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# Design and Development of an In-Lined Rice Parboiling Economy Stove to Utilize Rice-Husk Fuel for Small Scale Entrepreneurs

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## *Abstract*

Rice, a staple food in Nigeria and across Africa, faces significant challenges in production and postharvest processing, including substantial losses and low-quality outcomes. This study explores the design and development of an in-line economy stove that utilizes rice husks as fuel, aiming to reduce energy losses during rice parboiling and promote environmental sustainability. The stove incorporates three-layered construction with fire clay bricks, a clay-salt mixture, and galvanized steel to optimize energy conservation. Performance tests revealed that the stove efficiently parboils 80 kg of paddy rice with minimal heat loss (0.53 kW) and achieves a high percentage energy utilization (70%) using 3.5 kg of rice husk fuel per batch. The stove was fabricated using durable materials, including galvanized sheet metal and refractory bricks, with a cost of ₦131,120. The projected monthly profit of ₦41,303 highlights its economic viability, with a return on investment achieved within three months. This innovative solution addresses critical issues in rice processing, such as deforestation and the underutilization of agricultural residues like rice husks, while offering a cleaner and health-friendly alternative to traditional methods.

The study recommends widespread adoption of the stove, supported by government and non-governmental initiatives, to improve the livelihoods of rural communities and enhance the rice value chain.

**Keywords:** Rice husks, In-line economy stove, energy losses, fire clay brick, economic viability, health-friendly alternative.

## *Introduction*

Rice (*Oryza spp*) is a staple food of immense importance in Nigeria and across Africa (Balasubramanian et al., 2007). The demand for rice as a staple food continues to rise significantly, far surpassing the region's production capacity, especially in the context of widespread poverty, security challenges, and a rapidly growing population (IRRI, 2012). Despite recent increases in rice production yields, postharvest losses both qualitative and quantitative remain a major concern. Poor postharvest practices lead to losses estimated at around 30%, stalling the development of the rice value chain (IRRI, 2015).

Locally produced rice often suffers from substantial quality issues, including a high proportion of broken grains, chalky kernels, impurities, and significant energy requirements during processing. As a result, it is commonly sold unbranded and at a low economic value (Demont et al., 2012). In response, the Federal Government has initiated measures aimed at reducing postharvest and energy losses to below 10%, thereby enhancing the availability and competitiveness of local rice in Nigerian and African markets (Demont et al., 2013).

To ensure locally parboiled and non-parboiled rice meets the quality standards of imported rice particularly in urban markets targeted improvements in processing and branding must be prioritized (Amovin-Assagba et al., 2013).

To enhance the physical, culinary, and nutritional quality of locally milled parboiled rice to compete effectively with imported varieties, it is crucial to improve the technology underlying the parboiling process (Odenigbo et al., 2013).

In Nigeria and across Africa, the parboiling of rice primarily relies on

firewood as an energy source, using traditional three-stone stoves. These stoves, often purchased or transported over long distances, contribute to the high cost of locally parboiled rice. Furthermore, as shown in Fig. 1, the three-stone stove design results in significant energy losses and prolonged boiling times (Demont et al., 2012). Alternatives such as biomass and rice husk briquettes, when used in open combustion chambers, also experience considerable heat loss and demand excessive energy (Bhattacharya et al., 2000). Additionally, open stoves pose serious health hazards to users due to exposure to harmful emissions (Vivan et al., 2012).

