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Performance Investigation of Wood Gasification

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ABSTRACT: *Wood gasification has brought alot of benefits to the world economy in terms of energy conservation, health and environment. The infinite biomass resources are wood waste, wood chips and organic waste which have potential for use as feedstock for biogas production. This paper presents performances of mahogany and obeche wood chips. The aim was to know the best wood for biogas also to provide quantitative in sequence about biogas use, from villages to large cities in order to assess the major distinctiveness of biogas application and to solve the problem of energy crises. The performance investigation has analyzed the opportunities and constraints of the different biomass applications provided the source for strategy for the growth of biogas plants and fine-tuning the scale of biogas expansion to match local requirements. One of the best way of producing energy as an alternative source of fuel at a reduced cost is by wood gasification. The method used were analytical, two downdraft fixed bed reactor were designed and constructed with 3mm mild steel plate, Mahogany and Obeche woodchips were used. 10kilogramme of chips were supply through the top of the combustion chamber via air-lock system in two different bed reactors. Chips were burnt in the reactors, pyrolysis took place at the temperature of 300 ^{0}C and 400 ^{0}C, while oxidation was observed at 1000 ^{0}C to 1400 ^{0}C and 1250 ^{0}C to 1500 ^{0}C. These were carried out using thermocouples and temperature regulators mounted on the body of the furnace. Producer gases were generated at a cheaper price and its environmental friendly with high efficiency and reliability which reduces $C0_2$ emissions thus reducing global warming, which were hoard in the storage tanks for domestic purposes such as heating furnance and cooking of food. The pressure gauges were found rising at 25 KN/m^2 and 24KN/m^2 indicating the storage of gas. Mahogany and Obeche wood chips of 10kg each produced 1500 and 1200 kilowatts or more of energy. Further studies, incorporation of cooling device is important. Also provision of purifier would be needed to power internal combustion engine.*

KEYWORDS *Bed reactor; Combustion of fuel; Gas; Mahogany wood; Obeche wood; Biomass; Analytical equations.*

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I. INTRODUCTION

Shortage of fossil fuel which allied with the problem of green house gasses has raised great attention on the exploitation of biomass possessions were reported by Abu et al.(2019), It was also in agreement with the results obtained by several authors (Shaddix, 1999; Hardesty 1999). Biogas known as biofuel technology has brought a large number of payback to health, economy, environment and energy conservation through the fermentation of organic waste according to Abu et al. (2019). Presently, energy services are paramount; there is no much development in any country that is beyond a subsistence economy without ensuring at least minimum access to energy services for an extensive sector. It also provides an essential ingredient for almost all human activities reported recently by Ohunakin et al. (2013). Modern energy for industrial development is a dominant engine of economic and social development which is largely based on fossil fuels, if coupled with other human activities, have been unequivocally shown to be responsible for the warming of the climate system shown by Adeyemo (2000).

Biogas is fashioned through anaerobic digestion from raw materials, such as animal waste, like dung, industrial wastes and agricultural waste like wood according to Xinshan (2005). Energy generated from biomass via anaerobic incorporation which reduces distinctive methane emissions and creation of biogas. Studies from Estoppey (2010) proved the effectiveness of this technology to manage organic waste and agricultural residue like woods in an environmental-friendly and cost-effective manner. In developing countries like African; Sub-

Saharan, despite successes and the development subsistence of favourable conditions for its generation and sustainance, biomass technology have suffered a impede. These setbacks have contributed partly to failure of governments to shore up biomass technology through a focused energy policy, lack of information regarding its economic reported by Mohammed et al. (2017).

Biomass gasification is the conversion of solid fuels like wood and other agricultural residues into a combustible gas mixture, is a fairly new technology in East Africa with most of the projects either at planning or exhibition stages. The technology has been applied in electricity generation especially in rural areas allowing households to access their energy needs according to Shaddix and Hardesty (1999). The utilization of wood gasification peaked during the Second World War when roughly a million gasifier were used all over the world, mainly vehicles operating on domestic solid fuels instead of gasoline was reported by Axelsson (1969).

