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Research Article

Modification, Development and Design Experimental Investigation of an Updraft Biomass Gasifier Stove with Sawdust as Fuel

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Abstract

This work presents the development of an updraft biomass gasifier stove which has been shown to apply the use of biomass fuels for the production of combustible gases. The updraft biomass gasifier stove designed was modified in order to ease the disposal of ashes, which is subsequently constructed using locally available material resources. The gasifier applies the principles of updraft producer gas flows, whereby the stove utilizes rice husk as it useable fuel. The modified gasifier stove was experimentally tested using rice husk as fuel, which was selected based on its availability as is usually classified as a wasteful product: hence the need for its utilization in order to combat environmental effects. Tests were conducted based on loading capacities of the rice husks: 5, 10, 15 and 18 kg respectively and were evaluated accordingly. The gasifier stove performance depends on these loading capacities and the highest was for the 18 kg value, as it gave the highest time of stable flame production of 150.0 min. Furthermore, the 5 kg recorded the least time of stable flame production, implying that the higher the loading capacity the higher the time of stable flame production.

Keywords: updraft gasifier, biomass fuel, rice husk, producer gas, loading capacity, stable flame

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Introduction

The updraft gasifier is a stove that uses biomass fuels for the production of combustible gases and is one of the key sources of renewable energy (Panwar, 2009 and Ojolo et al. 2012). It consists of a pot support, reaction chamber (reactor), char chamber, grate, blower and supporting legs as the major component parts (Uduodo, 2007). In this type of stove, the biomass fuel is fed at the top of the reactor and moves downwards as a result of the conversion of the fuel, into the useful gas (Singer, 1983). The air intake is at the bottom and the gas leaves at the top and finally, ashes as the final product of combustion are removed. The biomass moves in counter current flow direction with the combustible gas, it passes through the process zones accordingly (Diji, 2013, Diji et al., 2013, Uduodo, 2012): drying - distillation - reduction - hearth zone. Drying takes place in the drying zone, while decomposition into volatile gases and solid char is in the distillation (or pyrolysis) zone. The heat flow for pyrolysis and drying is mainly delivered by the upwards flowing producer gas and partly by radiation from the hearth zone (Ali Azam, 2007, Bhakta, 2010). In the reduction zone chemical reactions involving char takes place, whereby carbon dioxide and water vapour are produced as product of the gasification (Diji et al., 2013). Also produced are carbon monoxide and hydrogen as other major constituents of the producer gas. At the hearth zone, the remaining char is combusted in the form that generate more heat, this helps in enhancing the performance of the reduction zone (Ephrem, B., 2007), hence the reaction for carbon dioxide and water vapour is better achieved.

Excluding human and animal energy, the sources of energy supply by gasification process can be classified into traditional and modern energy classes. Traditional sources include wood fuel, agricultural residue and charcoal and cattle dung collectively known as biomass. The use of producer gas (or town gas or coal gas) to run internal combustion engine was first tried in around 1881 (Ali Azam, 2007, Bernhard and Antje, 2007) and it was referred to as suction gas, which is because the gas used by the engine from the gasifier is usually sucked. A variation of this gas using steam or hydrogen instead of oxygen or air is also known as synthesis gas because a variety of chemical compounds can be made from it (Iqbal, et al. 2010). The essential chemical species in all these gases are carbon monoxide (CO) and Hydrogen (H_2): both burnt as released heat (Quaak, 1999, Krigmont, 1999). Town gas was predominantly used for street lighting in early European cities like London and it was lost out to natural gas (Panwar, 2009), due to the presence of the poisonous carbon monoxide (Rao, 1996). Gradually the use of producer gas as a domestic fuel was taken over by cheaply available natural gas (Ali Azam, 2007). Recently and in line with the global trend in sustaining energy and reducing greenhouse gases (Sahn and David 2003), biomass energy is getting increasing attention as future potential source of energy.

Gasifier stove can act as a simple and very important device for energy needs and can facilitate improved kitchen environment (Rao, 1996) for cooking and other heating activities required in mass. The requirement for the optimization of the previously developed gasifier and the needs to certify the global trend (Krigmont, 1999), the present work concentrate on modifying the design of the updraft gasifier by Udoudo, (2007), as in Figure 1. This helps in improving the efficiency with the new design, as insulation will be involved which is expected to significantly reduced effect of heat losses (Sherka, 2011, Abubakar, 2013) and with safety in operation (Sahn, and David 2003). Also to be included in the modified design is the ashes disposal device (grate or lever) after the completed combustion process. It is therefore the aim of this current work, to modify the previously developed updraft gasifier stove (Udoudo, 2007), developed the modified design and to carry out an investigative experimental test of the modified facility. This will be follow up by evaluating the test data found based on the loading capacities of rice husk fuel (Sadaka, 2007, Guillaume, 2007, Belonio, 2005) that is expected to reveal the performance of the modified updraft gasifier.