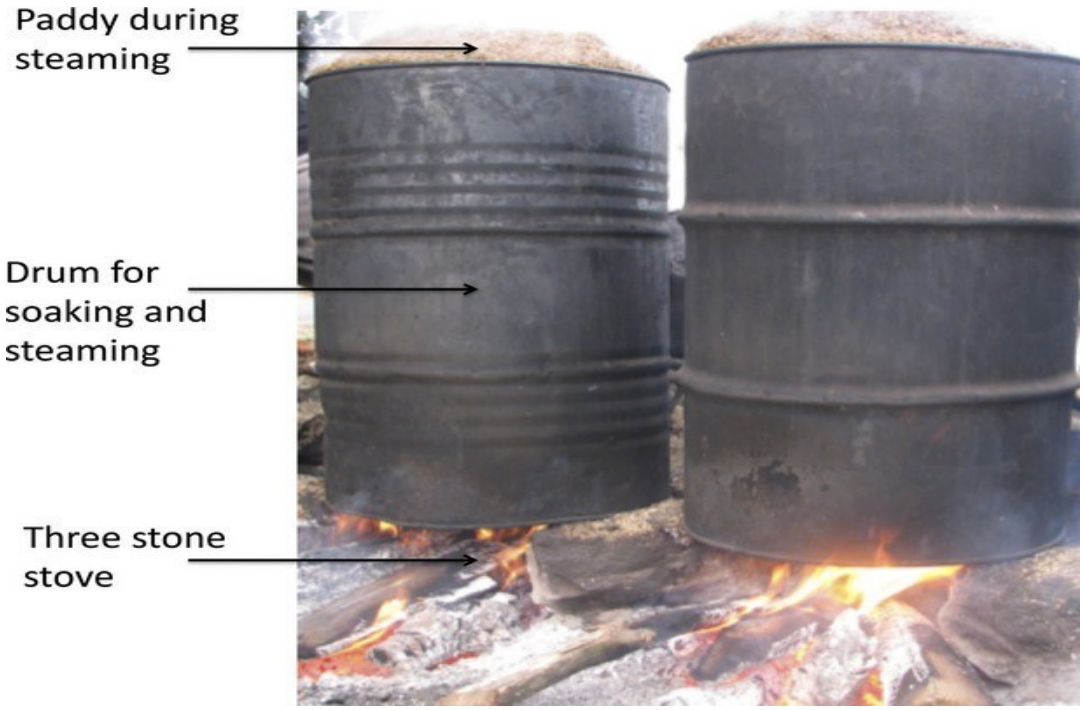



Fig. 1: The three stone stove local rice parboiling.

Regardless of the methods employed, the majority of locally parboiled rice supplied to urban markets in Adamawa State originates from rural areas. Notably, women represent the largest group of entrepreneurs engaged in this production. However, they reap minimal economic benefits from their labor, primarily due to the high costs associated with parboiling, which are driven by significant energy losses during the process.

To address the issue of excessive heat loss during rice parboiling, the development of an in-line economy stove designed to utilize rice husks as fuel has been explored. This innovation aims to enhance energy efficiency and reduce production costs in rice parboiling.

## OBJECTIVE

The main objective of the research are as follows:

i. To design and develop an efficient economy stove capable of performing rice parboiling processes (steaming and soaking) with minimal energy consumption and reduced heat loss.

ii. To provide an affordable, clean, and health-friendly combustible stove for rice parboiling, specifically tailored to meet the needs of rural communities.

iii. To promote environmental sustainability by reducing deforestation and minimizing the environmental impact caused by tree felling for firewood, while encouraging the utilization of rice husks as an alternative fuel source.

## MATERIALS AND METHODS

### Materials

Design and development of the in-lined rice husk, rice parboiling economy stove requires judicious and careful selection of materials and methods for structural fabrication and the lagging processes using in-service reliable refractory bricks to ensure perfect result. The materials and equipment needed for the structural fabrication of the in-lined rice parboiling economy stove that utilizes rice husk as fuel are listed as shown in table 1 below.

