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An Efficient and Environmental Friendly Modified Natural Draft Coffee Husks Gasifier Stove For Coffee Farmers in Tanzania

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Abstract: **Coffee growing areas in Tanzania have abundant coffee husks resources; however these resources are not efficiently utilized in the existing stoves. The main objective of the study was to develop, fabricate and evaluate the performance of gasifier stove that uses coffee husks as source of energy for household cooking purpose. Kalinzi village in Kigoma region was taken as case study for this project. The results for this project were achieved through different methods including visiting Kalinzi village to collect some preliminary data, conceptual design, and design analysis, fabricating and testing the performance of the existing and developed stoves. The result shows that thermal efficiency was improved from 12.8% of the existing stove to 24% for the developed stove. Not only thermal efficiency but also burning rate become lower (5.2 gm/min) for the developed stove than existing stove (14.5 gm/min). Specific fuel consumption has changed from 200 (gram coffee husk/ kg water) to 100 (gram coffee husk/ kg water) of existing stove and developed stove respectively.**

Keywords: **Gasification; Coffee Husk, Gasifier Stove, Farmers.**

1. INTRODUCTION

1.1 Background:

Household cooking stoves in the rural coffee-growing regions like Kalinzi in Kigoma Tanzania contribute to deforestation and respiratory health issues. Kalinzi area in Kigoma has abundant coffee husks resources, but these resources are so far not efficiently utilized because of the poor efficiencies of the existing stoves. This project therefore initiated a study to develop a biomass gasifier stove that uses coffee husks efficiently.The main objective of this study was to develop, fabricate and evaluate the performance of gasifier stove using coffee husks as source of energy for house hold cooking purpose.

2. METHODS

To achieve the objective of this study, a number of methods were considered in data collection and analysis.

2.1 Ultimate Analysis (Dry Basis):

Elemental analysis was obtained from literature (Lugano W., 2010) to determine the amount of chemical elements of coffee husk used by the stove as feedstock. This analysis was carried out through ASTM D3176 method.

2.2 Proximate Analysis (Dry Basis):

Proximate analysis is a measure of the quantities of volatile matter, fixed carbon, moisture, and ash-content contained by the material. The result of this analysis was obtained from literature, and the analysis was carried out by using ASTM D3172-5 method (Lugano W., 2010).

2.3 Stove Performance Testing:

Water boiling test (WBT) was used as a standard test. In a water boiling test, a known quantity of water is heated on the cook stove. No lid is used to cover the vessel to allow evaporating water freely escape from the vessel. Heat gained and quantity of water evaporated after complete burning of the fuel was determined to calculate the stove efficiency by using the following "Eq (1)."

$$\eta = \frac{m_{w,i} \times c_{p,w} \times (T_e - T_i) + m_{w,evap} \times H_l}{m_f \times H_f}$$

(1)

Where;

mw_i = initial mass of water in the cooking Vessel, kg

Cp_w = specific heat of the water (in kJ/kg°C)

mw_{evap} = mass of water evaporated (in kg)

m_f = mass of fuel burned (in kg)

Te = temperature of boiling water (in °C)

Ti = initial temperature of water (in °C)

Hi = latent heat of evaporation of water at 100°C and 105 Pa (in kJ/kg)

Hf = Calorific value of fuel (in kJ/kg)

2.4 Development of Stove to Improve Performance:

In this stage three different concepts were generated, and among which the best alternative was selected by using a controlled convergence matrix method. A Controlled convergence matrix method is a method through which criteria such as stove durability, affordability, portability, fuel reduction, safety, reliability, and smoke reduction were given weight, and generated concepts were evaluated by using these criteria to obtain the best concept which was further developed.

2.5 Design analysis of Biomass Stove and Construction Details:

The design of the biomass stove involved the choice of various geometric dimensions of the stove. Through the use of computational fluid dynamics (CFD), it was possible to come up with a good design of the stove.

3. RESULT AND DISCUSSION

3.1 Proximate Analysis Results:

Typical characteristics of coffee husk were analyzed to identify its moisture content, volatile matter, fixed carbon content, and ash content. Results of this test are presented in Table 1.

