



## EFFECTS OF INSULATION MATERIALS AND FUEL TYPE ON THE COMBUSTION PERFORMANCE OF A BIOMASS COOKSTOVE

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### ABSTRACT

Insulation material is a vital component of a cookstove while determining the amount of useful energy converted to heat. The objective of this study is to assess two insulation materials (fibre glass and ceramic) and three biomass briquettes (saw dust, rice husk and sugarcane bagasse) to determine the performance of a double burner conventional biomass cookstove while conducting water boiling test. The dependent variables used for the test were the specific fuel consumption (SFC), thermal efficiency, ebullition time and cooking energy cost as key indicators for comparison. Three types of tests were conducted on the cookstove: cold start, hot start and simmer phase. Results obtained show that the fire power for the cold starts phases were 8.8 kW, 7.72 kW for the fibre glass combustion chamber (FGCC) and ceramic combustion chamber (CRCC), respectively when the saw dust briquette was used, while 8.1 kW, 7.72 kW were respectively obtained for FGCC and CRCC when Rice husk briquette was used. Similarly, 8.72 kW and 7.99 kW were obtained for FGCC and CRCC, respectively when sugarcane bagasse briquette was used. The thermal efficiencies for FGCC and CRCC of 21.23 % and 19 %; 22.23 % and 19.32 %; 21.25 % and 19 % were obtained for the three tests. The energy efficiency of 42.47% was observed for fibre glass grate as compared to 34.56 % of Ceramics grates. Thus, the absorption of heat into the body of the ceramic material in the cold start phase results in better performance than hot start phase while hot start and simmer phases recorded higher values of efficiencies.

**Keywords:** Biomass, Briquettes, Combustion Chamber, Cookstove, Insulation Materials

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### INTRODUCTION

Most of the people living in the rural areas, especially in developing countries especially Nigeria, depend on biomass fuels such as wood, cow dung, and charcoal for cooking and other domestic heat requirements [1]. Combustion of these fuels is done indoors on open fires in most cases, with little or no means of ventilation. Extended exposure to biomass emissions significantly increases the risk of acute respiratory infections, chronic bronchitis, and obstructive pulmonary disease [2]. Approximately half a million premature deaths and nearly 500 million cases of illness are estimated to occur annually as a result of exposure to smoke coming from uncontrolled biomass combustion. It was reported that indoor air pollution is the third leading health risk affecting the people directly or indirectly especially women and female children in the rural areas and around the globe [3]. It was estimated that about 56% of the children are under the age of five [4].

However, awareness of the environmental and social cost of using traditional fuels and stoves has grown. At the same time, Research studies have resulted in proven strategies to reduce the problems associated with the use of the fuel and its harmful emission. Unfortunately, the local stoves currently available do not always represent the best designs that modern technology could offer. Heat transfer is currently

underutilized as a means of increasing stove thermal efficiency and through appropriate material selection for construction and the use of high energy biomass for solid fuel production. The greatest potential is, therefore, to enhance performance and provide more people with improved cooking procedures [5]. With over 2 billion of the world 's population using biomass energy to cook every day, the possibility of improved stoves which could help to mitigate climate change would generate increasing attention [6]. Previous studies on biomass briquetting has shown that Sugarcane Bagasse and Rice Husk has been proved to be good materials for briquette production. [7, 8]. The unsustainable use of solid fuels especially in conventional traditional cookstoves has over the years increased the rate of deforestation and emission of greenhouse gases, which has negatively impacted the climate. The objective of this study was, therefore, to investigate the effect of combustion chamber insulation material on the performance of a developed double burner biomass cookstove using three briquettes of different biomass sources as fuel (saw dust, rice husk and sugarcane bagasse).

### MATERIALS AND METHODS

The materials used in conducting the study includes water, fibre glass, ceramic fibre, saw dust, rice husk and



**Figure 1:** fiber glass combustion chamber



**Figure 2:** Ceramic combustion chambers

sugarcane bagasse. The equipment used for instrumentation are: 50 kg capacity weighing balance (WT1000KF, 0.001 accuracy), heat resistant pad used to protect the scale, digital thermometer (with an accuracy of 0.1°C), with thermocouple probe suitable for immersion in liquids, small shovel/spatula to remove briquette/charcoal from stove, tongs for handling charcoal, dust pan for transferring briquettes, small standard pot(s) of 3.5 litres and metal tray to hold charcoal for weighing, wood fixture for holding thermocouple probe in water, heat resistant gloves and three bundles of briquettes fuelwood (saw dust, rice husk and sugarcane bagasse) each weighing between 1 and 2 kg for each test.