Table 1. Materials and Equipment for development

| S/N | Material/ Equipment | Selection Criteria |
|---|---|---|
| 1 | 10 mm flat bar | For rigidity of structural frame work and support for heavy object(s) |
| 2 | 1.5mm galvanized sheet metal | For framing of the outer layer of the economy stove |
| 3 | 12mm Iron rod | To serve in the vertical frame work construction |

| | | |
|---|---|---|
| **3** | Red Oxide paint | Rust protection of the metallic parts of the economy stove. |
| **4** | Fire clay bricks | Heat resistant bricks (molded from Vimtim clay, kaolin, sodium silicate and rice husk) |
| **5** | Vimtim Clay | Special base clay for the refractory bricks and as thermal crack resistant lagging material. |
| **6** | Rice husk | Additives for the mixture of the clay refractory bricks. |
| **7** | Salt | Reduce and maintain the thermal effects on the bricks. |
| **8** | Measuring tape | For dimensioning |
| **9** | Hack saw | For cutting of the metallic parts to dimension |
| **10** | Hand grinder/ cutting machine | For smoothening of the metallic sharp edges<br>For cutting of sheet metals beyond the capabilities of hack saw. |
| **11** | Sand paper | Smoothing of the metallic parts after grinding. |
| **12** | Arc-welding machine | For joining of the metallic parts to form a rigid structure |
| **13** | Chipping hammer | For chips removal. |
| **14** | Wheel barrow | Transportation of the clay and metallic materials |
| **15** | Shovel and hand trowel | For proper mixing of the clay with the other additives. |

**Method**

**The Structural assembly of the Economy Stove**

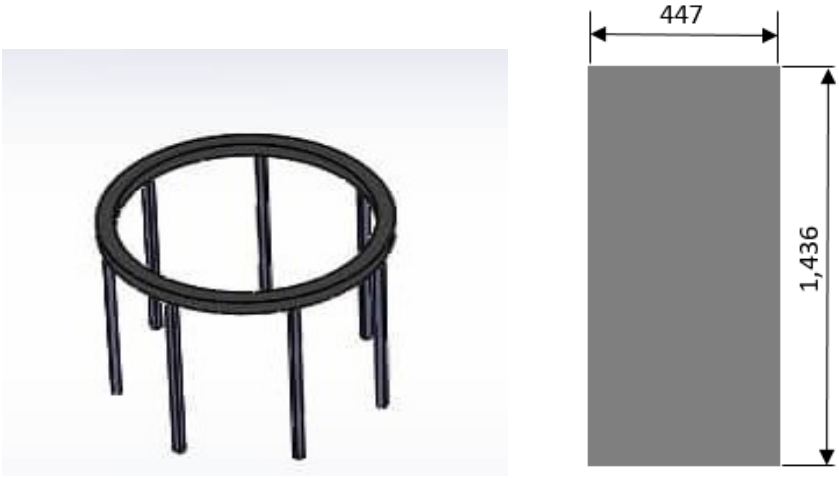
The structural work comprising of a circular ring of 457mm diameter formed from the 10mm thick flat bar and placed on 8 vertically arranged 12mm rod along the trajectory of the circular ring bar of length 447mm each. The spaces between the vertical bars are covered with a sheet metal of 1436mm x 447mm x 1.5mm.

A fire clay bricks of 150mm x 100mm are arranged to form the inner core layer of the oven. This form the combustion chamber where the rice husk is feed in to serve as the fuel of the combustion. The fire clay bricks separated by a 30mm thick clay-mixture with salt (for the purpose of considerable thermal crack reduction) also shielding the external metallic parts from direct contact with the heat.

During the construction of the economy rice parboiling stove, the inlet air vent made of metal were constructed and connected to the air supply for continuous supply and support of the combustion of the rice husk. The smoke exhaust connections were also inter-connected to the main chimney for proper and hygienic

disposition of the smoke without causing some adverse health effect to the operator.

The external metallic parts of the economic stove are painted to protect it from the effect of environmental conditions. The metallic frame work arrangement of the economy stove is shown in Fig. 2 below.




(a) (b)

Fig. 2: Metallic framework of the economy stove: (a) Flat bar arrangement (b) Flat sheet plate closing the gaps between stands.