TABLE 1: PROXIMITY ANALYSIS RESULTS (LUGANO WILSON, 2010)

Element	(%) by Weight
Moisture	10.10
Ash content	2.50
Volatile content	83.20
Fixed Carbon	14.30
HHV, MJ/kg	18.34

3.2 Ultimate Analysis Results:

This is an elemental analysis done to identify the elemental composition of coffee husk. Elemental analysis helps to estimate some combustion characteristics, such as calorific value and the equivalence ratio (air required for complete combustion). Higher values of C, H, and S increase the heating value, while O and N lowers the heating value. Table 2 contains summary of elemental composition of coffee husk.

TABLE 2: ELEMENTAL COMPOSITION (%), DRY BASIS (LUGNAO WILSON, 2010)

Element	Symbol	(%) by Weight	Molecular Weight
Carbon	C	49.40	12
Hydrogen	H	6.10	2
Nitrogen	N	0.81	28
Chlorine	Cl	0.03	34
Sulphur	S	0.07	32

3.3 Developed stove:

Fig. 1 represents the schematic diagram of the developed stove. Other parameters for this stove are presented in Table 6 which compares parameters with existing stove.

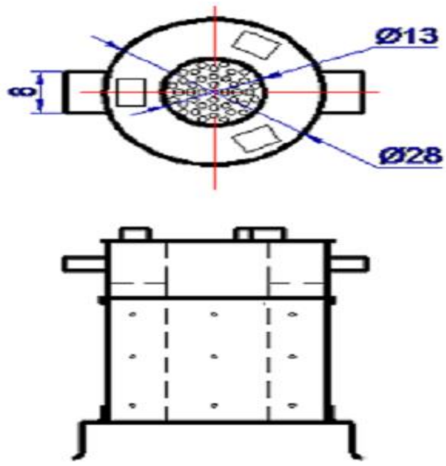

Fig. 1: Developed stove

Table 3 below shows the distinct of various performance parameters between existing stove and developed one.

TABLE 3: PERFORMANCE COMPARISON BETWEEN EXISTING AND DEVELOPED STOVE

Parameter	Existing Stove	Developed Stove
Time to boil water (Δth)	22 min	18 min
Thermal efficiency (hh)	12.8%	24%
Burning rate (rbh)	14.508 gm/min	5.2 gm/min
Specific fuel consumption (SCh)	200 g coffee husk/kg of water	100 g of coffee husk/kg of water
Fire power (Fp)	4.48 kJ/sec	1.61 J/sec

3.3.1 Energy Needed:

This refers to the amount of heat energy (Qn) needed to be supplied by the stove; this can easily be estimated based on the amount of food to be cooked. Assume a family of seven people can eat 2 kg of rice. The amount of energy needed to cook food can be computed using the formula (Belonio A. T., 2005);

$$Q_n = \frac{M_f \times E_s}{T} \qquad (2)$$

Where:

Qn – Energy needed, Kcal/hr

Mf –Mass of food, 2 kg

Es – Specific energy, for cooking rice

Es=79.3Kcal/kg at 72^{o}C

T – Cooking time, 22 min

Qn = 432.54 kCal/hr

3.3.2 Fuel Consumption Rate, FCR:

Is the amount of fuel fed into the stove and used in a specific time. This can be computed by using "Eq (3)."

$$FCR = \frac{Q_n}{HVf \times h_h} \quad (3)$$

Where,

FCR – fuel consumption rate, kg/hr

HVf – Heating value of fuel, Kcal/kg

hh – gasifier stove efficiency, %

Since the heating value of coffee husk (HVf) is 18.34 MJ ≡ 4380.4 kcal/kg and the assumed design efficiency, hh = 30%

FCR= 0.32915kg/hr

3.3.3 Determination of Stoichiometric Air to Fuel Ratio (A/F) of Coffee Husks:

To determine A/F ratio, each constituent (Table 2) is taken separately and the amount of oxygen required for complete combustion is found from the chemical equations not included in this paper which is equal to 1.322967 kg.

Air required/kg of fuel = 1.322967/0.233

Air required/kg of fuel = 5.706kg/kg of fuel (assumed air contain 23.3% O_2 by mass)

Thus, theoretical air required = 5.706 kg/kg of fuel

Nitrogen (N_2) associated with this air = 5.706−1.3296

=4.3764 kg

The stoichiometric A/F ratio = 5.706/1, is the minimum amount of air that would be required for combustion if the mixing of fuel and air by the burner is perfect. In practice mixing is never perfect, a certain amount of excess air is needed to complete combustion and ensure that release of the entire heat contained in the biomass fuel. Less air would lead to incomplete combustion and smoke. Hence, there is an optimum excess air level for each type of fuel, and for this design of coffee husk stove was assumed to be 20%. Through the analysis not included in this paper, amount of air needed for gasification is 3.00499×10^{-3} m^3/s.

