Fabrication And Performance Evaluation Of An Improved Biomass Cook Stove

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ABSTRACT

The design, fabrication and testing of an improved biomass cook stove was undertaken in the work. The design improvement of the stove entail improvement in the following areas. Provision of insulation around the combustion chamber to reduce conduction of heat loss across the walls of the chamber, provision of a pot skirt for increasing heat transfer efficiency, establishing the same cross sectional area everywhere as well as the provision of insulated short chimney right above the fire to ensure sufficient draft for good combustion and provision of a graft or fuel tray for complete combustion of a variety of biofuels. Performance test on fuel types reveal sawdust is the most economical in specific fuel consumption as well as giving the least smoking time of the fuel types.

Keywords;Biomass,Duncan multiple test,Fuel consumption,Smoked time

INTRODUCTION

In rural areas, cooking is one of the largest energy consuming activities in less developed countries. In fact, about half of the total population cooks with bio fuels. Firewood and charcoal from forests has been the major source of this energy (ERG, 1986) with the advent of coal gas the cooking ranges became somewhat less elaborate and the designs and the designs concentrated more on the efficient utilization of heat. About the middle of the first half of the 20th century interest in gas fired ranges began to develop in the United states and England while these revolution in cooking methods and cooking ranges was taking place in most of Europe and America, majority of countries in Africa was still using the primitive methods of open wood fires for cooking, even today this is the principal method of cooking food in the villages of sahel and Sudan zones of Africa. In sharp contrast to the situation that existed in primitive times in Europe or even in these zones of Africa in the last century, ample supplies of wood for cooking is scare and where it must be brought accounts for 10 to 20 percent of income of a typical family;A state of the art survey final report, (1977) . In addition, and more seriously, the use of wood in these agreed is resulting in deforestation and decalcification; a critical global problem. Considering the problems of the less developed countries Nigeria inclusive a significant reduction in the use of fuel wood for cooking could be realized Stout et al,(2001). Wherever stick-wood is plentiful and at a low cost, conventional improved cook stoves are attractive options. In the ever-increasing areas where charcoal and firewood are becoming a scarce and/or an expensive commodity, there arises a need to develop an option to cleanly burn alternative biomass fuels It is in the light of the foregoing that this work entails to bridge by developing a simple improved biomass stove and performing a series of test to evaluated the best biomass fuels in terms of their fuel consumption and level of emission reduction on the basis of the smoking time.

DESIGN DESCRIPTION

The biomass cook stove is circular in section and consists of a combustion chamber, top section and the base. The hearth of the combustion chamber is made of ceramic the outside of which is lined with fibreglass and encased in a mild steel casing. The top of the stove consists of the pot seat and the pot skirt with specified channel gaps that increase heat transfer efficiency. The base made up of a grate into which the unburned fuel is placed and from where it feeds into the the fuel magazine or firebox which leads to the combustion chamber. The opening of the firebox, the size of the channel gaps within the stove through which hot air flow and the chimney were all made the size sizes to maintain constant cross sectional area. The chimney which is also a part of the base is vertical placed above the combustion chamber to provide updraft needed to maintain the fire. The principle of operation of this stove is simple. As fire burns within the combustion chamber, air is drawn into the combustion chamber from below by convection, ensuring that any smoke from smouldering wood near the fire is also draw into the fire and chimney. The heat from the combustion chamber rises and impinges directly on the base of the cooking pot.

In addition exhaust gases from the fired travelling in the annulus between the cooking pot and pot skirt also transfer heat into the sides of the pot. As a result the efficient use of energy from the fire is greatly enhanced resulting in quick cooking times and a reduction in the quantity of fuel used. The advantage of the stove is that very small sizes off wood can be used, which reduced fuel consumption when compared to traditional open fires.