**The Heat Tranfer Process In The Economy Rice Parboiling Stove.**

The economy rice parboiling stove is designed forming a three layer (the fire clay brick, the clay plus salt mixture, and the galvanized mild steel) with the intention of conserving the energy in the combustion chamber. During the parboiling process, heat tranfered is espected to occur across the surfaces of the wall of the three layers.

Using the Fourier's law, a heat transfer through the three layers of the economy rice parboiling stove can be analysed.

Considering a square meter slice of the wall in Fig. 3 below, with the dimentions and thermal conductivities of each layer as provided. The fire clay brick is 100mm thick, 0.85W/mK; clay + salt mixture is 30mm thick, 0.25W/mK and galvanized steel 1.5mm thick, 50W/mK. The measured temperatures across the layers are: $t_0$ = 155°C, $t_1$ = 43°C, $t_2$ = 35°C and $t_3$ = 29°C.

Thus

$$q = -K\Delta T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$\Rightarrow \frac{\delta Q}{\delta t} = -KA\left(\frac{\delta T}{\delta x}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

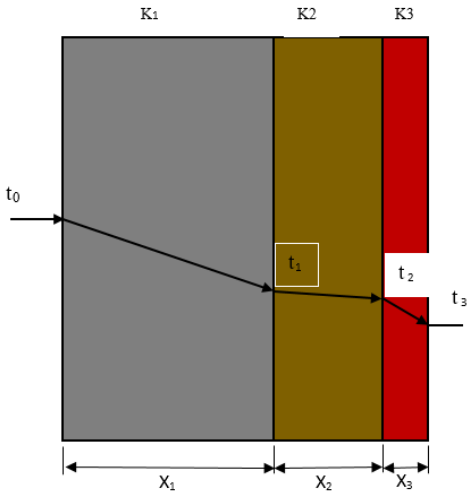



Figure 3: Heat transfer through a composite wall.

**PERFORMANCE TEST ANALYSIS**

The In-lined rice parboiling economy stove designed to utilize rice husk as its fuel source is tested for performance. The designed and developed parboiling economic oven was fully charged with average 2kg of rice husk as fuel source for soaking and 1.5 kg of same fuel for parboiling of average 80kg paddy rice within an average period of 6 hours. This process was repeated three times and examined for proper sampling and validation. The process was found to be economical considering the physical design with less possibility of energy loss.

Where $Q_p$ = Amount of heat energy needed to parboil a specific mass of rice

M = Mass of rice (kg),

S = Specific heat capacity of rice (1.7kj/kg),

$T_1$ = Temperature at which Soaking start,

$T_2$ = Temperature at which Soaking stop,

$T_3$ = Temperature at which Parboiling start,

$T_4$ = Temperature at which Parboiling stop. See table 3 as used for the performance test.

$$Q_p = MS(T_2 - T_1) + (T_4 - T_3)$$

Table 3: Performance test values for three samples 1, 2, and 3 respectively.

| S/N | Parameters | Sample 1 | Sample 2 | Sample 3 | Average |
|---|---|---|---|---|---|
| 1 | Mass of rice (kg) | 60 | 80 | 100 | 80 |
| 2 | Mass of fuel rice husk used (Kg) | 3.4 | 3.5 | 3.6 | 3.5 |
| 3 | $T_1$ (°C) | 70 | 65 | 72 | 69 |
| 4 | $T_2$ (°C) | 90 | 85 | 86 | 87 |
| 5 | $T_3$ (°C) | 65 | 60 | 64 | 63 |
| 6 | $T_4$ (°C) | 71 | 70 | 72 | 71 |

**Percentage Energy Utilization (P.E.U.)**

$$P.E.U. = \frac{Total\ theoretical\ heat\ energy\ required\ to\ parboil\ a\ rice}{Total\ energy\ input\ of\ \ fuel\ rice\ husk\ used} \text{.....3}$$

