American Journal of Environmental and Resource Economics
2023; 8(3): 52-57
http://www.sciencepublishinggroup.com/j/ajere
doi: 10.11648/j.ajere.20230803.12
ISSN: 2578-7861 (Print); ISSN: 2578-787X (Online)

Energy Analysis of Rice Husk as Source of Cooking Fuel

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To cite this article:
Muhammad Salihu Balarabe. Energy Analysis of Rice Husk as Source of Cooking Fuel. *American Journal of Environmental and Resource Economics*. Vol. 8, No. 3, 2023, pp. 52-57. doi: 10.11648/j.ajere.20230803.12

Received: August 25, 2023; **Accepted**: September 11, 2023; **Published**: September 25, 2023

Abstract: This study explores the untapped potential of rice husk waste as a sustainable energy source in Nigeria, a nation facing increasing energy demands. I conducted a comprehensive analysis of rice husk composition, encompassing crucial factors such as moisture (13.80%), ash (10.25%), volatile matter (63.30%), and fixed carbon (12.62%). Additionally, I explored the ultimate composition, revealing percentages of carbon (75.94%), oxygen (18.52%), hydrogen (6.32%), nitrogen (0.91%), and sulfur (0.38%). Remarkably, rice husk boasts an impressive Average Higher Heating Value of 14.40 MJ/Kg, positioning it as a promising and environmentally friendly alternative to conventional biomass sources like wood and coal. This research is pivotal for Nigeria's sustainable energy future, offering an eco-conscious solution to energy needs while reducing reliance on fossil fuels. By harnessing the power of rice husk waste, It can contribute to a cleaner and more sustainable energy landscape, thereby mitigating environmental impacts and enhancing energy security. The potential benefits extend beyond Nigeria, as similar regions facing energy challenges can also adopt this sustainable approach. This study underscores the viability of rice husk waste as a valuable renewable energy resource, providing a path towards a greener and more energy-efficient future. Its utilization not only addresses Nigeria's energy demands but also aligns with global efforts to combat climate change by reducing greenhouse gas emissions associated with traditional energy sources. This research serves as a catalyst for further exploration and adoption of sustainable energy solutions worldwide.

Keywords: Energy, Rice Husk, Composition, Biomass, Sustainable

1. Introduction

In response to the energy crisis and escalating domestic cooking fuel costs, society is shifting towards renewable resources such as solar energy, wind energy, and biomass materials [1]. In many developing nations, like Nigeria, the practice of recycling agricultural waste products into valuable resources remains uncommon. Consequently, this has given rise to environmental challenges, including pollution leading to the accumulation of refuse on our streets, clogged drainage systems, and waterways. Such conditions have, in turn, contributed to flooding during rainy periods due to the obstruction of water flow. Moreover, this disposition has also played a role in the outbreak of epidemics within our communities today [2]. The agricultural residues with minimal collection and drying challenges, typically linked to biomass, include rice husk, groundnut shells, and coffee husk, which are obtained through a drying process [3].

Rice husk, a by-product of rice production and a naturally abundant waste, is prevalent in various regions of the country, particularly in Northern Nigeria. Currently, it is commonly disposed of through burning in fields, along roads, or by dumping along riverbanks or lagoons. Astonishingly, each year, over 6.5 million metric tons of rice husks are discarded Widely, representing a significant untapped potential for generating ample energy for domestic purposes [4-6]. Rice husk, a common by-product of rice, possesses a calorific value of approximately 3000 kcal per kilogram. Despite its lower calorific value compared to wood and other agricultural residues, rice husk stands out as an excellent biomass fuel due to its good flow ability, moderate moisture content (Usually 10-12%), and lower ash content with fewer alkaline minerals [7]. Ultimate and proximate analyses serve the purpose of determining the elemental compositions within rice husk waste. These compositions encompass nitrogen content, oxygen content, hydrogen content, total carbon, sulfur content, as well as moisture content, volatile matter, ash content, and fixed carbon. These parameters assume significant importance when evaluating a feedstock's suitability as an energy source [8].

