Renewable Gas Production System for Electricity Generation by Gasification Technology

Chinyere O. Chidume, Uche C. Ogbuefi, Victor O. Ajah, Ejike K. Okoye and Emenike C. Ejiogu

***Abstract*—The world today is faced with challenges of energy production, management and sustainability due to overuse of fossil fuel in automobiles, power generation and other thermal applications. Various governments and other global regulatory bodies have imposed regulations on the emission of certain gases in other to reduce environmental pollutions and climatic change. This work investigates the use of sawdust, domestics and municipal waste as alternative source of fuel production. An up-draught gasification plant has been built due to its simple design and less sensitivity to moisture content, size and geometry of the solid fuel. Sample of the abundant quantity of sawdust in Nsukka, Nigeria has been tested and gasified. The results shows that 12.56kg of sawdust gives shows 82.6% carbon mono-oxide, 12.8% of hydrogen and 4.6% of methane. The heating value is 17.0 MJ/kg and the 12.56kg of saw-dust yields power output of 13.872MJ. These results show that gasification of waste such as sawdust is beneficial since it serves as a clean energy source, frees up landfills and dump sites, eliminates pollution and spread of diseases and mitigates climatic change.**

***Index Terms*—Gasification, Pyrolysis, Producer gas, Equivalence ratio.**

I. Introduction

ENERGY is essential for human development, hence there is need to exploit several sources of energy such as renewable energy power generation option using gasification technology. Gasification is the process of converting waste materials into combustible gases under controlled supply of air. This technology is an efficient and clean way of providing fuel for powering generators [1]. Waste is available in large quantity in most countries at no cost, especially developing nations like Nigeria. Management of these waste has been challenging to individuals and government at large. Presently in Nigeria, landfill constitutes approximately 60% [2] of the residential and factory wastes disposals and this takes up land space, spreads diseases and becomes an eyesore in the environment. Open field burning waste poses danger to human health and climatic change.

Gasification of waste such as saw-dust is done by breaking down of the material into gases like hydrogen (H_2), carbon monoxide (CO), Nitrogen and little methane (CH4) by the application of heat under limited supply of oxygen. The “synthetic gas” or “producer gas” as they are called can be used to run internal combustion engine for generation of electricity [1, 2]. This energy generation method contributes to the reduction of greenhouse effect and in developing countries, biomass is ranked fourth energy source as it provides 35% of their energy [3].

Gasification process is easy, however, obtaining it in the proper quantity and quality for continuous running of generators is a challenging task [4]. This work will check the availability of saw-dust in Nsukka Nigeria, test its chemical compositions and gasification parameters for possible synthetic gas production. Also build a prototype gasifier plant with gas filtration system to produce clean syngas and carryout analysis on the gas. Some of the benefits of this work will be to provide alternative way for power generation and less dependence on fossil fuel, making landfill and dump sites available for other use, eradication of diseases outbreak from dump sites, elimination of environmental pollution, reduction of climatic change due to elimination of open field burning, employment opportunities and saving of foreign currency as a result of decrease in the importation of petroleum products.

II. Overview

A. Gasification Technology

Gasification process has been in use since the 18th century; the first application was the production of town gas from coal [7]. In the 1920s, gasification was used to produce synthetic chemical and the most well-known is the production of fischer-Tropsch oil out of synthesis gas in Germany which was used to run the military machinery during the Second World War [7]. This process involves conversion of waste to energy through thermal/chemical reaction, or starved air as agent of combustion. Which means that stoichiometric amount of air or oxygen needed is little or less for the process. Therefore, solid wastes were converted into a producer gas that can be used in furnace applications, internal combustion engine system and gas turbines for electricity generation [8, 5]. These arrangements

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are in order of up-draught gasification process as represented in Fig 1.

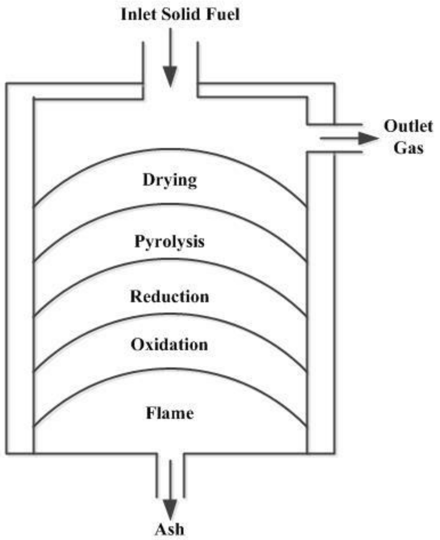

Fig. 1. The order of gasification process in updraft gasifier

The process has different stages as shown in figure 1. Drying stage is where the moisture contents of the solid fuel (waste materials) are removed by evaporation. Pyrolysis is de-volatilization and decomposition of biomass in absence or insufficient supply of air. This process takes place at a temperature above $500°C$, 75 - 95% of the volatile component goes into steam together with gases and condensable hydrocarbons. These volatile gases are, $CO_2, CO,$ methane, other hydrocarbons and the remaining product is char [9].