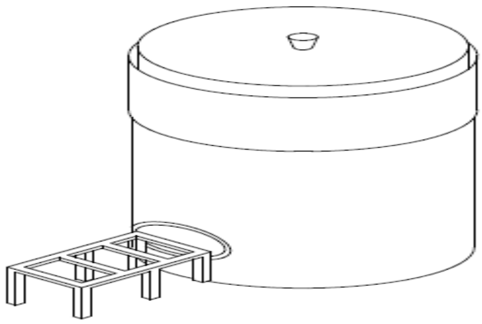

Figure 1: Isometric projection of a Biomass stove

DESIGN ANALYSIS AND CALCULATIONS

Based on the choice of a family sized cooking stove, the following parameter, are chosen for the design; Height of the combustion chamber 30cm: internal radius of combustion chamber r_1= 60mm, internal radius of insulation lining r_2=100mm; internal radius of mild steel casing r_3= 120mm; external radius of mild steel casing r_4= 122mm; external diameter of pot Seat =250mm. Thermal conductivity of ceramic K_1=180w/mk; thermal conductivity of fiberglass, K_2=0.037w/mk; Internal conductivity of mild steel K_3= 39w/mk; measured external temp of combustion chamber T_0= 35^{o}C ;measured Internal temp of combustion chamber T_i =550^{o}C

DETERMINATION OF AREA UNDER THE POT

Maintaining a constant cross – sectional area under the pot entails the determination of the channel gaps that measure heat transfer efficiency.

The following channel gaps as shown in fig 1 below are calculated; based on Winiaski method

GapA= $\frac{AREA\ OF\ FEED\ CHAMBER}{PERIMETER\ OF\ FEED\ CHAMBER} = 3cm$ ……..(1)
Where area of feed chamber = πr^2=113.1cm^2
The following channel gaps. Gap A, gap B, gap C And gap D were calculated to be 3cm, 1.06cm, 1.2cm and 0.9cm respectively employing the Winiarski’s method.

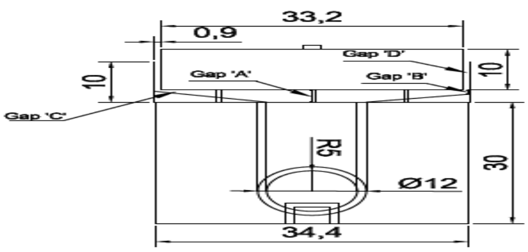

Figure 2: Orthographic Front view of Biomass stove.

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Heat Loss across the Cylindrical Walls of the Heating Chamber

The radial conduction heat flow for a hollow cylinder is expressed by the Fourier's law as:

$$Q = -KA\frac{dT}{dr} \qquad \text{.......... (1)}$$

where: K is the thermal conductivity of the cylinder material; A is the area of the walls of the cylinder heating chamber across which heat transfer occurs; and dT/dr is the radial temperature gradient across the walls.

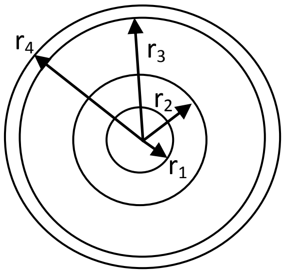

Figure 3. A composite hollow cylinder

For a composite cylinder (see Fig. 3) with known inside and outside surface temperatures and having 'n' layers of different materials the form of Eq. (1) becomes

$$Q = \frac{t_1 - t_{n+1}}{\sum_{i=1}^{n}\frac{1}{2\pi K_1 L} xloge\,[(r_i+1)/r_1]} \qquad \text{........ (2) (Kumar 2007)}$$

For the composite hollow cylinder consisting of three layers of materials: ceramic surrounding the combustion chamber, insulating fiberglass and a steel casing, Eq. (2) becomes

$$Q = \frac{t_1 - t_{n+1}}{\left[{}^{1}/_{2\pi k_1 L}\, xloge\, {}^{r_2}/_{r_1}\right] + \left[{}^{1}/_{2\pi k_2 L}\, xloge\, {}^{r_3}/_{r_2}\right] + \left[{}^{1}/_{2\pi k_3 L}\, xloge\, {}^{r_4}/_{r_3}\right]} \qquad \text{.......(3)}$$

Substituting for the various parameters gives Q=61.44W

Therefore, the heat transfer through the wall of the stove per second is determined to be 61 W.

FEED CHAMBER

In order to provide for proper combustion of fuel, provision was made for adequate ventilation within the stove. A 12cm diameter feed chamber and of length 5cm was provided.

THE STOVE STAND

These are three 50 mm high metallic structured located at equal distances around the circumferences of the bottom part of the stove. These were provided to prevent rusting and heat losses through leakage occasioned by direct contact between the stove bottom and the ground surface.

