonnes		
Production cost/tonne of cement:	37.48	US$	1,650	Rs
Prod. cost/40kg bag of cement:	1.50	US$	66	Rs

VARIABLES

Quantities:		
Limestone:	300	tonnes
Coal:	60	tonnes
Rice husk:	1,950	tonnes
Power:	26,820	kwh
Empty 40kg bags:	15,000	bags

The data concerning prices and output are the same as in table 2A

Table 3

PRODUCTION COSTS OF SODIUM SILICATE FROM RICE HUSK ASH

Capital costs in 1980 terms:	
Husk fired furnace:	15,000 Indian Rs
Extraction vessels and evaporators:	10,000 Indian Rs
Vacuum filter:	15,000 Indian Rs
Filteration funnels, S.S. Ladles, etc.	20,000 Indian Rs
Building:	15,000 Indian Rs
Total	75,000 Indian Rs
Assumed price index 1992: (1980 = 100)	329
Capital costs in 1992 terms:	246,750 Indian Rs
Life of structure :	5 years
Interest rate:	20.0%
Annualised capital cost:	82,508 Indian Rs
Operating and Maintenance Costs per Year:	
Maintenance:	24,675 Indian Rs
Management:	18,000 Indian Rs
Labour:	18,900 Indian Rs
Soda ash:	1,458,000 Indian Rs
Caustic soda:	1,368,000 Indian Rs
Husk:	202,500 Indian Rs
Insurance:	2,468 Indian Rs
Interest on working capital:	123,702 Indian Rs
Contingencies (5%):	160,812 Indian Rs
Total:	3,377,056 Indian Rs
Total production costs/year:	3,459,565 Indian Rs
Output per year:	900.0 tonnes
Production costs/tonne of Sodium Silicate	3,844 Indian Rs

Note : The calculation of the 1992 price index is based on the evolution of exchange rate between the US$ and the Indian Rupee; in 1980 US$1 = Ind. Rupees 7.863; Mid-1992 US$1 = Indian Rupees 25.89.

APPENDIX 2

Funding Proposal for Project Continuation

Title: Production of High Quality Rice Husk Ash.

Project objectives:

i) to evaluate the technology for production of high quality rice husk ash and consider the design and introduction of an improved system;

ii) to seek ways to maximise product quality in the context of heat and/or power applications for combustion of rice husk ash;

iii) to assess the potential for production of high quality RHA and to demonstrate the NRI combustion technology in a selected country;

iv) to devise a strategy for wider technology transfer within a chosen region on a case-by-case basis.

Phase II.

1. Liaise with potential overseas institutional/commercial collaborators in Sri Lanka and India. From opportunities identified make arrangements for a visit to discuss collaborative evaluation and demonstration project. Identify potential for integration of this exercise with other European workers in order to submit CEC proposal for cofunding. (25 mds, Yr 1)

2. Undertake a visit to the selected country to carry out a technical and economic evaluation of the prospects for production of high quality RHA through use of NRI rice husk combustion technology. (40 mds, Yr 1)

3. With data collected from technical evaluation, design improved combustion system. Based upon information acquired and measured performance of NRI furnaces (brick and fluid bed systems), consider potential financial and environmental benefits of providing NRI technology. (70 mds, Yr 1)

4. Consider ways in which energy usage from combustion of rice husk may be maximised with sustained quality production of rice husk for commercial outlets. (mds included in 3. above, Yr 1)

5. Carry out desk study of rice husk ash market requirements with a view to production in countries of three regions - Asia, Africa and South America - which have potential access to utilise the NRI rice husk combustion technology. Collect data on potential industries that generate rice husk, or have access to rice husk, their energy requirements, scope for using RHA or possibilities of selling RHA in local or export markets. Appraise local institutional and engineering support for a technology transfer programme. (40 mds, Yr 1)

6. From the desk study results, choose one region and short-list countries with potential to support a technology transfer programme. Select a country and carry out a detailed feasibility study. Make arrangements for a commercial demonstration programme possible through fostering a joint venture involving European organisations, at a rice processing mill or industry with access to rice husk, for a system using NRI-furnace technology. (mds included in 5 above, Yr 1)

7. Set up programme of work to install, commission, test and develop the NRI-designed furnace in assigned country as part of a scheme under commercial operating conditions in liaison with the involved local organisation and any joint venture collaborative organisation. (80 mds, Yr 2)

8. Procure and install equipment; build rice husk furnace using available local craft skills and materials. Commission

system and train personnel. Operate and monitor performance of system over one year period (mds in 7 above,Yr 2).

9. Carry out techno-economic evaluation based on experience acquired and form a strategy for wider regional dissemination programme on a case-to-case basis.(70md,Yr 3)

Participants

a) Natural Resources Institute.
b) Local institutions/organisations such as Indian Institute of Technology, Lanka Refractories and RPRDC, Sri Lanka.
c) Government departments in assigned country.
d) Potential European collaborators for CEC funding schemes.
e) Commercial operations and/or trade associations to develop marketing of RHA.

Estimated costs for Phase II above are:

Year 1

Task	**Time**	**Bd**
Identification of potential collaborators.	25 mds	2
Exploratory visits and report	35 mds	2
Support	5 mds	3
Evaluation, system design and report	35 mds	2
Support	25 mds	3
	10 mds	4
Desk study	20 mds	2
	20 mds	3

Sub-Totals	115 mds	2 (£46.6k)
	50 mds	3 (£16.8k)
	10 mds	4 (£ 2.7k)
Grand Total	175 mds	
	(£66.1k) **(1)**.	

Overseas visit:

Initial exploratory visits of 2 weeks each to India and/or Sri Lanka to identify collaborators and collect data.

Cost: travel - £4.0k
subsistence - £2.8k Total £6.8k **(2).**

Project total for Year 1 of Phase II (1+2), £72.9k.

Year 2

Task	**Time**	**Bd**
Liaison with collaborators	20 mds	2
Commissioning and testing visit	30 mds	2
Support	20 mds	3
Report	10 mds	2

Sub-Total	60 mds	2	(£25.2k)
	20 mds	3	(£7.0k)
Grand total	80 mds(£32.2k) **(1).**		

Overseas visits:

i) visit to commission and test NRI furnace, 8 weeks.

Cost: travel - £2.0k
subsistence - £5k Total £7k **(2).**

Equipment: Furnace with fan and heat exchanger components estimated at £10k **(3).**

Project total for Year 2 of Phase II (1+2+3), £49.2k.

Year 3

Task	**Time**	**Bd**
Techno-economic evaluation report	50	2 (£21.8k)
	20	3 (£7.4k)
Total	70 md	(£29.2)k (1)

Overseas visit
Evaluation visit to assigned country 4 weeks
Travel £4k
Subsistance £10k   Total £14k (2)
Project total for Year 3 of Phase II (1+2) =£33.2k

Note;
(a) travel and subsistence may be significantly reduced with the use of i) flight savers and ii) accommodation outside the major cities.
(b) inputs, times and costs for years 2 & 3 are to be confirmed and detailed in the light of the year 1 progress.