Materials and Methods

Material Selection

The materials that were used in modifying the design and in also constructing the biomass gasifier stove include (Ephrem, 2007, Ojolo et al., 2012): plain mild steel, alloy steel hinges, round steel bars, mild steel lock, 7 mm mild steel rod, 2.5 mm thick mild steel, welding electrode, rice husk and cement. The shapes and sizes (or thickness) of individual components for modification, were firstly estimated at the design stage before finally selecting the material

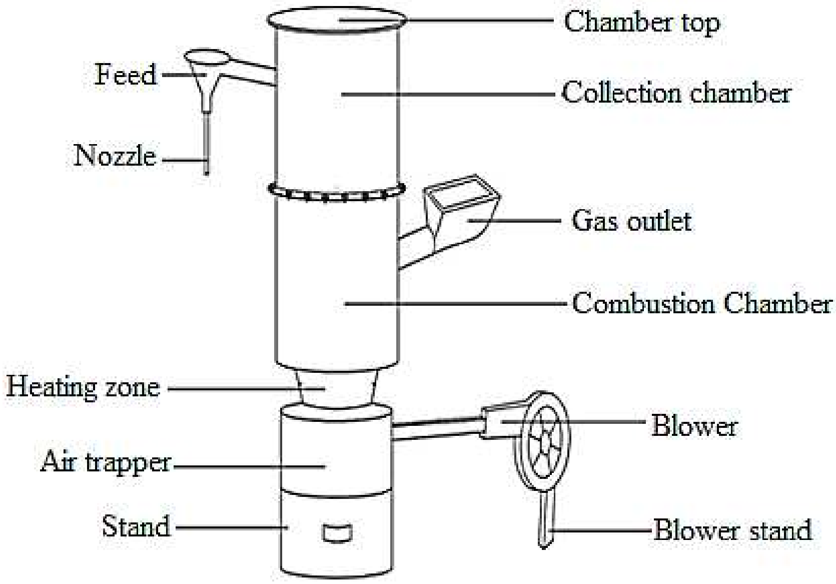

Figure 1 Schematic view of an updraft biomass gasifier stove (Udoudo, 2007).

for the construction of the modified gasifier. The cost and the life span of the stove unit are basically affected by the size of the material, as shown in Table 1. Worthy of note is that thin metal sheets are difficult to weld using an electric arc welding and the application of oxyacetylene gas welding was sorted. In order to simplify the construction of the modified designed updraft gasifier, the following considerations were made when selecting the materials:

- A low thermal conductivity insulating materials: Rice husk ash and Cement were used which have been shown to reduce effects of heat losses.
- Thermal conductivity, densities and heat capacity of the stove wall material were considered and have been initially included in the design.
- A heat resistant material (mild steel) for the inner cylinder of the reactor has been carefully chosen, as the material should be directly in contact with the burning fuel hence it also requires insulation.

Table 1: Bill of Engineering Measurement and Evaluation

S/NO	MATERIAL	QUANTITY	U. PRICE (₦)	AMOUNT (₦)
1.	16 G mild steel pipe (0.9 mm thick)	2 Sheet (4'' × 8'')	7,500: 00	15,000: 00
2.	1'' × 25.4 mm Mild Steel Angular Iron	2 Links	2,000: 00	2,000: 00
3.	1'' 25 mm ф × 500 mm GI pipe and gudgeoned pin	(25 mm ф X 500 mm)	1,000: 00	1,000: 00
4.	7 mm ф mild steel rod	4 Length	2,400: 00	2,400: 00
5.	G12 welding electrode	1 Packet	1,700: 00	1,700: 00
6.	File	1	400: 00	400: 00
7.	Blower	1	4,900: 00	4,900: 00
8.	Paint	1 Bucket	2,200: 00	2,200: 00
9.	Hinges	1 Set	200: 00	200: 00
10.	Lock	1	200: 00	200: 00
11.	Cutting disc	6 Pieces	700: 00	4,200: 00
12.	Square pipe	1 Length	1,000: 00	1,000: 00
13.	Labour/miscellaneous		25,000: 00	25,000: 00
			TOTAL	60,200: 00