Water is an inorganic, transparent, tasteless, odourless, and nearly colourless chemical substance, it was used for the water boiling test (WBT). Ten (10) liters of clean water was used for each WBT. Fiber glass is formed by bonding long glass fibers with a thermosetting resin to form blankets and batts, semi rigid boards, high density rigid boards and preformed pipe sections. It is available in two types: Fibrous is available as flexible blanket, rigid board, pipe insulation and other pre-molded shapes. Service temperature range is -40°F to 100°F. Cellular is second type of fibre glass that is available in board and block form capable of being fabricated into pipe insulation and various shapes.

Service temperature range is -450°F to 900°F, [9], Figure 1. Ceramic fiber is made from highly purity alumina and silica grains melted in an electric furnace and blasted by high velocity gases into light fluffy fibers. It is suitable for very high temperatures approaching 2800°F (Figure 2), [9]. Stove insulations or liners are the most essential part of the combustion chamber. Combustion insulators are typically exposed to temperatures of 600-800°C in natural-draft wood stoves and 600-1100°C in charcoal stoves [10]. It was constructed with a clay, molded to a circular shape of 126 mm diameter to a height of 250 mm, and fired under 900°C for 12 hrs. Biomass briquettes used are a biofuel substitute to coal and charcoal. Briquettes are used in this study are sugarcane bagasse, rice husk and sawdust based (Figure 3). The moisture content of all the briquettes were kept at 15% at the commencement of the tests, a moisture level safe for briquette storage [3].



**Figure 3 (a):** Sawdust briquettes



**Figure 3 (b):** Rice husk briquettes



Figure 3 (c): sugarcane bagasse

### Performance tests

Three types of test were conducted on the cookstove: cold start, hot start and simmer phase as recommended by FAO [3].

### Procedures for cold start

The procedure for cold-start (CS), high-power test began by tightly fitting the ceramic and fibre glass insulation materials separately into the double burner biomass cookstoves (Figure 4) at the same time at room temperature. The pre-weighed bundle of briquettes (saw dust, rice husk and sugarcane bagasse) were then used to boil 10 litres of water in two standard pots of 3.4 litres each. The boiled water was then replaced in two fresh pots of cold water to perform the second phase of the test. Thus The first stage begins with the water and the stove at room temperature with a gradual increase to boiling temperature, after which the pot and fuel were replaced with another set (same weight) at room temperature for the next phase i.e. the hot start [11]. The mass of fuel consumed and that of water evaporated were determined.



Figure 4: Pictorial view of the developed cookstove

### Procedures for hot start

The second phase, otherwise known as the hot-start (HS), high-power test, follows immediately after the first test while stove is still hot. The pre-weighed bundle of briquettes (saw dust, rice husk and sugarcane bagasse) were used to boil a 2.5 kg quantity of water in standard pots provided. Repeating the test with a hot stove helped to identify differences in performance between the two insulations in the stove when it was both cold and hot. The hot start phase, therefore, aims to perform the test with the stove preheated. The phase ends when the water reaches the boiling temperature [11].

### Procedures for simmer phase

The third phase (simmering phase) followed immediately after the second. Here, the amount of fuel required to simmer a 3.4 litre of water was determined at below boiling for 45 minutes. This combination of tests measures some aspects of the stove's performance at both high and low power outputs, which were associated with the stove's ability to conserve fuel. This stage would provide information about the amount of fuel needed to simmer a specific amount of water below its boiling temperature [11].

### Performance parameters

The thermal efficiency for boiling water was determined using Eqn. (1) as suggested by Bhatia [7].

$$\eta = \frac{M_w C_p (T_f - T_i) + h_{fg} M_{wv}}{M_{fw} E_{fw}} \times 100 \quad (1)$$

Where:  $\eta$  = thermal efficiency (%),  $M_w$  = mass of water (kg),

$C_p$  = specific heat capacity of water (J/kgK),  $T_f$  = boiling temperature ( $^{\circ}$ C),

$T_i$  = initial temperature of water ( $^{\circ}$ C),  $M_{wv}$  = mass of water evaporated (kg),

$h_{fg}$  = enthalpy of vapourization of water (kJ/kg),  $M_{fw}$  = weight of dry wood consumed (kg), and  $E_{fw}$  = calorific value of food fuel.