Fuel encompasses natural or synthetic organic materials utilized as both energy sources and raw materials in various industries. Fuels, based on their state of aggregation, are categorized into three main types: solid, liquid, and gaseous [9]. The discovery of rice husk as a new solid fuel source offers a sustainable solution to curbing the widespread disposal of rice husk in Nigeria's rice-growing regions. This, in turn, contributes significantly to the reduction of tree cutting for fuelwood, ultimately mitigating the risk of desertification over time [2].

This research aims to analyze the proximate and ultimate compositions of a rice husk sample and, using the findings from these analyses, calculate its energy content, specifically the Higher Heating Value.

2. Materials and Procedures

2.1. Collection of Rice Husk Sample

Rice husk sample was obtained from Tudun wada Gusau, Zamfara state, Nigeria.

2.2. Sample Preparation

The rice husk was finely ground using a clean, dry mortar and pestle, and the resulting sample, labeled as Sample A, was stored in a polyethylene bag in a dark cupboard at room temperature for analysis.

2.3. Procedures

The procedures employed in this study adhere to the guidelines and recommendations set forth by the American Society for Testing and Materials (ASTM 1991, 1992, 1998, 2003) and the Association of Official Analytical Chemists (AOAC, 1989).

2.3.1. Moisture Content

The procedure involved measuring the weight of the crucible using a digital weighing balance, recorded as w_1 (g). Using a spatula, 2g of finely pulverized rice husk sample was placed inside the crucible. The crucible's weight was then measured and noted as w_2 (g). Subsequently, the crucible, along with its contents, underwent heating in a muffle furnace at 105°C for one hour. Afterward, the crucible was removed, allowed to cool in a desiccator, and its weight was recorded as w_3 (g) [11].

The calculation for the percentage moisture content (% M.C) was performed using the following formula:

$$\%\, M.C = \frac{w2 - w3}{w2 - w1} \times 100$$

Where: (w_2 - w_3) represents the loss in weight of the rice husk sample.

(w_2 - w_1) signifies the initial weight of the rice husk sample.

2.3.2. Volatile Matter

A 2g portion of moisture-free, finely pulverized rice husk sample was placed in a crucible and weighed using a digital weighing balance, denoted as w_1 (g). The sample was then subjected to heating in a covered crucible in a muffle furnace, maintaining a temperature of 950°C for 7 minutes. After the process, it was allowed to cool within a desiccator and weighed once more on the digital balance, recorded as w_4 (g) [11].

To calculate the percentage of volatile matter (% V.M), the following formula was applied:

$$\%\, V.M = \frac{w3 - w4}{w3 - w1} \times 100$$

Where: (w_3 - w_4) represents the loss in weight of the moisture-free rice husk.

(w_3 - w_1) signifies the initial weight of the moisture-free rice husk.

2.3.3. Ash Content

The process began with the weighing of the crucible on a digital balance, marked as w_1 (g). Using a spatula, 2g of the rice husk sample was carefully placed into the crucible, which was then measured and recorded as w_6 (g). The sample, in an open crucible, was subsequently subjected to combustion (in the presence of air) at a temperature of 750°C in a muffle furnace until a constant weight was attained. The remaining ash residue was measured and noted as w_7 (g) [10].

To determine the percentage of ash content (% Ash), the following formula was applied:

$$\%Ash = \frac{w7 - w1}{w6 - w1} \times 100$$

Where: (w_7 - w_1) represents the weight of the residual ash formed.

(w_6 - w_1) signifies the initial weight of the rice husk taken for analysis.