3.4 Stove Performance Test:

The water boiling test was done in an energy laboratory. Fire was started from ignition of small amount of coffee husk at the lower punched plate at the bottom of stove with the aid of 10 mls of kerosene. Table 4, Table 5, Fig. 2, and Fig. 3 present data collected and performance graphs for both existing stove and developed stove respectively.

TABLE 4: DATA COLLECTED FROM EXISTING GASIFIER STOVE

Parameter	Results	
Time at start of the test (min)	thi	0
Time at end of test (min)	thf	36
Water temperature before test (^oC)	Thi	26
Water temperature after test (^oC)	Thf	100
Weight of empty pot (gm)	P	300
Weight of pot with water before test (gm)	Phi	3300
Weight of pot with water after test (gm)	Phf	2950
Weight of empty stove (gm)	f	5700
Weight of stove and coffee husk fuel before test (gm)	fhi	7500
Weight of stove and coffee husk fuel after test (gm)	fhf	6150

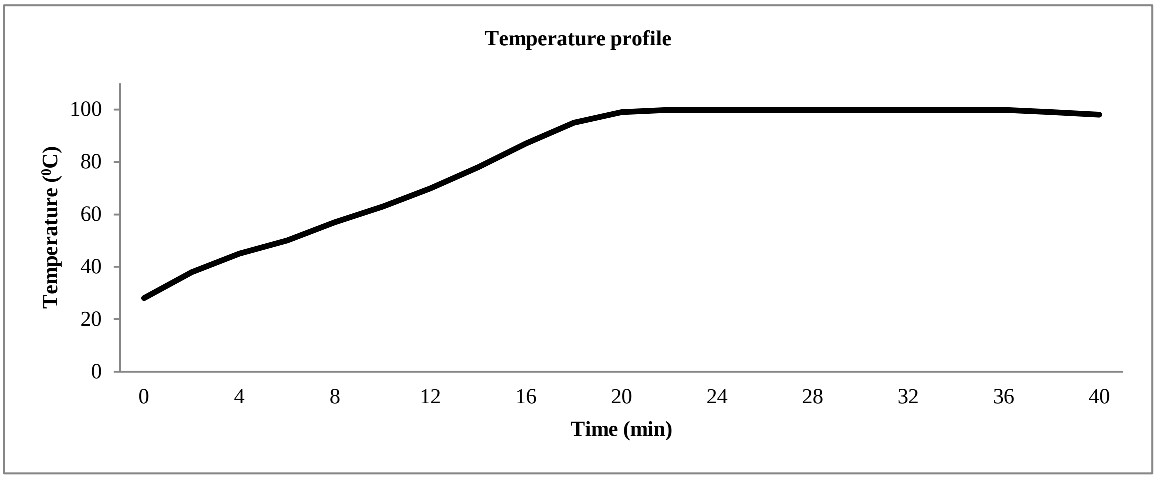

Fig. 2: Water Temperature Profile of Existing Gasifier stove

TABLE 5: SHOW THE WATER BOILING TEST (WBT) RESULTS OF DEVELOPED GASIFIER STOVE

Parameter	Results	
Time at start of the test (min)	thi	0
Time at end of test (min)	thf	64
Water temperature before test (°C)	Thi	24
Water temperature after test (°C)	Thf	100
Weight of empty pot (gm)	P	300
Weight of pot with water before test (gm)	Phi	3300
Weight of pot with water after test (gm)	Phf	2650
Weight of empty stove (gm)	f	6600
Weight of stove and coffee husk fuel before test (gm)	fhi	8550
Weight of stove and coffee husk fuel after test (gm)	fhf	7185