In situations where the fuel wood does not burn completely to ashes:

$M_{fw}$  = weight of wood burnt - weight of charcoal left (2)

while the fire power (P) represents the ratio of the wood energy consumed by the stove per unit time (W) during each phase of the test as presented in Eqn. (3), [9].

$$P = \frac{M_{fw} \times E_{fw}}{60(T_f - T_i)} \quad (3)$$

The specific fuel consumption ( $S_{fc}$ ) was determined using Eqn. (4) being the amount of fuel wood required to produce one litre of boiling water as suggested by Bhatia [9].

$$sfc = \frac{E_{fw}}{W_{wf}} \tag{4}$$

Where  $W_{wf}$  equals the weight of water boiled. The expression of  $S_{fc}$  in terms of quantity of the fuel wood consumed per unit mass of food cooked was expressed in Eqn. (5); [9].

$$S_{fc} = \frac{M_{fw} - \left| Mc \left( \frac{E_{fw}}{E_{ch}} \right) \right|}{1kg \text{ (food cooked)}} \tag{5}$$

Where:

$M_c$  = mass of charcoal remaining at the end of the test (kg)

$E_{ch}$  = calorific value of charcoal.

Energy costs otherwise referred to as the cost of thermal energy ( $C_t$ ) was determined from in Eqn. (6):

$$C_t = \frac{P_F}{M_{fw} \times E_{fw}} \tag{6}$$

(6)

Where:  $P_F$  = price of fuel; the product ( $M_{fw} \times E_{fw}$ ) = energy consumed, [7].

**Statistical analysis**

Results of WBT for the double burner conventional improved biomass cook stove were analyzed using the Independent sample t-test for unequal variances using Microsoft Excel (Version 2017) Statistical Package to determine the significant differences between the performances of the insulation materials (fibre glass and

ceramic) and three biomass briquettes (saw dust, rice husk and sugarcane bagasse) in terms of mass of fuel consumed and that of water evaporated. The analysis of variance (ANOVA) was to determine the effect of variation between the performance parameters and their interaction were assessed at 5% level of significance.

**RESULTS AND DISCUSSION**

Analyses of the WBT results and the performance evaluation of the two combustion chamber materials: Fibre Glass Combustion Chamber (FGCC) and Ceramics Combustion Chamber (CRCC) were presented for the various phases of the tests conducted: cold start phase, hot start phase, and low power simmering phase as presented below:

**Cold start phase**

Results obtained from the study (Table 1) indicates that there were no significant differences between the burning rate and firepower for high power cold start for all combustion chamber grate materials. However, what stood out was the difference between both the specific fuel consumption and the energy efficiency for ceramic compared with FGCC grates indicated a significant difference at  $p < 0.05$  level. It was also observed that energy efficiency was lower for FGCC grate; this could be due to the low thermal conductivity of the fibre glass. It acts as an insulation material absorbing some of the heat into the body of the stove and directing this heat to the cooking pot unlike the CRCC as earlier envisaged by Jetter and Kariher [12].

Specific fuel consumption for FGCC was observed to be lower compared to Ceramics. The energy efficiency of 21% obtained from the CRCC was closer to what was obtained by Jetter [12] who reported 25% energy efficiency on the Gyapa stove (Tables 2 and 3) The slight difference in value may be due to the difference in moisture content of fuel as well as the composition of the insulation material. This is in perfect agreement with findings of Jetter and Kariher [12].

**Table 1:** Analysis of Variance results for effect of fuel quantity, air inflow, and fuel size on thermal efficiency at high power cold start phase

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
<b>F</b>	2	0.03138	0.01569	174.98	<0.0001**
<b>A</b>	3	0.01854	0.00927	103.41	<0.0001**
<b>S</b>	1	0.00015	0.00015	1.70	0.2006NS
<b>F*A</b>	4	0.00450	0.00113	12.56	<0.0001**
<b>F*S</b>	2	0.00674	0.00337	37.58	<0.0001**
<b>A*S</b>	2	0.00382	0.00191	21.30	<0.0001**
<b>F*A*S</b>	4	0.01641	0.00410	45.75	<0.0001**
<b>Error</b>	36	0.00322	0.00009		
<b>Corrected Total</b>	53	0.08478			

