

Experimental Study of A Furnace Equipped with Refractory Bricks

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Abstract Faced with the continued growth in global energy demand and the persistent dependence of rural households on solid fuels, alternative solutions are needed to improve the efficiency of cooking systems while reducing their environmental impact. This work presents an experimental study on improving the thermal efficiency of charcoal furnaces through the integration of insulating refractory bricks locally made from clay. In a context where more than 80% of the Burkinabe population depends on wood energy, this innovation aims to reduce fuel consumption, polluting emissions and pressure on forest resources. The designed furnace includes a combustion chamber surrounded by refractory bricks that store the heat produced by the combustion of charcoal and release it gradually, thus prolonging cooking. To evaluate thermal performance, a test protocol was applied (three-phase water boiling test) with measurement of furnace temperatures, water boiling time and charcoal consumption. The results reveal a clear superiority in performance of the furnace with refractory bricks: a reduction of nearly 64% in coal consumption, and a thermal efficiency of 0.48. The furnace with refractory bricks also maintained a high temperature longer after the fire was extinguished, demonstrating its ability to conserve thermal energy. This research thus provides a sustainable solution to domestic energy challenges in rural areas, while contributing to the fight against deforestation and the transition to cleaner and more efficient cooking methods.

Keywords: Improved furnace, refractory bricks, charcoal, thermal efficiency

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1. Introduction

Global energy demand continues to grow due to socioeconomic development and rapid population growth [1]. More than three billion people worldwide still rely on solid fuels such as firewood, charcoal or agricultural residues to meet their domestic energy needs, particularly for cooking [2,3]. In rural areas of developing countries, these traditional biomass sources account for more than 90% of domestic energy consumption. In Burkina Faso, approximately 81% of the population uses wood energy, mainly in the form of firewood and charcoal [4]. This high dependence puts significant pressure on forest resources, leading to accelerated deforestation and also significant greenhouse gas emissions. Traditional furnaces used in these regions are often inefficient, consuming a large amount of fuel while emitting fumes that are harmful to health and the environment. To address these problems, several initiatives have been implemented to promote improved furnaces. These not only provide greater energy efficiency, but also reduce pollutant emissions. Studies

have shown that these furnaces can reduce wood consumption by 28 to 31%, while reducing cooking time by around 18%. In addition to these benefits, they contribute to forest preservation and the fight against climate change [5]. The integration of high-performance materials, particularly refractory bricks, represents a major advance in the design of improved furnaces. These materials, capable of withstanding high temperatures, thermal shocks and chemical attacks, also have the particularity of storing and releasing heat for a long time [6]. Thanks to their controlled porosity, insulating refractory bricks reduce heat losses and considerably improve the energy efficiency of cooking systems. They thus play a key role in the thermal efficiency of furnaces, maintaining high temperatures for longer, while limiting fuel use and GHG emissions [7]. However, local production of refractory bricks remains limited, particularly in West Africa, where industries rely largely on imported materials, which increases manufacturing costs and hinders their diffusion [8]. To overcome this dependence, research has been conducted on the use of local raw materials and organic additives to manufacture porous refractory bricks at a lower cost. Materials such as

silica, magnesium, clay, and alumina have been shown to be effective in forming pores, improving thermal insulation, and lightening bricks [9-12]. In this context, clay appears to be an abundant local resource, commonly used but whose potential remains largely exploitable. Rich in minerals and fine matter, it could be further exploited as a basic material in the production of insulating refractory bricks, particularly thanks to its ability to bind effectively to pore-forming additives.

This work therefore aims to study the insulating behavior of refractory bricks made from clay with the aim of developing an alternative, accessible and efficient raw material for the domestic production of refractory bricks. Such an innovation would contribute to reducing dependence on imports, lowering production costs, and supporting the widespread use of improved furnaces in the service of the energy transition and the fight against deforestation.