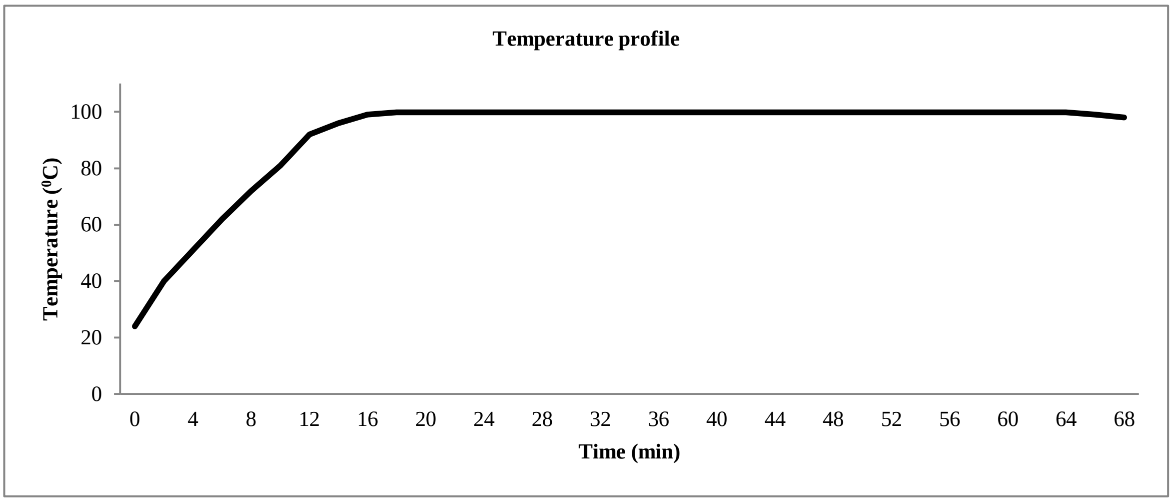

Fig. 3: Water Temperature Profile of Developed Gasifier Stove

4. DISCUSSION

Laboratory tests were conducted to examine the performance of the stove. International Testing Standard water boiling test protocol was followed using coffee husks as fuel. Table 3 shows the distinct of various performance parameters between existing stove and developed one. It was observed that, the design parameters of the improved stove produce higher performance compared to the existing one, i.e. thermal efficiency increased to 24%, and the burning rate (5.2gm/min) also became very low compared to the existing stove (14.5gm/min). The burning rate shows direct correlation with specific fuel consumption.

4.1 Effect of Parameters Variation on Improvements of Stove Design:

The results, Table 6, were generally consistent, with each configuration having unique observable behaviours and trends. However, some configurations had more variation than others between trials and several factors may have contributed towards these discrepancies.

TABLE 6: PARAMETER VARIATION BETWEEN EXISTING AND DEVELOPED GASIFIER STOVE

Parameters	Existing Stove	Developed Stove
Height	24cm	35cm
Diameter of outer cylinder	27.5cm	30cm
Diameter of inner cylinder	13cm	10cm
Number of primary holes	26	422
Number of secondary holes	-	32
Diameter of primary holes	5.5mm	7.0mm
Diameter of secondary holes	-	15mm
Control of secondary airflow	-	Adjustable

4.2 Effect of Chamber Diameter:

The diameter of the inner chimney determines the rate of fuel burning, surface area in which the fuel is exposed to fire is the greater factor which determine the burning rate, the larger the diameter the pretty primary air supply to the shaft and large amount of fuel burning in the given time.

Fig. 4: Burning Rate Experimental Set-Up

4.3 Effect of Primary Airflow and Secondary Airflow:

The experiments conducted reveal that, primary airflow has great impact on ignition of the fuel in the biomass stoves. It was observed that the ignition speed does not increase proportionally with the primary airflow, but there is a flow rate of air at which the ignition speed reaches maximum and then decreases as the flow rate of air increases. This phenomenon seems to be caused by the increase of convective cooling as a result of increased primary airflow that in turns lower ignition speed. On the other hand, if the secondary air flow is increased at the same time as primary air, the increased amount of fuel-gas can be entirely combusted, which will increase the power output of the stove.

4.4 Emission Reduction:

During the experiment, it was visually observed that, the developed stove produced minimal amount of smoke emission compared with the existing gasifier stove. The smoke emissions appear at about five (5) minutes since ignition point. As the fire intensifies the smoke emissions fade away, this improvement of emission reduction is caused by complete combustion due to sufficient oxygen through secondary holes.

5. CONCLUSIONS

The parameters variation in the developed stove as presented in Table 6 were the key measure of performance improvement to this stove as compared to the existing one. Both experiments (WBT and Burning rate) and theoretical investigations indicate the distinct in performance. The results from WBT shows developed stove has parameters which provide the reasonable improvements compared to existing one. Experiments conducted on biomass mass loss rate reveal that, relevant air flow determines the ignition and the combustion rate. In most cases the fully opened secondary airflow and fully opened primary airflow shows the positive results compared to existing stove.

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