Biomass gasifier is a chemical reactor that converts wood, or other biomass substances into a combustible gas that can be burned for heating, cooking or for running an internal combustion engine according to Muradov and Veziroglu (2008). The gasification system basically consists of three major units, the bunker, a purification system and energy converters. The gasifier is essentially a chemical reactor that uses wood chips such as mahogany and obeche which burnt in a process of incomplete combustion owing to controlled air supply. Resources like soot (which require to be removed periodically from the gasifier) and generator gas, Solid ashes are main merchandise of gasification process that is moderately oxidized. Bridgwater (2005) has shown that the main flammable component of the resulting generator gas contains roughly 20% Carbon monoxide (CO), 20% Hydrogen (H_2), and 55 to 60% Methane (CH4) while the remaining non- combustible products are Nitrogen (N_2), Carbon-dioxide (CO_2) & Water vapour (H_20).

Conversion of biomass to liquid fuels can be carried out in three ways; direct biomass liquefaction, fast pyrolysis, and gasification to syngas followed by catalytic conversion to liquid fuels (or indirect liquefaction). When the temperature is far above the ground, hydrogen was added and the feestock was in contact with the catalyst which is called undeviating biomass liquefaction. The product is bio-oil. Pyrolysis and gasification are thermo-chemical conversion technologies that decompose biomass and its residues into valuable intermediate products according to Shaddix and Hardesty (1999).

II. MATERIALS AND METHODS

Down-draft fixed bed gasifier methods were adopted. The reactor vessel were made of 3mm steel.10kilogramme of mahogany and obeche chips were introduced into the gasifiers at the top in a process of incomplete combustion owing to controlled air supply at high temperature of 250/800 ^{0} C in the reactor. The main flammable components of producer gas are carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). Pyrolysis breaks down the rest of the material into relative gasses in complete combustion while flammability has being removed as a result of heat generated. From hydrogen, carbon, and water carbon dioxide is generated. Oxygen from the fuel was incorporated in the combustion products, thereby decreasing the amount of combustion air needed.

Depiction of combustion is as follows;

$C + O_2 \rightarrow CO_2$ -401.9KJ/mol

$2C + O_2 \rightarrow 2CO_2$ -200.559KJ/mol

$H + 2O_2 \rightarrow H_2O$ -241.1KJ/mol

$2H + O_2 \rightarrow 2H_2O$ -120.51KJ/mol

In this experiment, carbon dioxide (CO_2) and water vapour (H_2O) are transformed to carbon monoxide, hydrogen and methane, which are the main combustible components of producer gas. In the reduction zone of a gasifier, reaction took place between solid reactants and gaseous which are given below.

$2C + CO_2 \rightarrow 2CO_2$ + 82.50 kJ/kmol

$2C + H_2O \rightarrow 2CO + H_2$ + 61.30 kJ/kmol

$CO + H_2 \rightarrow 2C + H_2O$ + 42.30 kJ/kmol

$2C + 4H_2 \rightarrow 2CH_4$ 0 kJ/kmol

$CO_2 + 4H_2 \rightarrow CH4 + 2H_2O$ -411.0 kJ/kmol

2.1Pyrolysis Reaction

The pyrolysis the biomass has engrossed high interest in production of liquid fuel product as a result of great advantages in terms of transport, storage and flexibility in application such as combustion engines, boilers, turbines in the midst others. Pyrolysis is a thermal decomposition method of biomass that occurs in the absence of oxygen and its residue with short habitation period at intermediate temperatures (400 – 500°C) into valuable intermediate products such as charcoal (solid), and with rapid quenching of vapours into a liquid ‘bio-oil which reported by Shaddix and Hardesty (1999). Bridgwater (2005) reported that the core variable of biomass affecting the quality produced. This technology has the capability to produce bio-fuel with high fuel-to-feed ratios for competing and eventually replacing non-renewable fossil fuels. Conversely, the subsequent brave for pyrolysis to achieve advanced technologies in terms of growth, researchers should invest more to achieve this target. It is necessary to convert biomass into liquid fuels for direct use in vehicles, trains, ships and aeroplanes to replace petrol and diesel were in agreement with the results obtained by several authors (Demirbas, 2002; Abu et al. 2019).