2. Materials and Methods

2.1. Materials

2.1.1. Materials Used

The furnace was made with:

- 10mm sheet of metal
- 35mm steel corners
- grid
- refractory bricks
- four casters

2.1.2. The Different Parts of the Furnace

Refractory bricks: They serve as insulation in the coal combustion chamber to limit heat loss. They are 4 cm thick and are placed on the side surfaces.

The grate: this is the part of the furnace where the charcoal will be placed, or the combustion chamber. It is placed 5 cm above the bottom of the oven to be as close to the bottom as possible and also to ventilate the combustion space.

The supports and the casters: they allow the furnace to be kept balanced depending on the location and also ensure its mobility.

Figure 1 and Figure 2 show the refractory bricks in the furnace and the furnace with the grate respectively.



Figure 1. Refractory bricks in the furnace



Figure 2. The furnace made with the grid

2.1.3. Measuring Devices

The masses are recorded using a balance. The temperatures are monitored using a data logger connected to thermocouples. An aluminum container is used as a pot to hold the water.

Figure 3 shows the data logger and thermocouples used.



Figure 3. Data logger and thermocouples

2.2. Experimental Protocol

The Boiling Water Test (BWT) is a cooking simulation. It is conducted in three (03) phases [8]:

The high power phase with cold start, the test begins with the furnace at room temperature and uses a pre-weighed batch of coal to bring a measured amount of water to a boil in the pot. Then this boiling water is replaced by water at room temperature to carry out the second phase of the test.

The high power phase with hot start is conducted after the first phase while the furnace is still hot. Again, we use the remaining pre-weighed coal to boil this measured amount of water. Performing this test at high power helps identify the differences in furnace performance when it is cold and when it is hot.

The low power or simmer phase reveals the amount of coal needed to simmer a quantity of water for 45 minutes. This stage of the test simulates long-term cooking. During this phase, the water temperature must not drop more than 6°C below the boiling point. If this happens, the test is invalid.

In order to demonstrate the ability of refractory bricks to store heat, we conducted a second set of tests during which combustion continued after the water boiled until the coal was completely consumed and the furnace cooled. The temperatures of the water in the pot and on the surfaces (internal and external) of the furnace were

measured at five-minute intervals. The masses of the water and coal were also recorded.

Figure 4 shows a photo of the water heating test



Figure 4. Water boiling test

2.3. Performance Calculation Equations

- In order to ensure accurate and consistent assessments of actual capacities, we will use the

$$\eta_G = \frac{4,18[(M0 - MV)(100 - T0) + 2260(M0 - M1)]_{froid} + 4,18[(M1 - MV)(100 - T0) + 2260(m1 - m2)]_{chaud}}{29000[(F0 - F1)_{froid} + (F1 - F2)_{chaud}]} \quad (5)$$

- Total coal consumption CT is calculated with equation (6)

$$CT = F0 - F2 \quad (6)$$

- Mass of evaporated water M_{ev} is given by equation (7)

$$M_{ev} = M0 - M2 \quad (7)$$

Each of these parameters is calculated for each test (cold and hot)

Table 1 and Table 2 give the masses of water and coal at the start of the different tests.

Table 1. Test data with the furnace without refractory bricks

Mass Matter	Initial mass (kg)	Boiling mass cold start (kg)	Boiling mass hot start (kg)
Water	5.34	4.39	3.71
Coal	3.75	3.39	2.59

Table 2. Test data with a furnace equipped with bricks

Mass Matter	Initial mass (kg)	Boiling mass cold start (kg)	Boiling mass hot start (kg)
Water	5.34	4.56	3.39
Coal	3.75	3.42	3.27