THE COMBUSTION CHAMBER

This consists of 565.5cm^3 capacity of insulating ceramic surrounded by a mild steel casing enclosure designed to accommodate any biomass material as fuel. A grate or fuel tray at height of 50 mm above the ground is provided at its base to allow for free air intake by updraft and the passage of ashes during combustion.

EXPERIMENTAL PROCEDURE AND PERFORMANCE EVALUATION

The test conducted on the biomass stove included a fuel consumption test and a emission reduction test involving the determination of the smoking time. The apparatus were three big size aluminium pots, a weighing balance, three mercury-in-glass thermometers, a stopwatch, water, rice, bean, matches and fuel consisting of weighed amounts of coal,charcoal,sawdust and wood respectively. These test were carried out to simulate or match the cooking method commonly adopted in rural committees in Africa.The relative humidity and temperature were recorded as 32^{0}C and 50% respectively

The initial temperature of the water was recorded using a mercury-in-glass thermometer before the pot were placed on the stove. The charcoal was sprinkled with 10ml of kerosene and then ignited with a match. The subsequent changed in temperature up to the boiling point were recorded at 2-minute intervals with the thermometer permanently inserted in the opened pots. During the boiling of water the smoked emitted was recorded. At boiling the pots were removed from the stoves and weighed. Also the fire was put out immediately and the remaining fuel was weighed. This procedure was carried similarly for coal, charcoal and sawdust respectively.

CONTROLLED COOKING TEST (CCT)

Controlled Cooking Test (CCT) was conducted out-doors on a cool morning to simulate traditional approach to cooking in rural areas of African and to compare the fuel consumption rate and time spent in cooking a meal of rice on the stove. Equal quantities (0.2kg) of rice were placed in the two aluminium pots procured each containing 2 litres of water. The stove was charged with the given quantity of fuel and the pot was placed on the lit stove. Stopwatches were set to monitor cooking duration and at the end of cooking, the time taken as well as quantity of fuel were noted and recorded. The smoke emission time was recorded. These tested was done taking water, bean and rice as treatment, while the blocks were taking as the fuel consisting of wood, charcaol,coal and sawdust respectively.

ANALYSIS OF RESULTS.

A two way analysis of variance (ANOVA) for fuel consumption and smoking time are shown in the following tables below employing fuels as blocks, while types of food as treatment

Table 1:ANOVA for Fuel consumption (Grammes)

	Wood	Charcoal	SAWDUST	COAL	Xi
BEANS	1217 481 1220	947 772 402	457 460 450	1134 1135 1135.5	
Xij.	2918	2121	1367	3405.5	9809.5
RICE	1393 1400 1450	588 580 582	614 614 750	937 904 920.5	
	4243	1750	1978	2761.5	10732.5
WATER	650 650 764	411 350 400	457 468 577	1003 1004 1003.5	
Xij.	2064	1161	1502	3010.5	7737.5
Xi.	9225	5032	4847	9175	28279.5

x…. 28279.5

Table 2 shown below is Anova summary table for fuel consumption

Table 2: ANOVA SUMMARY TABLE:

Source	df	SS	MS	F ratio
Block	3	2019147.549	673049.193	29.266
Treatment	2	392087.169	196043.845	8.525
Interaction	6	706343.93	117722.887	5.199
Error	24	551934.5	22997.271	
Total	35	36699513.18		

Block: $F_{cal} > F_{j-1\,(k-1)}\ \alpha$

Treatment: $F_{cal} > F_{1-1,\,IJ\,(k-1)}\ \alpha$

Interaction: $F_{cal} > F_{(1-1)\,(J-I),\,IJK\,(k-1)}\ \alpha$

In this case, $\alpha = 0.05$

Table 3;Anova table for smoking time

Block Treatment	WOOD	CHARCOAL	SAWDUST	COAL	Xj..	
BEANS	4.03 3.17 3.83	2.83 3.17 3.08	2.17 2.08 3.08	15.05 14.37 14.77		
Xij	11.03	9.08	7.33	44.19	71.63	
RICE	5.17 5.83 4.17	3.17 3.08 2.80	2.83 2.67 3.17	13.87 14.10 13.97		
Xij	15.17	9.05	8.67	41.94	74.83	
WATER	5.00 4.83 3.17	3.43 3.83 3.17	2.17 2.00 3.17	15.83 16.53 16.18		
Xij	13.00	10.43	7.34	48.54	79.31	
X.j.	39.20	28.56	23.34	134.67	225.77	