\*= Significant at ( $P \leq 0.05$ ) \*\*= Significant at ( $P \leq 0.01$ ) NS= Not Significant

**Table 2:** Water Boiling Test for Cold Start

Parameters	Cold Start Phase		Hot Start Phase		Simmer Phase	
	FGCC	CRCC	FGCC	CRCC	FGCC	CRCC
Initial temperature (°C)	30	29.6	31	30.1	32.2	32.1
Initial Mass of Fuel (kg)	2.59	3.12	2.09	2.52	1.69	2.02
Final mass of fuel (k)	2.09	2.52	1.79	2.04	1.1	0.55
Mass of fuel consumed (kg)	0.437	0.491	0.341	0.392	0.5	1.194
Initial mass of water (kg)	1.95	1.95	1.95	1.95	1.5	1.55
Mass of water evaporated (kg)	0.45	0.41	0.45	0.4	0.2	0.15
Initial tempt. of water (°C)	31	30.8	33.1	32.6	97.4	97.2
Final tempt. of water (°C)	98.6	98.3	98.6	98.3	95.6	95.8
Time of boiling (Minutes)	13	17	9	9	45	45

**Table 3:** Derived parameters from WBT for cold start

Parameters	Cold Start Phase		Hot Start Phase		Simmer phase	
	FGCC	CRCC	FGCC	CRCC	FGCC	CRCC
Boiling time (minutes)	13	17	9	9	45	45
Burning rate (g/minutes)	25.71	24.55	28.42	32.67	11.11	26.53
Thermal efficiency (%)	21.23	19	27.4	20.2	42.47	34.56
Specific Fuel Consumption (g/L)	219.19	227.44	196.01	225.42	366.7	385.8
Fire power (kW)	8.8	7.72	8	10.17	3.55	8.34

**Hot start phase**

Studies conducted show that hot start phase indicated no significant difference between burning rate for ceramic and fibre glass (Table 1). However, energy efficiency, specific fuel consumption and firepower for CRCC and FGCC indicated a significant difference at  $p < 0.05$  level.

The FGCC grate recorded the highest efficiency and a lower specific fuel consumption as compared to other grate materials (Table 4). The results obtained shows absorption of heat into the body of the ceramic material in the cold start phase results in better performance in the hot start phase (Tables 5 and 6).

**Table 4:** Analysis of Variance results for effect of fuel quantity, air inflow, and fuel size on thermal efficiency at high power hot start phase

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
F	2	0.03133	0.01566	283.08	<0.0001**
A	2	0.00669	0.00334	60.45	<0.0001**
S	1	0.00015	0.00015	2.65	0.1123NS
F*A	4	0.01308	0.00327	59.09	<0.0001**
F*S	2	0.00274	0.00137	24.77	<0.0001**
A*S	2	0.00794	0.00397	71.78	<0.0001**
F*A*S	4	0.00730	0.00182	33.01	<0.0001**
Error	36	0.00199	0.00006		
Corrected Total	53	0.07123			

\*=Significant at ( $P \leq 0.05$ ) \*\*= Significant at ( $P \leq 0.01$ ) NS= Not Significant

**Low power simmering phase**

Results obtained also indicated that the burning rate of 1 g/min was obtained for simmer phase for all combustion chamber grate materials (Table 7). A high energy efficiency of 42.47% was observed for fibre glass grate as compared to 34.56 % of Ceramics grates (Tables 5 and 6). The energy efficiency from hot start to simmer was an indication that the fibre glass material continued to serve as an insulating liner in the stove, conserving

energy from the fuel and directing it to the cooking pot, thus, reducing the amount of fuel used.

Further, the results obtained shows that the fire power for the cold starts phases were 8.8 kW, 7.72 kW for the FBCC and CRCC, respectively when the saw dust briquette was used in the double burner conventional cook stove (Table 7). The thermal efficiencies for FGCC and CRCC was 21.23% and 19%

in the cold start meanwhile, hot start and simmer phases recorded higher values of efficiency. Similarly, the results obtained shows that the fire power for the cold starts phases were 4.4 8.1 kW and 7.72 kW for the FGCC and CRCC, respectively when Rice husk briquette was used in the double burner conventional cook stove (Tables 5 and 6). The thermal efficiencies for FGCC and CRCC was 22.23% and 19.32% in the cold start meanwhile, hot start and simmer phases recorded

higher values of efficiency. Additionally, the results from the study shows that the fire power for the cold starts phases were 8.72 kW and 7.99 kW for the FGCC and CRCC, respectively when sugarcane bagasse briquette was used in the double burner conventional cook stove (Tables 8 and 9). The thermal efficiencies for FGCC and CRCC was 21.25% and 19% in the cold start meanwhile, hot start and simmer phases recorded higher values of efficiency.