**RESULTS AND DISCUSSIONS**

1. Amount of Heat Energy Needed ($Q_p$) to Complete a Parboiling Process of a Specified Mass of Rice Using the In-Lined Economy Oven.

$$Q_p = MS(T_2 - T_1) + (T_4 - T_3)$$

$$Q_p = 80 \times 1.7(87 - 69) + (71 - 63) = 2{,}456W = 2.456kW$$

The average amount of heat energy needed to parboil 80kg of rice using the developed economic stove estimated to (2.456kW)

***Heat loss during the parboiling process using the designed and developed economy stove***

Using Fig. 3 above and its heat transfer parameters as stated earlier, the heat loss during the parboiling process is presented as seen below.

$$Heat\ loss\ across\ \ fire\ clay\ bricks\ (R_f) = \frac{x}{K} = \frac{100mm}{0.85W/mK} = \frac{100}{0.85 \times 10^3} = \frac{100}{850} = 0.1176kW$$

$$Heat\ loss\ across\ clay + salt\ mixture\ (R_c) = \frac{x}{K} = \frac{30mm}{0.25W/mK} = \frac{30}{0.25 \times 10^3} = \frac{30}{250} = 0.12kW$$

$$Heat\ loss\ across\ Galvanize steel\ metal\ (R_G) = \frac{x}{K} = \frac{1.5mm}{50W/mK} = \frac{1.5}{50 \times 10^3} = \frac{1.5}{50{,}000} = 0.00003kW$$

$$Heat\ loss\ across\ the\ three\ surfaces\ (R_t) = (0.1176 + 0.1200 + 0.00003)kw = 0.2376kW$$

$$Total\ heat\ loss\ (Q)\ across\ the\ three\ surfaces \Rightarrow Q = \frac{\delta T}{R_t} = \frac{\left[(155+273)+(29+273)\right]}{0.2376}$$

$$= \frac{428-302}{0.2376} = 530W$$

Therefore, the total heat loss across the entire lagged surfaces is 530w which is equivalent to 0.53kW

From table 3 above, the average fuel (rice husk) required to parboil an average 80kg of paddy rice using the developed economic stove was estimated to 3.5kg.

Therefore, the percentage energy utilization (P.E.U.) can be determined.

$$P.E.U. = \frac{2.456}{3.5} \times 100 = 70\%$$

***Cost Estimate***

Table 2: Cost estimate

| S/N | Material/ Equipment | Quantity | Unit price (₦) | Cost Estimate (₦) |
|---|---|---|---|---|
| **1** | 10 x 50 mm flat bar | 1 | 18,000 | 18,000 |
| **2** | 1.5mm galvanized sheet metal | 2 | 8,500 | 17,000 |
| **3** | 12mm Iron rod | 2 | 8,500 | 17,000 |
| **3** | Red Oxide paint | 4 liters | 12,000 | 12,000 |
| **4** | Fire clay bricks | | 25,000 | 25,000 |
| **5** | Vimtim Clay | | 5,000 | 5,000 |
| **6** | Rice husk | | 200 | 200 |
| **7** | Salt | | 5,000 | 5,000 |
| **8** | Labor | | 20,000 | 20,000 |
| Total Cost | | | | **119,200** |

The result from the table shows that ₦119,200 Naira was used for the development of the economy oven. Taking10% of the above cost for miscellaneous, the overall cost was realized to be ₦131,120.

The daily profit of using this new innovation of the developed economy stove rice parboiling process using fuel rice husk will be.