Design Analysis and Calculation

Design Parameters

D = diameter of the reactor (m)
H = height of the reactor (m)
V = volume of the reactor (m^3)
ρ = density of fuel (kg/m^3)

FCR = fuel consumption rate (kg/hr)
SGR = specific gasification rate of biomass ($kg/m^3 hr$)

Height of the Reactor

This refers to the total distance from the top to the bottom end of the reactor, it shows how long the reactor would take to operate with fuel loading. Basically is a function of the number of variables such as the required time to operate the gasifier (T), the specific gasification rate (SGR) and the density of fuel. Equation 1 helps in computing the height of the reactor and it depends on T, SGR and ρ (Sadaka, 2007).

$$H = \frac{SGR \times T}{\rho} \quad \text{.......(1)}$$

Assuming density ρ of the rice husk be $= 120\ kg/m^3$ and time $T = 1.02\ hr$

$$H = \frac{100 \times 1.02}{120}$$
$$H = 0.85m \ or \ 850mm$$

Diameter of the Reactor

Equation 2 shows the formula that was used in calculating the diameter of the reactor.

$$D = \sqrt{\left(\frac{1.27 \times FCR}{SGR}\right)} \quad \text{.......(2)}$$

$FCR \ is \ assumed \ to \ be, 9kg/hr$
$SGR \ assumed \ to \ be, 100kg/m^2hr$

$$D = \sqrt{\frac{1.27 \times 9}{100}}$$
$$D = 0.3m \ or \ 300\ mm$$

Volume of the Reactor

Equation 3 used to compute the volume of the reactor and is based on the amount of the biomass fuel that the reactor will contained:

$$V = \pi \frac{d^2 h}{4} \quad \text{.......................................(3)}$$

$$V = \frac{3.142 \times 0.3^2 \times 0.85}{4}$$

$$V = 0.06\ m^3\ \ or\ 60\ mm^3$$

Design of the Blower

Material: Mild steel was used for the centrifugal blade and galvanized sheet metal was used for the casing.

Design Parameters used for the blower include:

D = diameter of the blade, m
B = width of the blade, m
V = velocity of the blade, m/s
W = angular velocity, rad/sec
N = speed of the blade, rpm
t = thickness of the blade, m