Demirbas (2009) has shown that the thermal degradation of cellulose proceeds through two types of reaction: a gradual degradation, decomposition, and charring on heating at lower temperatures; at temperature above the ground there was a rapid volatilization that go along with the structure of laevoglucose in the presence of pyrolysis which involves heating the original material which is often shredded and fed from the top into the reactor in the absence of air at the temperature of about 420 and 500 ^{0}C according to Mohammed et al. (2017).

2.2 Gasification Reaction

When adequate air is conceded through red – hot cake, producer gas is generated. With the presence of heat, oxygen in the air oxidizes the coke (CO) and turns it to carbon II oxide (CO_2), nitrogen in the air remain the same because of its limpness.

At The Combustion Zone

$$2C(s) + 2O_2(g) \rightarrow 2CO_2$$

$$2C(s) + O_2(g) \rightarrow 2CO(g)$$

Table 1

Component	Mahogany wood (vol. %)	Obeche wood (vol. %)	Charcoal Gas (vol. %)
Nitrogen	49 – 59	50-70	40 – 65
Carbon monoxide	15 – 25	10-15	20 – 35
Carbon dioxide	5 – 15	10-20	0 – 5
Hydrogen	14 – 22	10-10.8	8– 20
Methane	2 – 4	35-35.8	0 –5
Gas heating value kJ/m³	4000 – 5000	3500-4000	4000 – 6000

2.3 Gasifier Efficiency

There are factors that determining the actual technical operation, as well as the economic feasibility of using a gasifier system, which is the gasification efficiency that allow conversion of about 75% of fuel energy content into a combustible gas that can be used as fuel for internal combustion engine or engine applications.