**Table 5:** The water boiling test for hot start phase

Parameters	Cold start phase		Hot start phase		Simmer phase	
	FGCC	CRCC	FGCC	CRCC	FGCC	CRCC
Initial tempt. (°C)	29.5	29.6	31	30.1	32.2	32.1
Initial Mass of Fuel (kg)	2.4	3.12	2.09	2.52	1.69	2.02
Final mass of fuel (k)	1.99	2.52	1.69	2.02	1	0.5
Mass of fuel consumed (kg)	0.411	0.491	0.341	0.392	0.5	1.194
Initial mass of water (kg)	1.92	1.95	1.95	1.95	1.5	1.55
Mass of water evaporated (kg)	0.43	0.4	0.43	0.4	0.21	0.17
Initial tempt. of water (°C)	31.1	30.9	33	32.5	97.3	97.1
Final tempt. of water (°C)	98.6	98.3	98.6	98.3	95.6	95.8
Time of boiling (Mins)	14	18	10	10	45	45

**Table 6:** Derived parameters from water boiling test for hot start phase

Parameters	Cold start phase		Hot start phase		Simmer phase	
	FGCC	CRCC	FGCC	CRCC	FGCC	CRCC
Boiling time (mins)	14	18	10	10	45	45
Burning rate (g/min)	26.11	25.45	27.43	33.56	11.15	26.98
Thermal efficiency (%)	22.23	19.32	27.98	20.21	39.87	24.77
Specific Fuel Consumption (g/L)	227.44	219.19	225.42	196.01	385.8	366.7
Fire power (kW)	8.1	7.22	8	9.97	3.45	8.35

**Table 7:** Analysis of Variance results for effect of fuel quantity, air inflow, and fuel size on thermal efficiency at low power simmering phase

Source	DF	Anova SS	Mean Square	F Value	Pr > F
F	2	0.00924	0.00462	40.99	<0.0001**
A	2	0.00482	0.00241	21.39	<0.0001**
S	1	0.00079	0.00079	7.00	0.0120*
F*A	4	0.00435	0.00109	9.65	<0.0001**
F*S	2	0.01869	0.00935	82.98	<0.0001**
A*S	2	0.00066	0.00033	2.95	0.0650NS
F*A*S	4	0.00881	0.00220	19.56	<0.0001**
Error	36	0.00406	0.00011		
Corrected Total	53	0.05142			

\*=Significant at (P≤0.05) \*\*= Significant at (P≤0.01) NS= Not Significant

**Table 8:** The Water Boiling Test for Low Power Simmering Phase

Parameters	Cold start phase		Hot start phase		Simmer phase	
	FGCC	CRCC	FGCC	CRCC	FGCC	CRCC
<b>Initial tempt. (°C)</b>	30.1	29.5	32	30.1	31.2	32.1
<b>Initial Mass of Fuel (kg)</b>	2.49	3.12	2.09	2.52	1.69	2.02
<b>Final mass of fuel (k)</b>	2.01	2.52	1.69	2.02	1	0.5
<b>Mass of fuel consumed (kg)</b>	0.412	0.491	0.341	0.392	0.5	1.194
<b>Initial mass of water (kg)</b>	1.91	1.95	1.95	1.95	1.5	1.55
<b>Mass of water evaporated (kg)</b>	0.43	0.41	0.45	0.4	0.2	0.15
<b>Initial tempt. of water (°C)</b>	29	30.8	33.1	32.6	97.4	97.2
<b>Final tempt. of water (°C)</b>	95.5	98	98.6	98.3	95.6	95.8
<b>Time of boiling (Mins)</b>	14.5	18.5	11	11	45	45

