Conversion of Rice Husks into an Energy Source through Gasification Technology

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Abstract: ***Kenya generates about 20 metric tonnes of rice husks which currently presents a burden to the environment in its disposal. Disposal usually is by burning or used to fill potholes or thrown by the roadside. With the foregoing, positive utilization of the rice husks in a gasifier stove as a fuel energy source will present a cheap, environment friendly and renewal alternative. The rice husks properties were determined from samples collected from Mwea rice mills (MRM). A gasifier stove to suit the fuel properties and the energy needs of a family of six in Mwea was then developed using locally available materials. Performance of the stove was tested using Water Boiling Test (WBT) and Controlled Cooking Test (CCT). The results of one-way analysis of variance at 5% level of significanceshows no significant difference in moisture content of fresh rice husks samples ($p>0.05$) while there is a significant difference in the bulk density ($p<0.05$). The gasifier stove performance and operating conditions was good with a thermal efficiency of 25.67%, Specific fuel consumption of 121g/liter and cooking time of 22mins. The resulting char has a calorific value of 7810kJ/Kg which can be used to make energy briquettes, as a propagation media for rice or as a soil additive.***

Keywords: Biomass, Carbonization, Gasifier stove, Rice husks

1. Introduction

1.1 Current sources and status of energy consumption in Kenya

Nationally wood fuel and other biomass account for 68% of the total primary energy consumption followed by petroleum at 22%, electricity at 9% and others at about 1% [1]. Upto 90% of the energy needs of rural households is from biomass energy that is firewood, charcoal and agricultural wastes of which a third is in the form of firewood [2]. This state of affairs has major adverse implications to the forest resources and on people's health resulting from indoor air pollution hence unsustainable. Many of the developing countries produce huge quantities of agricultural waste with the major once being rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks. Sawdust, a milling residue is also available in huge quantity.

1.2 Gasification

Gasification is the process of converting biomass into a combustible gas by thermo-chemical reaction of the oxygen in the air and the carbon available in these materials during combustion [3]. In complete combustion of fuel, the process takes place in excess air. In gasification process, on the other hand, it is accomplished with excess carbon. In order to gasify rice husks about 30 – 40% of the stoichiometric air (4.7kg of air per kg of rice husk) is needed [4].

1.3 Gasifier Stove

The operating performance of the rice husk gasifier stove basically depends on the type of the reactor used. Although there are several types of combustor that can be used for rice husks, the T-LUD or IDD under the down-draft type gasifier was proven to work well with rice husk as compared with the traditional bottom-lit downdraft type, cross-draft type, or updraft-type reactors [5]. Of the different types of reactor, the T-LUD/IDD Gasification has better operating characteristics in terms of ease of starting the fuel, least smoke emitted, and tar produced during operation [6].

2. Materials and Methods

To develop and evaluate the gasifier stove for rice husks, field visits, fabrication and tests were carried out in Biomechanical and Environmental Engineering Department of the Jomo Kenyatta University of Agriculture and Technology and Mwea. The tests involved determining the characteristics of the rice husks and biomass stove performance.

2.1 Characteristics and Availability of the rice husks

2.1.1 Determination of moisture content

Rice husks from freshly milled paddy rice were collected from Mwea Rice Mills (MRM) in Mwea. The rice husks were transported to JKUAT and moisture content determined using the oven dry method [7].

2.1.2 Measurement of bulk density

For meaningful results it was necessary to select a representative sample of the particulate solid with respect to moisture content, particle-size distribution and temperature. For the tests fresh rice husks sample for each individual test specimen and size sample of approximately 100g was used.

2.1.3 Measurement of Ash content

Standard method (ASTM E1755-010) for determination of Ash in Biomass was used [8].

2.1.4 Rice Husks Quantities

Useful in determining sustainability and energy contribution potential of the rice husks in the Mwea region. Total rice production was obtained and total rice husks calculated.