$$V = 2\pi RN \quad \text{.......................................(4)}$$

$$R = 0.11\ m$$

$$V = \frac{2\pi \times 0.11 \times 1200}{60}$$

$$V = 13.8 m/s$$

$$w = \frac{2\pi \times 1200}{60}$$

$$w = 125.66\ rad\ /\ s$$

(2) $$V = \frac{2\pi \times 0.11 \times 900}{60}$$
$$V = 10.37 m/s$$

$$w = \frac{2\pi \times 900}{60}$$

$$w = 94.25\ rad/s$$

(3) $$V = \frac{2\pi \times 0.11 \times 600}{60}$$

$$V = 6.9\ m/s$$

$$w = \frac{2\pi \times 600}{60}$$

$$w = 62.83\ rad/s$$

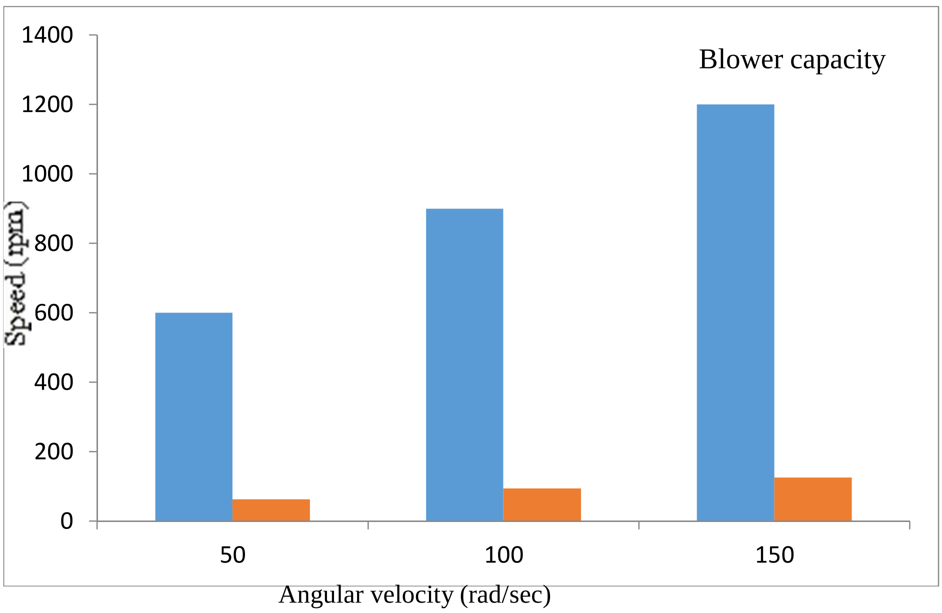

Figure 2 Effect of blower capacity with change in rotation

Figure 1 shows that the blower capacity critically depends on the speed of the blower: implying that the higher blower speed the higher the increased in angular velocity and vice- versa.

Moisture Content (MC) of the Fuel
This is the determination of the moisture content of the rice husk feedstock, this can be determined based on dry basis as well as on a wet basis (Iqbal, 2010).

$$MC = \frac{initial\ weight - dry\ weight}{dry\ weight} \times 100 \qquad (5)$$

Where initial weight is taken from the sample as 32.01 % and the final weight after drying is 30.23 %

Therefore $MC = \frac{32.01 - 30..23}{32.01} \times 100\,\%$

$MC = 5.57\,\%$

Construction
The gasifier stove was constructed using locally available material (mild steel sheets, welding electrode, mild steel square pipe, hinges etc) and simple technology which involved cutting, filing rolling and welding. The constructed gasifier stove, as Figure 3 shows was tested using rice husk fuel at different loading capacities.

Figure 3: Constructed biomass gasifier stove

Experimental Methods

A digital stopwatch was used in recording the time of boiling/cooking during the test experimentation. Initially, after attaining a stabled flame temperature of 1520 ^{o}C at ~ 90 min, records were also firstly initiated at ~ 20 min interval thereafter ~ 10 min intervals for every test.

Also used as measuring equipment was a digital thermocouple indicator in the range of 50^{o}C - 1600^{o}C, it helps in measuring the ambient or surface temperature, boiling/cooking temperature of water, stable flame temperature at ignition stage and temperature of the combustion chamber (reactor). The spring balance was also used in weighing the rice husk fuel and charcoal used. Electric power generator was used in powering the blower; this was used place of a battery system.

The gasification process was carried out in the gasifier by initiating combustion with the aids of charcoal. This was subsequently monitored using thermocouple wire after attaining the expected reactor temperature as found in the literature.

Results and Discussion

The Gasifier Tests Results

After series of testing and evaluation, relevant data of each parameter were gathered and the results were discussed. In determining the total time of stable flame production, Figure 4 shows the recorded time per trial of the rice husk gasifier at different loading capacities. Four trials were conducted. It was observed from the findings that at 18 kg loading capacity, it produced the highest time of stable flame production with 150.0 min. Furthermore, at 5 kg, it recorded the least time of stable flame production, it can also be seen from Figure 4 that the higher the loading capacity, the higher the time of stable flame produced and the lower the loading capacity the least time of stable flame produced vice-versa. The graph of the reactor temperature on loading capacity is also shown in the Figure 5: It was observed from Figure 4 that there was a slight change in temperature of the reactor on different loading capacity of the rice husk. Also, the loading capacity of the rice husk does not have much effect on the reactor temperature, which was based on the lower reaction temperature with variations in loading capacity.

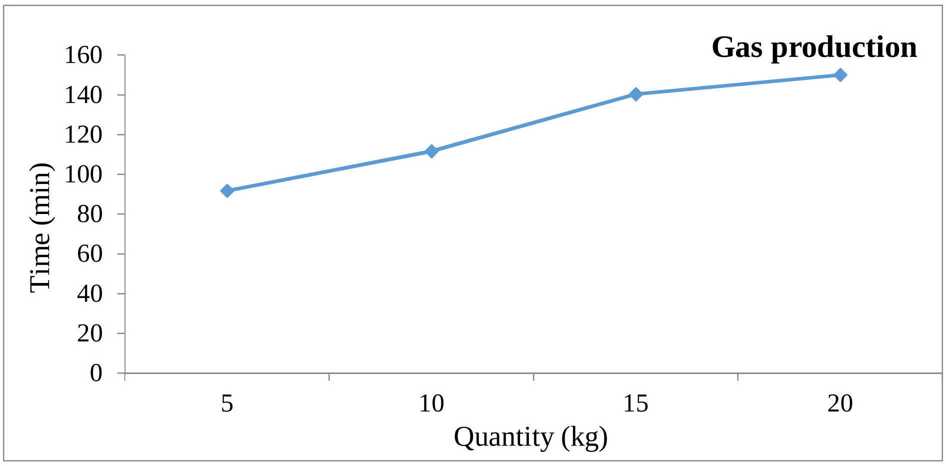

Figure 4 Influence of gas flow on loading capacity of the rice husk.