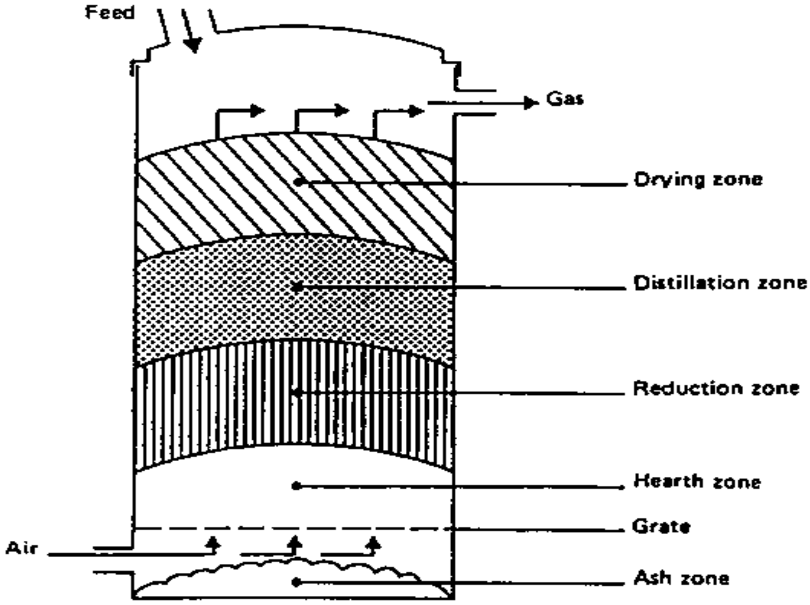

Figure 1

At the bottom of the chamber the gas leaves at the top and there was air intake, also combustion reactions occur near the grate of the reactor, followed by reduction reactions. Heating and pyrolysis of the feedstock occurred in the upper part of the gasifier as a result of heat transfer by forced convection and radiation from the lower zones. In the gas stream, the tars and volatiles that were produced during this process would be carried out while ashes are removed from the bottom of the gasifier according to Mohammed et al. (2017). Xinshan (2009) reported that this type of gasifier has so many advantages, in term of its simplicity, high charcoal burn-out and internal heat exchange which lead to low gas that exit temperatures and high equipment efficiency, as well as the possibility of operation with many types of feedstock such as sawdust, cereal hulls and animal dung etc. Downdraught gasifiers also suffer from the problems associated with high ash content fuels (slagging) to a larger extent than updraught gasifiers.

2.4 Gasifier Inner Part

Figure 2

2.5 Energy Content of the Fuel

The evaluation of efficiency of a given gasification system is subjective by the energy content. The heating values of fuel is higher on a moisture and ash free source, which pay no attention to the incombustible components and consequently provide estimates of energy content too high for a given weight of fuel, especially in the case of some agricultural residues (rice husks).Average lower heating values of wood, charcoal and peat are given below according to Estoppey (2010).

Fuel	Moisture content (%)	Lower heating value (kJ/kg)
Wood	15 – 35	13 – 15000
Charcoal	5 – 9	29 – 30000
Peat	30 – 55	12 – 14000

Table 2

2.6 Moisture Content of the Fuel

Ioelovich (2015) reported that the heating value of the gas produced by any type of gasifier depends at least in part on the moisture content of the wood chips. There would be reduction in thermal efficiency as a result of low heat in the presence of moisture content in the woodchips. The dampness content can be unwavering on the basis of dry and wet since it requires high temperature to compel off the water and consequently this energy is not available for the reduction reactions and for converting thermal energy into chemical bound energy in the gas. Thus, the stuffing of high humidity will result in low gas heating standards.

2.7 Volatile Matter Content of the Fuel

The amount of volatiles in the wood chips determines the necessity of special measures either in design of the gasifier or in the layout of the gas clean up train in order to remove tars from the product gas in engine applications according to Bridgwater (2005).

2.8 Bulk Density of the Fuel

Judy et al. (2014) shown that bulk density is the weight per unit volume of loosely tipped fuel. Squat volume concentration of fuels at times grant ascend to inadequate surge below the magnitude, consequential in low gas heating values and ultimately in burning of the char in the reduction zone but fuels with high bulk density are advantageous because they represent a high energy-for-volume and value. Therefore, the fuels obtained were as a result of need a lesser amount of space in the bunker for a specified re-fuelling moment. The average bulk densities of wood are given below:

Fuel	Bulk density (kg/m³)
Wood	300 – 550
Charcoal	200 – 300
Peat	300 – 400

Table 3

The bulk density varies significantly with moisture content and particle size of the fuel Murphy et al. (2011).In the down-draught gasifier, the fuel is introduced at the top, the air is normally introduced at some intermediate level and the gas is taken out at the bottom. The four segments of gasifier were characterize one after the other by one important step in the process of converting the fuel to a combustible gas.

a) Bunker Section (drying zone**)** ,
b) Pyrolysis Zone
c) Oxidation Zone
(d) Reduction zone

III. DESIGN ANALYSIS AND FORMULATION

The diameter of the throat, h_{nt}.

The throat segment is developed by a baggy gullet band hidden on a sustain ring which to be found at special levels less than the plunger tip flat surface by deviation of the amount of reserve rings among the support ring and the brackets that was welded to the fire-box fortification. This throat ring can easily be changed to acclimatize the gasifier to fresh working environment, and it can also simply be replaced if smashed by overheating.