X…. = 225.77

In this computation α = 0.05
In table 3.5, I = 3,J = 4, K = 3
Table 4Shown below is the ANOVA summary table for smoking time

Table 4: ANOVA Summary Table

Source	df	SS	MS	Ratio
Block	3	921.118	307.039	1176.395
Treatment	2	2.481	1.241	4.775
Interaction	6	8.693	1.449	5.552
Error	24	6.253	0.261	
Total	35	938.545		

Block $F_{cal} \rangle F_{j-I,IJ(K-1),}\alpha$

Treatment: $F_{cal} \rangle F_{j-I,IJ(K-1),}\alpha$

Interaction: $F_{cal} \rangle F_{J-1,IJ(K-1),}\alpha$

DUNCAN MULTIPLE TEST

Employing the duncan multiple test on data matrix table 1 and table 2 develop for fuel consumption ,the following analysis was carrying –out.

Standard error for column means, $S_{\bar{x}} = \sqrt{\frac{MSE}{IK}} = \sqrt{\frac{22997.21}{3x3}}$ = 50.550

Standard error for row means, $S_{\bar{x}} \sqrt{\frac{MSE}{JK}} = \sqrt{\frac{22997.21}{4x3}}$ = 43.777

Column Means Difference Test:

$\bar{x}_1$ = 538.556 $\bar{x}_2$ = 559.111, $\bar{x}_1$ = 1019.500 and $\bar{x}_1$ = 1025.000

Using $\alpha = 0.005, n_2 = 24$ and q values 2,3,4 the corresponding values for r from the Duncan table are as tabulated below.

Tables 5: r Values Table

q	2	3	4
r	2.93	3.08	3.16

TABLE 6:The least significant range (LSR) is obtained by multiply r – values by $S_{\bar{x}}$

q	2	3	4
LSR	148.112	155.694	159.738

The tests for difference are as follows:

q = 4 : $\bar{x}_4$ - $\bar{x}_1$ = 1025 – 538.556 = 486.444 > 159.738 (Significant)

q = 3 : $\bar{x}_4$ - $\bar{x}_2$ = 1025 – 559.111 = 465.889 > 155.694 (Significant)

$\bar{x}_3$ - $\bar{x}_1$ = 1019 – 538.556 = 480.444 > 155.694 (Significant) q = 2: $\bar{x}_4 - \bar{x}_3$ = 1025 – 1019 = 6 < 148.112

$\bar{x}_3 - \bar{x}_2$ = 1019 – 559.111 = 459 > 148.112 (Significant)

$\bar{x}_2 - \bar{x}_1$ = 559.111 – 528.556 = 20.555 < 148.112

Row Means Difference Test:

$\bar{x}_1$ = 644.792, $\bar{x}_2$ = 817.458 and $\bar{x}_3$ = 894.375

Using α = 0.05, n_2 = 24 and q values 2,3: r and LSR values are obtained and tabulated as below:

Table 7: r and LSR Values

q	2	3
r	2.93	3.08
LSR	128.267	134.833

The best for difference:

q = 3 : $\bar{x}_3 - \bar{x}_2$ = 894.375-644.792 = 249.583> 134.8333 (Significant)

q = 2: $\bar{x}_3 - \bar{x}_2$ = 894.375 – 817.458 = < 128.267

$\bar{x}_2 - \bar{x}_1$ = 817.458 – 644.792 = 172.666 > 128.267 (Significant)

Duncan Multiple Test for Smoking Time

Employing the duncan multiple test on data matrix table 3 and table 4 develop for smoking time ,the following analysis was carrying –out.

Column: $S_{\bar{x}} = \sqrt{\frac{MSR}{JK}} = \sqrt{\frac{0.261}{3x3}}$ = 0.029

Row: $S_{\bar{x}} = \sqrt{\frac{MSR}{JK}} = \sqrt{\frac{0.261}{4x3}}$ = 0.022

Column Means Difference Test:

$\bar{x}_1$ = 2.593, $\bar{x}_2$ = 3.173, $\bar{x}_3$ = 4.356 and $\bar{x}_4$ = 14.963

Apply α = 0.05, n_2 = 24 and q values 2,3,4 r and LSR are obtained as earlier discussed.