**Table 9:** Derived Parameters from WBT for Low Power Simmering Phase

Parameters	Cold start phase		Hot start phase		Simmer phase	
	FGCC	CRCC	FGCC	CRCC	FGCC	CRCC
<b>Ebullition time (mins)</b>	14.5	18.5	11	11	45	45
<b>Burning rate (g/min)</b>	25.71	24.55	28.42	32.67	11.11	26.53
<b>Thermal efficiency (%)</b>	21.23	19	27.4	20.2	39.42	24.56
<b>Specific Fuel Consumption (g/L)</b>	225.32	219.19	225.42	196.01	375.8	366.7
<b>Fire power (KW)</b>	8.72	7.99	8.5	9.87	4.35	8.93

## CONCLUSION

A study was conducted to determine the effects of insulation materials and fuel type on the combustion performance of a biomass cookstove. Two insulation materials (fibre glass and ceramic) and three biomass briquettes (saw dust, rice husk and sugarcane bagasse) were used to determine the performance of a double burner conventional biomass cookstove while conducting water boiling test. Results also showed that the thermal efficiencies for FGCC and CRCC was 21.23 % and 19 %, 22.23 % and 19.32 %, 21.25 % and 19% respectively in the cold start for the three tests, hot start and simmer phases recorded higher values of efficiency. This indicates that fibre glass grate type is the preferred choice because the biomass cook stove reached its boiling point with minimal fuel consumption unlike the ceramic combustion chamber. The results obtained recommend use of fibre glass combustion chamber as it gave high efficiency with low fuel consumption in comparison to the ceramic material.

## REFERENCES

1. AHMAD A.S., KUTUT S., & AGUS S. (2014) Gama Stove: Biomass Stove for Palm Kernel Shells in Indonesia Hermawan Febriansyaha. *Energy Procedia*, **47**: 123 – 132.
2. LACEY, F.G., HENZE, D.K., LEE, C. J., VAN DONKELAAR, A., & MARTIN, R. V. (2017). Transient climate and ambient health impacts due to national solid fuel cookstove emissions. *Proceedings of the National Academy of Sciences of the United States of America*, **114**(6): 1269–1274. <https://doi.org/10.1073/pnas.1612430114>..
3. WHO, (2006), Fuel for Life; Household Energy and Health, World Health Organization, Geneva: Switzerland.
4. WARWICK, H. & A. DOIG (2004). Smoke-the killer in the kitchen. London, UK, I TDG Publishing.
5. EBIEGA, E.O. (2012). Design, Construction and Testing of a Rocket Stove. Zaria: An

- Unpublished Undergraduate Project, Mechanical Engineering, Ahmadu Bello University.
6. KAREKEZI, S. (1992). The role of a stoves information network in addressing the indoor air pollution -an African perspective. Indoor Air Pollution from Biomass Fuel, Working Papers from a WHO Consultation, Geneva, Switzerland, pp. 89-104.
  7. SALEH, A., YUNUS, A. & FUMEN, G.A. (2022) Development and Performance Evaluation of a Screw Press Biomass Briquetting Machine Using Sugarcane Bagasse. *Nigerian Journal of Engineering Science Research* (NIJESR). Department of Mechanical Engineering, Gen. Abdulalami Abubakar College of Engineering, Igbinedion University, Okada, Edo State, Nigeria. **5**(3): 51-59, September, 2022. ISSN: 2636-7114.
  8. SALEH, A. & YUSHA'U, A.A. (2022). Production and Evaluation of Biomass Briquettes from Rice Husk using Different Binders. *Nigerian Journal of Engineering Science Research* (NIJESR). Department of Mechanical Engineering, Gen. Abdulalami Abubakar College of Engineering, Igbinedion University, Okada, Edo State, Nigeria. **5**(2): 92-102, June, 2022.
  9. BHATIA, A. (2021). Overview of Insulation Materials Continuing Education and Development, Inc. 22 Stonewall Court Woodcliff Lake, NJ 07677. Pp 1 – 64.
  10. GACC (2017). Handbook for Biomass Cookstove Research, Design, and Development. *A Practical Guide to Implementing Recent Advances. D-Lab*. (Global Alliance for Clean Cookstoves). pp 1-52. [www.cleancookstove.org](http://www.cleancookstove.org)
  11. DE LA HOZ, C.K. & GONZÁLEZ, W.A. (2020). Energy performance and variability of an improved top-lit updraft biomass cookstove under a water boiling test protocol. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 1–20. <https://doi.org/10.1080/15567036.2020.1819473>.
  12. JETTER, J. & KARIHER, P. (2009). Solid-fuel household cook stoves: characterization of performance and emissions. *Biomass Bioenergy handbook*, **33**(2): 294-305.