2.2 Development and testing of gasifier stove

Gasification of rice husks is accomplished in an air sealed chamber. Limited amount of air is introduced by a fan into the fuel column to convert the rice husks into carbon-rich char so that by thermo-chemical reaction it would produce carbon monoxide, hydrogen and methane gases, which are combustible when ignited. The batch feed, Top-Lit Updraft (T-LUD) also known as Inverted Downdraft (IDD) under the down-draft type gasifier was used in the reactor.

2.2.1 Design Consideration

Important parameters in determining size of gasifier stove included:

2.2.1.1 Energy requirement

This was determined based on the type and quantity of food or water cooked or boiled and their specific heat energy as shown by Table 3.1.

Table 3.1: Energy Requirement for Cooking Food and for Boiling Water

Food	Specific Heat (kJ/kg.^{0}C)	Total energy needed (kJ/Kg)*
Rice	1.76 – 1.84	331.79
Meat	2.01 – 3.89	236.40
Vegetables	3.89	311.71
Water	4.19	301.25

*at 72 °C temperature difference

Source:http://www.fao.org/docrep/t0512e/T0512e00.htm#Contents

$$Q_n total = Q_n rice + Q_n greengrams + Q_n water$$

= 1327.16 + 1628.828 + 1205

= 4160.988kJ/hr

The energy input from fuel considers the stove efficiency and heating value of fuel and is given by equation 3.1 below.

$$FCR = \frac{Q_n}{HV_f \zeta_g} \qquad 3.1$$

Where: FCR – Fuel consumption rate, Kg/hr

Q_n – heat energy requirement, kJ/hr

HV_f – heating value of fuel, kJ/kg

ξg – Gasifier stove efficiency, %

Based on the above assumption, the amount of fuel needed per hour for a biomass gasifier stove to be used to cook rice and also assume a stove efficiency of 17%. The heating value of fuel of rice husks is 12,552kJ/kg.

$$FCR = \frac{4160.988kJ/hr}{12{,}552kJ/kg \times 0.17}$$

$$= 1.95kg/hr$$

= 2kg of biomass per hour (when rounded off)

2.2.1.2 Cross-sectional Area and Height of the Reactor

Circular rather than rectangular or square cross section ensures uniform gasification. Height of the reactor affect operation time and gas amount produced. Usually the combustion zone moves down the entire height of the gasifier reactor at a speed of 1-2cm/min. However the higher the reactor the more pressure required to overcome resistance. Diameter is a function of the amount of the fuel consumption rate (FCR) to the specific gasification rate (SGR) of rice husks which is in the range of 110 - 210 kg/m^2-hr as expressed in equation 3.2

$$D = \left(\frac{1.27FCR}{SGR}\right)^{0.5} \qquad 3.2$$

Where: D – Diameter of kiln, m

FCR – Fuel consumption rate, Kg/hr

SGR – Specific gasification rate of rice husk, 110 – 210 kg/m^2-hr

Taking a specific gasification rate, SGR of rice husk to be 110kg/m^2-hr, the diameter, D is calculated as below.

$$D = \left(\frac{1.27 \times 2}{110kg/m^2 - hr}\right)^{0.5}$$

$$= 0.15m$$

Height determines how long the stove would be operated in one loading of fuel. It's a function of time required to operate gasifier (T), specific gasification rate (SGR), and the density of rice husks (ρ_{rh}) as expressed in equation 3.3

$$H = \frac{SGR \times T}{\rho_{rh}} \qquad 3.3$$

Where: H – Height of the reactor, m

SGR - specific gasification rate of husks, Kg/m^2-hr

ρ_{rh} - density of rice husks, Kg/m^3

Taking the SGR to be 100kg/m^2-hr, ρ_{rh} as 100kg/m^3 and time of operation as 20mins, the height of reactor is found as:

$$H = \frac{100kg/m^2 - hr \times 0.33}{100kg/m^3}$$

$$= 0.33$$

= 0.35metres when rounded

2.2.1.3 Time to consume Rice Husks

Includes ignition plus time to completely burn all husks in the reactor and is given by equation 3.4. It's a factor of rice husks density, volume of reactor and fuel consumption rate.