Table 3. Values of the different calculated parameters

	TE(min)	TES1(min/l)	TES2(min/l)	CS1(kg/l)	2(kg/l)	$\eta_1(\%)$	$\eta_2(\%)$	$\eta_G(\%)$	CT(kg)	Mev(kg)
Furnace without refractory bricks	24	10.35	7.63	0.14	1.17	30	14.79	13.38	1.16	1.63
Furnace with refractory bricks	17	7.10	5.83	0.13	0.13	18.58	40	48.12	0.48	1.93

initial water temperature correction coefficient. In fact, the water temperature will be brought back to the standard temperature of 25°C using the following formula:

$$K = \frac{100}{100 - T0} \quad (1)$$

- The specific boiling time (SBT) is determined by equation (2)

$$TES = \frac{TE}{M1 - MV} * \frac{100}{100 - T0} \quad (2)$$

- Consumption (Csp) is calculated by equation (3)

$$Csp = \frac{F0 - F1}{M1 - MV} * \frac{100}{100 - T0} \quad (3)$$

- The thermal efficiency η is calculated by the relation

$$\eta = \frac{4,18(M1 - MV)(100 - T0) + 2260(M0 - M1)}{29000(F0 - F1)} \quad (4)$$

- Overall performance η_G is calculated with equation (5)

3. Results and discussion

The results of the various tests obtained are recorded in tables or represented in the form of curves.

Table 3 shows the values of the different calculated parameters

The results show a clear superiority in the specific boiling time of the furnace with refractory bricks: the water reaches boiling in just 17 minutes compared to 24 minutes for the furnace without refractory bricks. This difference is explained by a faster temperature rise in the furnace with refractory bricks. This result shows that refractory bricks play a role as thermal insulation. Fuel consumption is another important indicator. The test revealed a consumption of 1.16 kg of coal for the furnace without refractory bricks, while the furnace with refractory bricks required only 0.42 kg, a reduction of more than 63%. This substantial saving highlights the thermal advantage of refractory bricks, which limit energy losses. The standard fireplace has an efficiency of 0.13, while the fireplace with refractory bricks achieves an efficiency of 0.48. This represents a significant improvement in energy efficiency. In order to demonstrate the ability of refractory bricks to store and release heat, a series of tests were carried out using the same quantity of coal.

Figure 5 shows the changes in the temperatures of the water and the furnace equipped with refractory bricks.

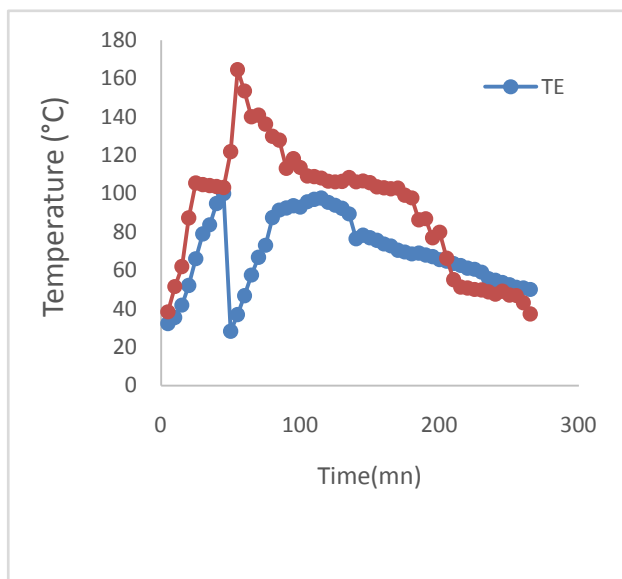


Figure 5. Evolution of water temperature (TE) and furnace temperature (TF) during the tests

The entire amount of coal was consumed during the first phase of the test. This caused a drop in temperature within the furnace. The evolution of the furnace temperature curve subsequently shows a slow decrease. Despite the lack of fuel in the furnace, the water temperature reached 100°C. These results show that the refractory bricks gradually released heat inside the furnace.

These observations confirm that the integration of refractory bricks significantly improves the thermal performance of the cooking system, while reducing fuel consumption, making it an advantageous solution both in terms of energy and economy. Dianda et al., 2024

obtained a thermal efficiency of 38% with an improved fireplace with two sources, primary and secondary [13]. The different results obtained with refractory bricks, in comparison with some of the literature, show that our fireplace is quite efficient.