2.3.4. Fixed Carbon

The calculation for the percentage of fixed carbon (% F.C) was determined by subtracting the sum of the percentage of moisture, percentage of volatile matter (PVM), and percentage of ash content (PAC) from 100, as illustrated below [17].

$$\%\, F.C = 100 - (\%\, moisture + \%\, volatile + \%\, Ash)$$

2.3.5. Carbon

The percentage of total carbon in the rice husk sample was calculated directly by summing the values of volatile matter and fixed carbon, as indicated below [11].

$$\%\, total\ Carbon = volatile + fixed\ carbon$$

2.3.6. Nitrogen

The estimation of nitrogen in the rice husk sample was carried out using the Kjeldahl method. Initially, 2g of the prepared rice husk sample was measured and recorded as w_8 (g). The sample was then subjected to a series of chemical reactions in a Kjeldahl flask, with the aid of concentrated

H_2SO_4, K_2SO_4, and $CuSO_4$. This process converted the nitrogen in the rice husk into ammonium sulfate. The key steps involved were as follows [13].

Digestion (Degradation)

$$\text{Sample} + H_2SO_4 \longrightarrow (NH_4)_2SO_{4(aq)} + CO_{2(g)} + H_2O_{(l)}$$

(i) Distillation (liberation and capture of ammonia)

$$(NH_4)_2SO_{4(aq)} + 2NaOH \longrightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)} + 2NH_{3(g)}$$

$$NH_3 + H_3BO_3 \longrightarrow NH_4^+ + H_2BO_3^-$$

(ii) Titration

$$(NH_4)_2SO_{4(aq)} + H_2SO_4 + 2NaOH \longrightarrow Na_2SO_{4(aq)} + (NH_4)_2SO_{4(aq)} + 2H_2O_{(l)}$$

In the titration step, the volume of the unused acid was determined by titration against a standard solution of NaOH. The amount of acid neutralized by the liberated NH3 from the rice husk sample was then calculated using the formula:

$$(\text{Titer value})\ Vt = V_1 - V_2\ (Cm^3)$$

Where: V_1 is the volume of H_2SO_4 neutralized (cm^3)

V_2 is the volume of H_2SO_4 neutralized in determination (cm^3)

w_8 represent the mass of Rice husk sample (g).

Finally, the percentage of nitrogen was calculated as follows:

$$\%\ Nitrogen = \frac{Vt \times Normality \times 1.4}{w8} \times \frac{100}{1}$$

2.3.7. Sulfur (Eschka Method)

The total sulfur content in the rice husk sample was determined by igniting 2g of the sample with an Eschka mixture (2 parts calcium magnesium oxide and 1part anhydrous sodium carbonate). Sulfur was dissolved in water, precipitated as barium sulfate, filtered, ashed, and weighed to calculate the total sulfur content [14].

$$\%St = (A - B)/C \times 13.74$$

Where:

St stands for the total sulfur content.

A corresponds to the mass of barium sulfate derived from the sample.

B indicates the mass of barium sulfate obtained from the blank.

C represents the mass of the sample used.

2.3.8. Hydrogen

The percentage of hydrogen in the rice husk sample was derived from the proximate results using the following formula [14].

$$\%\ Hydrogen = 3.6 + 0.05V - 0.0035M^2\,(1 - 0.02M)$$

Where V = Volatile matter

M = Moisture content

2.3.9. Oxygen

The oxygen content in the rice husk sample was determined by subtracting from 100 the sum of the percentages of the other components of the ultimate analysis, including carbon, hydrogen, nitrogen, and sulfur, following the formula below [14].

$$\%\ O = 100 - (Carbon + Hydrogen + Nitrogen + Sulfur)$$

2.4. Calculation of Higher Heating Value

$$HHV = 0.1559VM + 0.3536FC + 0.0078ASH$$

[18].

The Higher Heating Value (HHV) is calculated based on the values of Volatile Matter (VM) and Fixed Carbon (FC).

3. Results

The results obtained in the laboratory analysis are presented in the Tables below for the dried samples of Rice husk. All analyses were conducted five times, and average values were determined.