$$T = \frac{\rho_{rh} \times V_r}{FCR} \qquad 3.4$$

Where: T – Time required to consume the rice husks, hr

Vr – Volume of the reactor, m^3

ρ_{rh} – Rice husks density, Kg/m^3

FCR – Rate of consumption of rice husk, kg/hr

Assume a 0.15m diameter biomass gasifier stove with a 0.35m high reactor is to be operated at a fuel consumption rate of 2kg/hr. The time required to operate the stove will be,

$$T = \frac{\rho_{rh} \times V_r}{FCR}$$

$$= \frac{100kg/m^3 \times \pi \times 0.075^2 \times 0.35}{1.5kg/hr}$$

$$= 0.41hrs$$

$$= 24.71\text{minutes}$$

2.2.1.4 Amount of air for Gasification

This refers to the rate of flow of air needed to gasify rice husks. It's important in determining the size of the fan. This was determined using the rate of consumption of rice husks, the stoichiometric air of rice husks, and recommended equivalence ratio for gasifying rice husks(0.3 - 0.4) as expressed in equation 3.5

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho_a} \qquad 3.5$$

Where: AFR – Air flow rate, m3/hr
ε- Equivalence ratio, 0.3 – 0.4
FCR – Rate of consumption of rice husk, Kg/hr
SA – Stoichiometric air of rice husks, 4.5kg of air per kg rice husks
ρ_a – Air density, 1.2kg/m^3

With a fuel consumption rate, FCR of 100kg/hr, the Air flow rate is calculated as below

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho_a}$$

$$= \frac{0.3 \times 1.5kg/hr \times 4.5}{1.2kg/m^3}$$

$$= 1.688m^3/hr$$

2.2.1.5 Insulation of reactor

Rice husk ash was used as it's cheap and effective.

2.2.2 Fabrication of gasifier stove

Stainless steel (SS) sheet was used for construction of inner cylinder of the reactor and Mild steel for outer cylinder and for the char chamber. Sheet gauge 16 was used for the desired durability.

For the burner assembly, the outer cylinder is made of MS sheet material with the same gauge as that of the reactor with the inner cylinder which is in direct contact with the flammable gases made from SS sheet offering good resistance to heat. The pot support and the handle of the burner assembly including the frame for the char grate and the lever are also made of stainless steel material for better durability. The insulation of the stove is made of rice husk ash mixed with cement in equal ratios to form a good insulating material due to its high silica content. A d.c. fan operated with 6v battery was used to provide the air needed for gasification.

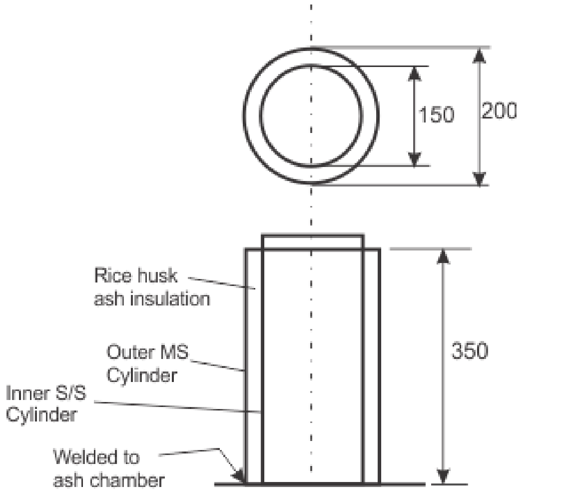

Figure 32.2.1.5: Drawing of the reactor (Dimensions in mm)

Plate 3.1: Gasifier stove under fabrication

2.2.3 Technical evaluation of gasifier stove

2.2.3.1 Water Boiling Test (WBT)

The Water Boiling Test (WBT) stove performance test protocol was initially developed by Volunteers in Technical Assistance (VITA) and was refined by the University of California-Berkeley in collaboration with Aprovecho Research Center (ARC) and other stove researchers [9],[10]. The WBT 4.2.3 and Aprovecho WBT 4.2.3 was used in this study to measure performance.