Table 8: r and LSR Values Table

q	2	3	4
r	2.93	3.08	3.16
LSR	0.085	0.089	0.092

q = 4: $\bar{x}_4 - \bar{x}_1$ = 14.963 – 2.593 = 12.370> 0.092 (Significant)

q = 3: $\bar{x}_4 - \bar{x}_2$ = 14.963 – 3.173 = 11.790> 0.0927 (Significant)

$\bar{x}_3 - \bar{x}_1$ = 4.356 – 2.593 = 1.763 > 0.089 (Significant)

q = 3: $\bar{x}_4 - \bar{x}_3$ = 14.963 - 4.356 = 10.60 > 0.085 (Significant)

$\bar{x}_3 - \bar{x}_2$ = 4.356 – 3.173 = 1.183 > 0.085 (Significant)

$\bar{x}_2 - \bar{x}_1$ = 3.173 – 2.593 = 0.58 > 0.08 (Significant)

Row Means Difference Test:

$\bar{x}_1$ = 5.969, $\bar{x}_2$ = 6236, $\bar{x}_3$ =6.069

Using α = 0.05, n_2 = 24 and q values 2,3. Then the values of r and LSR values are obtained as shown in table 9

Table 9: r and LSR Values

q	2	3
r	2.93	3.08
LSR	0.064	0.068

q = 3: $\bar{x}_3 - \bar{x}_1$ = 6.609 – 5.969 = 0.640 > 0.068 (Significant)

q = 2: $\bar{x}_3 - \bar{x}_2$ = 6.609 – 6.236 = 0.373 > 0.064 (Significant)

$\bar{x}_2 - \bar{x}_1$ = 6.623– 5.969 – 0.654 > 0.068 (Significant)

RESULT AND DISCUSSION

Result and Discussion on Fuel Consumption

The fuel type i.e wood, charcoal, sawdust and coal were taken as blocks and the food items on which the observations were made were regard as treatments. Refering to table 2.

$$F_B = \frac{MSA}{MSE} = \frac{673049.193}{22997.271} = 29.266$$

$$F_1 = \frac{MSB}{MSE} = \frac{196043.845}{22997.271} = 8.525$$

$$F_1 = \frac{MSAB}{MSE} = \frac{117722.887}{22997.271} = 8.119$$

$\alpha_j = 0$, $\beta_i = 0$ and $(\alpha\ \beta)_{ij} = 0$ implies no column effect, no row effect and no interaction effect respectively.

Rejection: $F_{cal} > F_{table}$

BLOCK

$F_{cal} = 29.666$

$F_{table} = 3.01$

Since $f_{cal} > f_{table}$ we have no evidence to accept the null hypothesis and we conclude that the fuel types have significantly different effects on heat generated by the wood stove.

TREATMENT

$f_{cal} = 8.525$

$f_{table} = 3.40$

since $f_{cal} > f_{table}$ we reject the null hypothesis and conclude that in cooking/boiling the food items consume different amounts of fuel.

INTERACTION

$f_{cal} = 5.119$

$f_{table} = 2.51$

Since $f_{cal} > f_{table}$

We reject the null hypothesis and support the argument that there is interaction effect among the fuel types and food items. The meaning of this statistical inference is that the amount of fuel utilized is dependent of the nature of food items and fuel types.

Result and Discussion on smoking time

$$F_B = \frac{MSA}{MSE} = \frac{307.039}{0.261} = 1176.395$$

$$F_T = \frac{MSB}{MSE} = \frac{0.241}{0.261} = 4.755$$

$$F_T = \frac{MSAB}{MSE} = \frac{1.449}{0.261} = 5.552$$

Rejection: $f_{cal} > f_{table}$

BLOCK

$F_{cal} = 1176.395$

$F_{table} = 3.01$

We fail to accept the null hypothesis because $F_{cal} = 176.395 > F_{table} = 3.01$. This conveys the argument that the smoking time is significantly influenced by the fuel type.