Table 1. *Proximate analysis conducted with dried samples of Rice husk.*

Analysis	A_1 (%)	A_2 (%)	A_3 (%)	A_4 (%)	A_5 (%)	Average (%)
Moisture	14.28	15.00	16.00	10.71	13.04	13.80 ± 1.80
Ash	10.00	9.60	8.29	10.50	12.90	10.25 ± 1.51
Volatile	63.88	62.96	60.86	65.21	63.63	63.30 ± 1.42
Fixed Carbon	11.84	12.44	14.85	13.58	10.43	12.62 ± 1.50

Table 2. *Ultimate analysis conducted with dried samples of Rice husk.*

Analysis	A_1 (%)	A_2 (%)	A_3 (%)	A_4 (%)	A_5 (%)	Average (%)
C	75.72	75.4	75.71	78.79	74.06	75.94 ± 1.55
N	1.2	1.01	1.16	0.73	0.49	0.91 ± 0.27
S	0.41	0.48	0.27	0.41	0.34	0.38 ± 0.07
H	6.28	6.17	6.03	6.54	6.59	6.32 ± 0.21
O	16.59	16.94	20.83	13.53	18.52	18.52 ± 2.39
HHV (MJ/kg)	14.22	14.28	14.80	15.04	13.70	14.40 ± 0.47

4. Discussions

Proximate Analysis

Rice husk exhibits specific characteristics, as detailed in Table 1 above. These include a relatively high volatile matter content, a significant ash content, and a relatively low fixed carbon content. Analyzing the five rice husk samples, we observe variations in moisture content, volatile matter, fixed carbon, and ash content, ranging from 10.71% (A_4) to 16.0% (A_3), 60.86% (A_3) to 65.21% (A_4), 10.43% (A_5) to 14.85% (A_3) and 8.29% (A_3) to 12.9% (A_5), respectively.

Moisture content: Table 1 shows the moisture content results of the same five samples of rice husk. The values ranges from 10.71% (A_4) to 16.0% (A_3). Notably, these findings align with Beagle's 1978 report on moisture, volatile matter, fixed carbon, and ash content in rice husk, which falls within the range of 5% to 16%. Moisture content significantly affects rice husk's quality as a fuel source, with higher moisture content decreasing heating value and overall system efficiency due to energy consumption during vaporization. Thus, dry fuel material is preferable for combustion [19, 20].

Volatile matter: Table 1 shows the volatile matter content results of the same five samples of rice husk. The values ranges from 60.86% (A_3) to 65.21% (A_4). Regarding volatile matter, rice husk possesses relatively high levels compared to lignite and bituminous coals (25-40%). Volatile content is crucial as it characterizes the potential condensable vapor contamination in thermochemical conversion systems. Volatiles burn as gas products in the flame, influencing the combustion process, while fixed carbon burns more slowly. Due to its high volatile content, rice husk readily devolatilizes, yielding less fixed carbon residue than lignite and bituminous coals [21].

Ash Content: Table 1 shows the Ash content results of the same five samples of rice husk. The values ranges from 8.29% (A_3) to 12.90% (A_5). The ash content in rice husk (8.29-12.90%) is somewhat higher compared to wheat straw (3-5%). High ash concentrations can negatively impact thermal decomposition by catalyzing the process and resulting in increased carbon and gas concentrations. Biomass ash has a relatively low melting point, leading to ash melting during thermal processes, generating slag. Slag formation obstructs energy transfer and reduces combustion efficiency [23, 24].

Fixed carbon: Table 1 shows the fixed carbon results of the same five samples of rice husk. The values ranged from 10.43% (A_5) to 14.85% (A_3) which is less than that of cocoa husk (23.80%) and peanut husk (21.09%) reported by Ebeling, J. M et al. [25]. Higher fixed carbon content positively influences combustion properties [25].

Ultimate Analysis

The ultimate analysis results for the rice husk samples are displayed in Table 2. The weight fraction of carbon exhibits variation, ranging from 74.06% (A_5) to 78.79% (A_4) Oxygen content displays a range of 13.53% (A_4) to 20.83%(A_3) while hydrogen content fluctuates between 6.03% (A_3) to 6.59% (A_5). These measured values for carbon, oxygen, and hydrogen align with the reported ranges by Ebeling, J. M et al. [25]. Discrepancies in these results may be attributed to seasonal variations when the rice husk was collected and analyzed by Ebeling, J. M et al. [25]. Nitrogen content exhibits variability, spanning from 0.49% (A_5) to 1.2% (A_1) while sulfur content ranges from 0.27% (A_3) to 0.48% (A_2).