The following indicators of stove performance of particular importance to end-users and stove designers were obtained:The fuel consumed (moist), The net change in char, The mass of water vaporized, Time to boil,The temperature-corrected time to boil, The energy released by the fuel, The change in energy of the water, The equivalent dry rice husk consumed, Thermal efficiency, Specific fuel consumption, Temperature corrected specific fuel consumption, Firepower

2.2.3.2 Controlled cooking test

Controlled cooking test, CCT is performed in order to evaluate the performance of a cook stove while actually cooking food. This test differs from the WBT in the medium through which the heat is transferred. In contrast to water in the WBT, food is used as a medium in CCT.

The following indicators of stove performance are calculated from the measurements done; Total weight of food cooked, Weight of char remaining, Equivalent dry wood consumed, Specific fuel, Total cooking time

3. Results and Discussions

3.1 Characteristics and Availability of the rice husks

3.1.1 Moisture content

The different samples from the mills collected gave moisture content as shown in Table 3.3

Table 3.3: Rice husk moisture content from different samples in Mwea

	Sample	Moisture Content On Dry Basis (% db)				
		Test 1	**Test 2**	**Test 3**	Mean	*p*-value
1	Sample 1	12.30%	11.30%	11.50%	11.70%	0.842
2	Sample 2	11.80%	12.00%	12.10%	11.87%	
3	Sample 3	12.00%	11.50%	11.80%	11.77%	

The mean moisture content was found as 11% on wet basis. There is no significant difference in the moisture content of the samples as shown in table 3.3 ($p>0.05$).

3.1.2 Bulk density

The selected fresh rice husk representative sample gave the following results as shown in Table 3.4.

Table 3.4: Rice husk bulk densityfrom different samples and p-value in Mwea

Sample	Test 1ρ	Test 2ρ	Test 3ρ	**p-value**
Sample 1	114.94	115.38	114.4	0.00
Sample 2	110.00	110.33	109.67	
Sample 3	102.05	102.04	101.94	
Mean ρfor the three samples			108.97	

Bulk density, ρ in Kg/m^3

There is a significant difference in the bulk density ($p<0.05$) as shown in table 3.4.

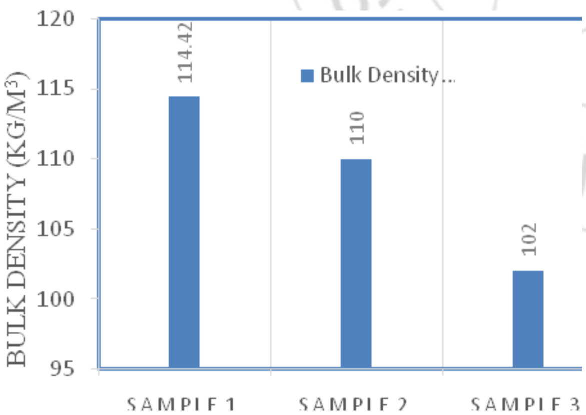

Figure 4.2.2.3.2: Graph showing comparison of bulk density of rice husks from three different samples

The bulk density of the rice husks ranges from 102kg/m^3 to 114.42kg/m^3. The varying bulk densities reflects the different rice varieties grown and milling machine efficiencies in Mwea. On the general, the very low bulk densities of rice husks makes it expensive to transport making it suitable for use at or close to the rice mill.

The summary of the physical and thermal properties of the obtained from samples from Mwea is as summarized in table 4.11.