Daily profit is equal to P.E.U. multiplied by the total cost of developing the economy stove.

$$P = \frac{70}{100} \times 131{,}120 = 91{,}784$$

Assuming 45% of the profit will be used for payment of staff salaries, maintenance of the oven and other contingences, a Monthly profit of ₦41,303 will be realized. Thus, the return on investment (I) of the designed and developed rice parboiling economy oven that uses rice husk as its fuel will be.

$$I = \frac{Total\ \text{cost}\ of\ economy\ oven}{monthly\ profit}$$

$$I = \frac{131{,}120}{41{,}802.8} = 3.1746 \approx 3month$$

## CONCLUSION

The designed and development of In-lined rice parboiling economy stove that utilizes rice husk as its fuel source has proven its credibility based on the performance evaluation test result obtained with less operational and maintenance effort as compared to other rice parboiling processes.

This can be seen form the result indicating that 80kg of paddy rice is parboiled experiencing a low heat loss of 0.53kW, with percentage energy utilization of 70%, return on investment of 3 month using 3.5kg of rice husk fuel per complete operation.

## RECOMMENDATION

1. The in-line rice parboiling economy stove is recommended for adoption in both urban and rural areas.
2. Non-governmental organizations (NGOs) and government empowerment programs should promote this technology to address environmental issues, including the accumulation of unused rice husk waste and the impact of deforestation.

3. Continuous improvements to the design and functionality of the in-line rice parboiling economy stove are encouraged to enhance its efficiency and effectiveness.

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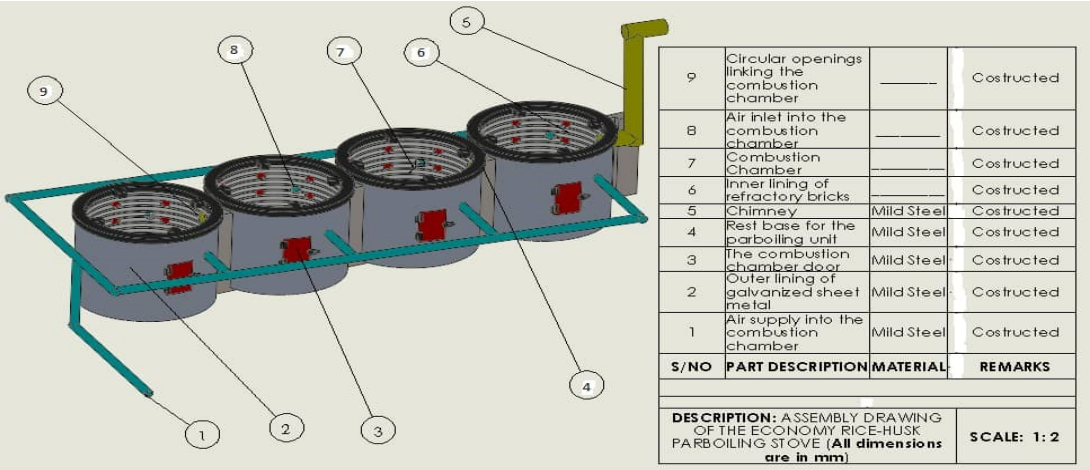
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| S/NO | PART DESCRIPTION | MATERIAL | REMARKS |
|---|---|---|---|
| 9 | Circular openings linking the combustion chamber | _____ | Costructed |
| 8 | Air inlet into the combustion chamber | _____ | Costructed |
| 7 | Combustion Chamber | _____ | Costructed |
| 6 | Inner lining of refractory bricks | _____ | Costructed |
| 5 | Chimney | Mild Steel | Costructed |
| 4 | Rest base for the parboiling unit | Mild Steel | Costructed |
| 3 | The combustion chamber door | Mild Steel | Costructed |
| 2 | Outer lining of galvanized sheet metal | Mild Steel | Costructed |
| 1 | Air supply into the combustion chamber | Mild Steel | Costructed |

**DESCRIPTION:** ASSEMBLY DRAWING OF THE ECONOMY RICE-HUSK PARBOILING STOVE (**All dimensions are in mm**) | **SCALE: 1: 2**

Figure 4: Assembly drawing of the Economy Rice Parboiling Rice Husk Stove.