Carbon as depicted in Table 1 for the five rice husk samples, exhibits a range of values, spanning from74.06% (A_5) to 78.79% (A_4) This falls in proximity to the range for coal, which is reported to be within 78.26% to 83.37% by Solomon A. R et al. [26]. This observation underscores the significance of carbon content in biomass composition, as its higher presence substantially enhances the heating value of biomass [27].

Hydrogen Table 1 presents the percentage results for the five rice husk samples, ranging from 6.03% (A_3) to 6.59% (A_5) These values are slightly higher than the reported range for coal, which typically falls between 5.73% and 6.00%, as indicated by Solomon A. R et al. [26]. Hydrogen content, in conjunction with carbon, plays a pivotal role in determining the energy properties of solid fuels. It contributes significantly to the heating value of the fuel, and during pyrolysis, a substantial portion of the hydrogen is found within the volatile matter [27].

Oxygen as presented in Table 1 for the five rice husk samples, exhibits a range of values from 13.53% (A_4) to 20.83% (A_3) These values surpass the oxygen content typically found in coal, which typically falls within the range of 7.98% to 12.55%, as reported by Solomon A. R et al. [26]. Oxygen content holds significant importance in biomass characteristics, as the presence of more oxygen in biomass facilitates easier ignition and combustion initiation [28, 29].

Nitrogen as indicated in Table 1 for the five rice husk samples, exhibits a range from 0.49% (A_5) to 1.2% (A_1) These values reflect significantly lower nitrogen content when compared to coal, which typically ranges from 1.0% to 3.0%, as reported V. Sekaren [30]. These low levels of nitrogen, along with the relatively low sulfur content, contribute to environmentally preferable fuel properties.

Sulfur as presented in Table 1 for the five rice husk samples, varies from 0.27% (A_3) to 0.48% (A_2) These values indicate a relatively low sulfur content in the rice husk samples, as opposed to coal, which typically contains sulfur levels ranging from 1% to 3%, as reported in the literature [30]. These reduced fractions of both nitrogen and sulfur contribute to more environmentally desirable fuel properties.

Heating Values

In this research, the higher heating value (HHV) of rice husk ranges from 13.70 MJ/Kg (A_5) to 15.04MJ/Kg (A_4) These values closely approximate the HHV of dry firewood, which stands at approximately 16 MJ/Kg, as well as sub-bituminous coal with a range of 17.4 to 23.9 MJ/Kg, as reported by NIST chemistry WebBook [31]. The heating value is a crucial thermal property essential for modeling thermochemical conversion systems [32]. HHV represents the amount of sensible heat that can be released during fuel combustion, and it flows steadily in a condensed state [33]. The HHV of rice husk yields reasonable estimates when compared to other biomass heating values.

5. Conclusions

This research explores the feasibility of utilizing rice husk for energy generation. The experimental analysis leads to the following key findings:

1. Sustainable Energy Source: Rice husk, abundantly produced by rice mills and farms, can be transformed into a high-quality solid fuel. This conversion not only mitigates environmental pollution caused by direct burning but also establishes rice husk as a sustainable energy source.
2. Environmental Benefits: Utilizing rice husk as a solid fuel reduces environmental harm and lowers the carbon footprint compared to conventional fossil fuels. This shift towards cleaner energy sources aligns with global sustainability goals.
3. Versatility: Rice husk-derived solid fuel exhibits versatility, making it suitable for various applications, including domestic heating, electricity generation, and industrial processes. Its adaptability adds value to its use.
4. Cost-Effective Solution: Leveraging rice husk as an energy source can yield cost-effective solutions, particularly in regions with a substantial rice production base. This can lead to economic advantages for both individuals and industries.

In summary, this study underscores the immense potential of rice husk as a sustainable and practical energy resource. By harnessing rice husk, we can take significant steps toward a cleaner, more affordable, and environmentally responsible energy future.

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