Table 4.1: Summary of physical and thermal properties of Rice husks

Parameter	*Measurement*
Diameter (cm)	0.24cm
Length (cm)	0.95cm
Bulk density (kg/m3)	109
Moisture content (% wb)	11%
Ash content (% db)	20%
Calorific value (kJ/kg)	13,250

3.1.3 Rice husks quantities in Mwea

The total paddy rice quantities handled by the millers is 50,476 tonnes [11] (KNBS, 2013) hence giving a rice husk production of 10,095.2tonnes (Taking a 20% rice husk production per kilogram paddy rice). This translates to an energy resource of 1.439X10^8 MJ per annum in Mwea from the rice husks.

3.2 Development and testing of gasifier stove

3.2.1 Energy requirement and gasifier properties

From the calculations the following is a summary of the gasifier stove data shown in table 4.14

Table 4.14: Summary of the designed gasifier stove properties

Parameter	Specifications
Energy requirement design	4160.988kJ/hr
Reactor Inner diameter	0.150metres
Reactor Outer diameter	0.200metres
Height	0.350metres
Cross sectional area	0.018m^2
Insulation material	Rice husk ash and cement in equal ratios
Inner cylinder material	Stainless steel(S/S) Gauge 16
Outer cylinder material	Mildsteel (MS) Gauge 16
Fan	12 V Dc Fan

3.2.2 Technical evaluation of gasifier stove

3.2.2.1 Water boiling test

The results of the water boiling test are as tabulated in table 4.14.

Table 4.2: Water boiling test calculations

Parameter	Stage Results		
	Cold start	Hot start	Simmering
Fuel consumed (g) - f_{cm}	284g	284g	416g
Net change in char (g)-	59g	59g	118g
Mass of water vaporized (kg) - w_{cv}	59g	58g	168g
Temperature corrected time to boil (mins)	7	8	-
Burning rate (g/min)	19.4	16.7	6.3
Equivalent dry rice husk consumed (g)	117.00	116.59	101.26
Thermal efficiency (%)	25.69	25.69	29.36
Specific fuel consumption (g/liter)	121	121	126
Temperature corrected – SC (g/liter)	147.69	147.61	
Temp-corrected specific energy cons.	1951	1950	1682
Firepower (Watts)	4260.90	3842	1319

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Waste paper was used to light the stove from the top. Time to start up was measured beginning when the rice husks is ignited to when a producer gas is ignited. Start-up time for the stove is found to be 50sec with paper weight used 2.5g. Burning Rate which is a measure of the average grams of rice husk burned per minute during the test was 19.4g/min and 16.7g/min during cold start and high start respectively. Firepower which is a measure of how quickly fuel was burning, reported in Watts (Joules per second) was 4260.90watts and 3842watts during cold and hot start respectively. It is affected by both the stove (size of fuel entrance/combustion chamber) and user operation (rate of fuel feeding).

3.2.2.2 Controlled cooking test

From the data obtained during the controlled cooking test and formulas above and in comparison with the CCT excel data calculation sheet 2.0 the following results were obtained:

Table 4.3: Controlled cooking test calculations

Parameter	*Results*
Total weight of cooked food (w_f) - g	1711
Weight of char remaining (ΔC_c) - g	410
Equivalent dry wood consumed (f_d) - g	117
Specific fuel consumption (SC) – g/liter	121
Total cooking time (Δt) - mins	22

3.3 Conclusion

1) Rice husks from the mills was found to have suitable moisture content for use in the stove thus requiring no further drying. Higher density rice husks were found to have more starting time compared to lower density ones but produced a bluer flame.
2) The gasifier stove required artificial air supply for proper gasification of rice husks to occur. The gasifier stove development gave a thermal efficiency of 25.67%, running time of 22mins with specific fuel consumption of 121g/liter. This is sufficient to cook a simple meal for a family of average six (6) members.

4. Acknowledgements

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