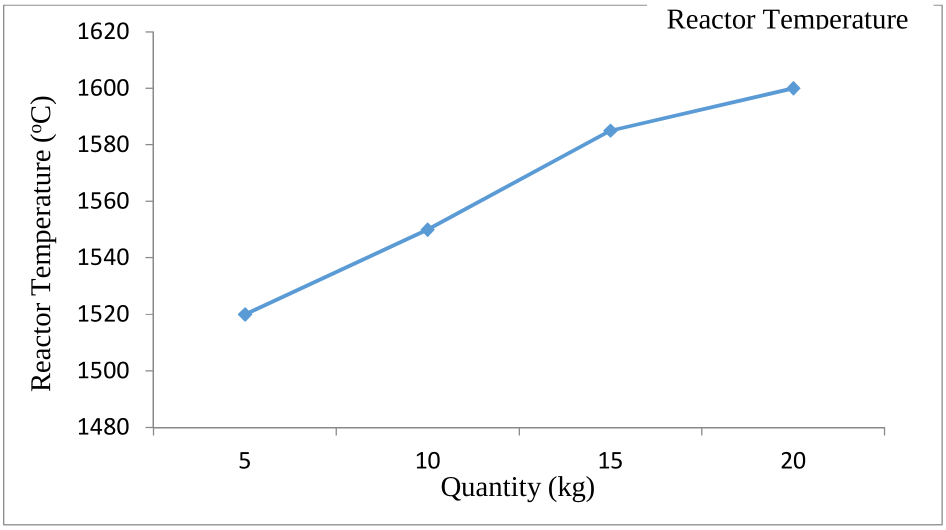

Figure 5 Influence of temperature on quantity of the rice husk.

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Testing Procedure

Initially 2 grams of charcoal was ignited on the grate at the bottom of the reactor and blew using a blower for a period of 5 minutes. The rice husk was then measured using a weight scale and poured directly to the burning charcoal in the reactor and heated for some minutes where different colour of smoke were observed at gas outlet before the gas was produced. A digital thermocouple rated - 50 to 1600 ^{o}C was used for the detection of the reactor temperature. The thermocouple contains a thermocouple wire which was dipped into the combustion chamber and as such the reactor temperature was detected and displayed digitally on the screen. A stopwatch was also used for recording time during the operations.

Gas Produced

The gas produced is composed mainly of CO_2, CO, H_2 and CH_4. The gas produced from the reactor has a relatively high content of tar and moisture when compared with a downdraft unit (Abubakar, 2013) because the products of pyrolysis and drying are added to those of reduction as they flow upwards toward the reactor outlet.

Combustion Chamber

The shape of combustion chamber of the gasifier stove was cylindrical, which was meant to keep the fuel in a packed environment as it burns down and decreases in size (Isaac, and Ayodeji, 2014, Sherka, 2011).

Safety during operation

In the operation of the gasifier, CO was obtained, which is toxic in nature. Therefore, it is recommended not to use the gasifier in an enclosed area (Sadaka, 2007). Subsequently after completion of the burning period some fuel is obtained as un-burnt material. Safety precautions have been shown to be adequate, as waste contents were properly disposed in a safe place, this was achieved at cooled temperature which an important requirement in operating the gasifier. The used of protective and safety wears were adequately practiced.

Conclusion

The updraft biomass gasifier was tested for four different loading capacities of 5 kg, 10 kg, 15 kg and 18 kg, respectively. The experimental result shows that the higher the loading capacity the more the time of stable flame production and the lower the loading capacity the less time of stable flame production.

The test results revealed that at different loading capacities of biomass fuel supplied to the gasifier, there was significance difference in the operations of the gasifier. At 5 kg of rice husk, the gasifier was able to boil 2 liters of water in 5 minutes, at a loading rate of 15 kg, boiling time took 4 minutes and at 18 kg of rice husk is ~ 3 minutes: the quickest time. This indicates that for the highest value of the loading capacity. Boiling time, Thermal efficiency and Fuel Combustion Rate (FCR) also showed relative difference at those loading capacities.

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