TREATMENT

$F_{cal} = 4.755$

$F_{table} = 3.40$

We have no sufficient evidence to accept the null hypothesis since $f_{cal} = 4.755 > f_{table} = 3.40$

INTERACTION

$F_{cal} = 5.552$

$F_{table} = 2.51$

Since $f_{cal} > f_{table}$ we have no evidence to reject the alternative hypothesis. This implies that there is interaction effect.

Duncan multiple range test

Further evaluation was undertaken on the data analysis since the overall tests of means, for block, treatment and interaction fall into rejection region. In this case, the Duncan multiple range test was employed. Assumption: equal sample sizes exists for both variables. Considering Table 2, Table 4, and their respective r and LSR Tables for column and row.

FUEL UTILIZED

Table 7: r and LSR and Table6: for column means

q	2	3	4
R	2.93	3.08	3.16
LSR	148.112	155.694	159.738

$$S_x = \sqrt{\frac{MSE}{IK}} = \sqrt{\frac{22997.271}{3x3}} = 50.550$$

$x_1 =$ 538.556, $x_2 = 559.111$, $x_3 = 1019$, $x_4 = 1025$

q = 4: $\bar{x}_4 - \bar{x}_1 > 159.738$

q = 3: $\bar{x}_4 - \bar{x}_2 > 155.694$

$q_2 = 2$: $\bar{x}_4 - \bar{x}_3 < 148.112$

$\bar{x}_3 - \bar{x}_2 < 148.112$

$\bar{x}_2 - \bar{x}_1 < 148.112$

x_i sawdust, x_2 charcoal, x_3 coal, x_4 wood

The implication of this is as follows;Between wood and sawdust the difference in their ability to generate heat is very significant.

The difference in the heating ability obtained between coal and wood is not significant.

$\bar{x}_1 - \bar{x}_2 < \bar{x}_3 < \bar{x}_4$

Their specific fuel consumption is of the following ascending order.

Saw dust → charcoal → coal → wood

Hence, sawdust is the most economical of the four fuel types.

SMOKING TIME

Table 8:r and LSR and Table9: for Column Means

q	2	3	4
R	2.93	3.08	3.16
LSR	0.085	0.89	0.092

$S_x = 0.305$

$\bar{x}_{x1}$ = 2.593, $\bar{x}_2 = 3.173$, $\bar{x}_3 = 4.356$ and $\bar{x}_4 = 14.963$

q = 4: $\bar{x}_4 - \bar{x}_1 > 0.092$

q = 3: $\bar{x}_3 - \bar{x}_1 > 0.089$

q = 2: $\bar{x}_4 - \bar{x}_3 > 0.085$

$\bar{x}_3 - \bar{x}_2 > 0.085$

$\bar{x}_2 - \bar{x}_1 > 0.085$

$\bar{x}_1$ = Sawdust, $\bar{x}_2$ = Charcoal, $\bar{x}_3$ Wood $\bar{x}_4$ = Coal.

The statistical inference here is that there exists significant difference among the smoking time of the four fuel types, but the least difference occurs between charcoal and sawdust.

$\bar{x}_1 < \bar{x}_2 < \bar{x}_3 < \bar{x}_4$

Thus the smoking time of the fuel types is arranged in ascending order as follows:

SAWDUST → CHARCOAL → WOOD → COAL

Sawdust gives the smallest smoking time.

CONCLUSION

The World Health Organization has documented the significant number of deaths caused by smoke from home fires. The negative impacts can be reduced by using improved cook stoves, improved fuels (e.g. biogas, or kerosene instead of dung), changes to the environment (e.g. use of a chimney), and changes to user behaviour (e.g. drying fuel wood before use). Based on these underlying facts an improved biomass cooking stove was fabricated and the results of performance analysis employing various biomass fuel such wood, coal, charcoal and sawdust as blocks showed that sawdust has the lowest fuel co(nsumption rate. Considering pollution emission level sawdust among the fuel type reveal the least smoking time. Having achieved these goals we do believe that this improved biomass cooking stove is more efficient, meaning that the stove's users is afforded the choice of using an alternative fuel like sawdust which is majorly considered as waste product , suffer less emphysema and other lung diseases prevalent in smoke-filled homes, while reducing deforestation and air pollution.

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