The general wet gas effectiveness of this style of gasifier defined as:

$$\eta_g = \frac{q_{Vg} \times H_{ig}}{q_{Mg} \times H_{if}}$$

where

$\square_g$ = overallcoldgasefficiency
q_{Vg} = gasvolumeflow
q_{Mf} = fuelmassflow
H_{ig} = lowergasheatingvalue
H_{if} = lower fuel heating value

3.1 Design Calculation
Throat diameter = dt
The nozzle loftiness of level surface beyond the throat = hnt
Height of reduction zone = hr
Fire box diameter = dr
Diameter of the Bunker = db
(A) Determining throat diameter dt

For this project, a fire box diameter dr is 120mm
dt/dr = 3.5
dr = 120 mm
dt = dr/3.5,where dr = 120 mm
dt = 120/3.5 = 34.29 mm

(A) The height of nozzle plane higher than the throat hnt is premeditated as follows
Inner dt = 40 mm
hnt/dt = 40/34.29 = 1.25 mm
hnt/dt = 1.25 where dt = 40 mm
hnt = 1.25 × 40 mm
hnt = 50 mm
The elevation of nozzle plane beyond the throat (hnt) is equivalent to 100 mm
(C) **Height of reduction zone hr**
The recommended height of the reduction zone should be more than 200 mm according to Axelsson (1969).
Standard height of 250 mm was measured in this project
hr = 250 mm

(D) **Bunker Diameter**
Considering inclination at 60^0 and the height of taper section as 100 mm.
From trigonometry ratio
Tan θ = Opposite/Adjacent
Tan 60 = 100/db-dr × 2
db – dr = 200/tan 60 = 115.5
db = 115.57 + dr
db = 115.5+120 =235.5mm
Diameter of the Bunker is 235.5mm

(E) **Diameter of nozzle Tip Ring (dnt)**
From throat diameter of 40mm
dnt/dt is 2.5
dnt = 2.5dt
since dt = 40
dnt = 40 × 2.5
dnt = 100mm
Diameter of nozzle Top ring = 100mm.
The rate nozzle flow area & throat area at the diameter of 40 mm was measured as 0.069.
An = area of the nozzle
At = area of the throat.
an/at × 100 = 6.9

$$\frac{100\times3\times1/4\times\Pi\times dn^2 r}{1/4\times\Pi\times dn^2 t} = 6.9$$

Where dn = throat diameter

$$\frac{100 \times 4 \times dn^2}{dn^2 t} = 6.9$$

$$dn = \frac{\sqrt{6.9 \times 100^2}}{4 \times 100} = 15mm$$

The nozzle diameter is 15mm

3.2 Result

The design and construction of a downdraft fixed bed reactor chamber was made using mild steel of 3mm thickness which could conveniently gasified 10kg oven dry mass of mahogany and obeche woodchips.

Producer gases were produced which is environmental friendly with high efficiency and reliability which reduces $C0_2$ emissions thus reducing global warming, which were hoard in the storage tanks for domestic purposes such as heating furnance and cooking of food. The pressure gauges were found rising at 25 KN/m^2 and 24KN/m^2 indicating the storage of gas. The temperatures were measured with oven thermometer. 10kg of Mahogany and Obeche wood chips produced 1500 and 1200 kilowatts or more of energy. The first test was carried out using bursen burner, which was technically connected to the storage tank outlet, which has a control value. When the valve was opened, spark of ignition from three crown matches was introduced and the fire to burn and the flame produced was a pure blue which proved that all other constituents have been removed, similar results were reported recently (Azadi et al. 2013). Mahogany chips produced the best producer gas when compared with obeche wood chips. This can be used effectively in several applications such as to fuel internal combustion engines if purified to produce shaft power, for generating electricity, water pumping, grain milling, sawing of timber and so on.

IV. CONCLUSION

A downdraft fixed bed reactor plant for mahogany and obeche woodchips for the production of producer gas had been designed and constructed. Two different gases were, gas generated from mahogany wood chips and found to support combustion at site of production. The gas could be used raw for domestic purposes such as heating furnance and cooking food. It could be used for industrial purpose if purified. Therefore gas generated from mahogany wood chips is better than that of obeche wood chips. Generation of this producer gas will solve the problem of energy crises worldwide and it is relatively cheap.

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