4. Conclusion

Our work involved determining the contribution of refractory bricks to a charcoal fireplace. The results showed a reduction in total charcoal consumption of approximately 64% and an improvement in overall efficiency of over 72%. The addition of refractory bricks therefore provides financial and environmental savings.

Nomenclature

- TES: Specific boiling time (min/l).
- TE: Time required to reach boiling (min)
- CS: Specific coal consumption (kg/l).
- η : Thermal efficiency of the furnace (%).
- η_G : Total or overall thermal efficiency of the furnace (%).
- CT: Total coal consumption during the test (kg)
- Mev: The mass of water evaporated during the test (l)

References

- [1] SC Bhattacharya, DO Albina, and P. Abdul Salam, "Emission factors of wood and charcoal-fired cookfurnaces", *Biomass and Bioenergy*, vol. 23, no. 6, pp. 453–469, 2002.
- [2] SD Pohekar, D. Kumar, and M. Ramachandran, "Dissemination of cooking energy alternatives in India - A review", *Renewable and Sustainable Energy Reviews*, vol. 9, no. 4, pp. 379–393, 2005.
- [3] S. Narnaware and D. Pareek, "Performance analysis of an inverted downdraft biomass gasifier cookfurnace and its impact on rural kitchen", *International Energy Journal*, vol. 15, no. 3, pp. 123–134, 2015.
- [4] African Energy Commission (AFREC), 2019.
- [5] The Center for International Forestry Research (CIFOR), Press release, 2022.
- [6] Komori S., Komatsubara K., and Suetake S, "Recent Technical Developments of Refractories and Ceramic Fiber Products for Reheating Furnace" Reports, 66(1), 1-11, 2023.
- [7] Khuram Rashid, Ehsan Ul Haq, Muhammad Sajid Kamran, Nazish Munir, Amber Shahid, Iqra Hanif, "Experimental and finite element analysis on thermal conductivity of burnt clay bricks reinforced with fibers", *Construction and Building Materials* Volume 221, 10 October, 190-199, 2019.
- [8] Esezobor DE, Obidiegwu EO and Lawal GI, "The Influence of Agro-forestry waste additive on Thermal Insulating Properties of refractory bricks from Osiele Clay", *Journal of Emerging Trends in Engineering and Applied Sciences*, 5(5), 305-311, 2014.
- [9] Mgbemere HE, Obidiegwu EO, and Ubong AU, "The Effects of Sintering Temperature and Agro Wastes on the Properties of Insulation Bricks", *Nigerian Journal of Technological Development*, 17(2), pp.113-119, 2020.
- [10] Angel G., Albena Y. and Stoyan D, "Effect of Wheat Straw and Sunflower Seeds Husks as Pore Forming Agents on the Properties of Porous Clay Bricks", *Journal of Chemical Technology and Metallurgy*, 52(5), 885-891, 2017.
- [11] Davies Oladayo Folorunso, Fatai Olufemi Aramide, Peter Olubambi, Joseph Olatunde Borode, "The Effects of Firing Temperature on the Performance of Insulating Firebricks Containing Different Proportion of Alumina and Sawdust", *Journal of Minerals and Materials Characterization and Engineering*, 3(4), 309-317, 2015.

- [12] Obidiegwu EO, Ochulor EF and Mgbemere HE, "Evaluation of Thermo-Mechanical Properties of Insulating Refractory Bricks Made from Indigenous Clay Mixed with Gmelina Seed Shells Particulates", *ABUAD Journal of Engineering Research and Development* , 3(2), 19-26, 2020.
- [13] DIANDA Boureima, OUEDRAOGO Lareba Adélaïde, COMPAORE Abdoulaye, ZONGO Wendtoin Estelle, KAM Sié and Dieudonné Joseph Bathiébo, "Experimental study of improved cookfurnace with primary and secondary sources", *World Journal of Advanced Research and Reviews* , 23(01), 907–917, 2024.



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