In the reduction stage, Carbon dioxide (CO_2) and water (H_2O) are reduced by char to form producer gas in the presence of heat. This producer gas comprises of hydrogen (H_2), carbon-monoxide (CO), water (H_2O) and Nitrogen (N_2) if air is used as gasifier agent [1, 9]. The water and air reacts with hot char in a heterogeneous reversible water gas reaction as follows:

$$C + H_2O(+131.5\, kJ/kM) = CO + H_2 \tag{1}$$

According to [8, 9], the following water gas shift reaction occurs

$$CO + H_2O = CO_2 + H_2 \tag{2}$$

$$C + CO_2(+172.9\, kJ/kM) = 2CO \tag{3}$$

The most important reactions are the water gas reaction of (1) and (3). The endothermic reactions increase the gas volume of CO and H_2 at a higher temperature and lower pressure, however, high pressure suppresses the gas volume. According to [7] and [9] the producer gas contains little methane as a result of methanisation reactions of (4) and (5) below.

$$C + 2H_2 = CH_4(-75\, kJ/kmol) \tag{4}$$

$$CO + 3H_2 = CH_4 + H_2O(-285.9\, kJ/kmol) \tag{5}$$

The oxidation stage is an exothermic reaction that releases the heat necessary for reduction, pyrolysis and drying stage. The important oxidation reactions are shown in (6) and (7):

$$C + O_2 = CO_2\,(-283.8KJ/kmol) \tag{6}$$

$$C + \tfrac{1}{2}O_2 = CO\ (-111.1KJ/kmol) \tag{7}$$

B. *Gasification Determinants Variables*

These are variables that must be considered before building a gasifier plant. They include equivalence ratio, superficial velocity of the gas, hearth load, turn-down ratio, heating value, gas flow rate, gas production, fuel consumption and efficiency.

III. Methodology

A. *Sawdust Availability and Composition Analysis*

Waste materials such as sawdust is found in large quantity in Nsukka Nigeria. Sample has been collected and proximate analysis is carried out to determine product distribution. Ultimate analysis is conducted as well to know the basic component of the fuel.

TABLE I
PROXIMATE ANALYSIS

Parameters	Values (%)
Moisture content	8.2
Volatile mater	48.55
Fixed carbon	42.26
Ash content	0.98

Table I shows the results of proximate analysis of sawdust sample in percentage while Table II shows the results from ultimate analysis

TABLE II
ULTIMATE ANALYSIS

Parameters	Values
Carbon –monoxide	29 %
Hydrogen	4.52%
Methane	1.6%
Nitrogen	42%
Sulphur	0.03%
Oxygen	0.6%
Higher heating value	17.01 kJ/.kg^{-1}
Low heating value	11.2kJ/kg^{-1}

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B. *Design Procedure*

The design is done base on the parameters in Table III. Gasification plant of 2.7kVA capacity is desired at assumed feedstock input power of 3.5kVA. Other parameters are obtained from work done previously on gasification as referenced in the table.

$$Pg = Q_1 \times n_g \tag{8}$$

Q_1 *and* P_g are the input and output of the gasifier (kW), n_g is the efficiency (%)

Therefore, if input power is taken to be 3.5kVA, then the fuel consumption rate which is the amount of energy needed for the gasifier in terms of biomass fuel for it to produce the

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required output power can be calculated [13], as shown in (9)

$$FCR = \frac{P_g}{HGV_{SD} \times n_g} \quad (9)$$

FCR is the fuel consumption rate in (kg/h), HGV_{SD} is the higher heating value of fuel in (kJ/kg). Therefore, the consumption rate is determined to be $12kg/h$.
The amount of air flow rate needed to gasify the saw-dust can be determined based on the fuel consumption rate, equivalence rate (ε), air density and stoichiometric air of the biomass [14].

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho_{air}} \quad (10)$$

The stoichiometric Air, SA is given by

$$SA = \overline{AF}\left[\frac{M_{air}}{M_{fuel}}\right] \quad (11)$$

Where $\overline{AF}$ is the air to fuel ratio on molar mass, M_{air} and M_{fuel} are the molecular weight of air and fuel respectively. The air to fuel ratio on molar mass was determined from combustion reaction (12)

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$$CH_{1-28}O_{0.92} + a\,(O_2 + 3.76N_2) = bCO_2 + cH_2O + dN_2 \quad (12)$$

The constants a, b, c and d is calculated from the elemental balance of the equation. The air to fuel ratio on molar basis and stoichiometric air were taken to be 5.8 and 6.1kg of air kg^{-1} of fuel respectively. Based on this, air flow rate was determined to be $21.3m^3/h$.

TABLE III
GASIFIER DESIGN

Description	Value	Remark
Gasifier output (P_g)	2.7kVA /3.5kVA	Assumed
Efficiency in (%)	92	[27]
LHV of the producer gas (LHVg) (kJ/M^3)	4	[28]
Specific gasification rate (SGR) kg. (kg.m^{-2}h^{-1})	110	[29]
Duty cycle (Time)	7	Assumed
Equivalence ratio (ε)	0.3	[30]
Density of air (air) (kg-m^{-3})	1.29	[31]
Biomass molecular formula	$CH_{1-28}O_{0.02}$	Calculated
HHV of saw-dust (HHV_{SD})kJ/Kg^{-1}	17.01	Measured

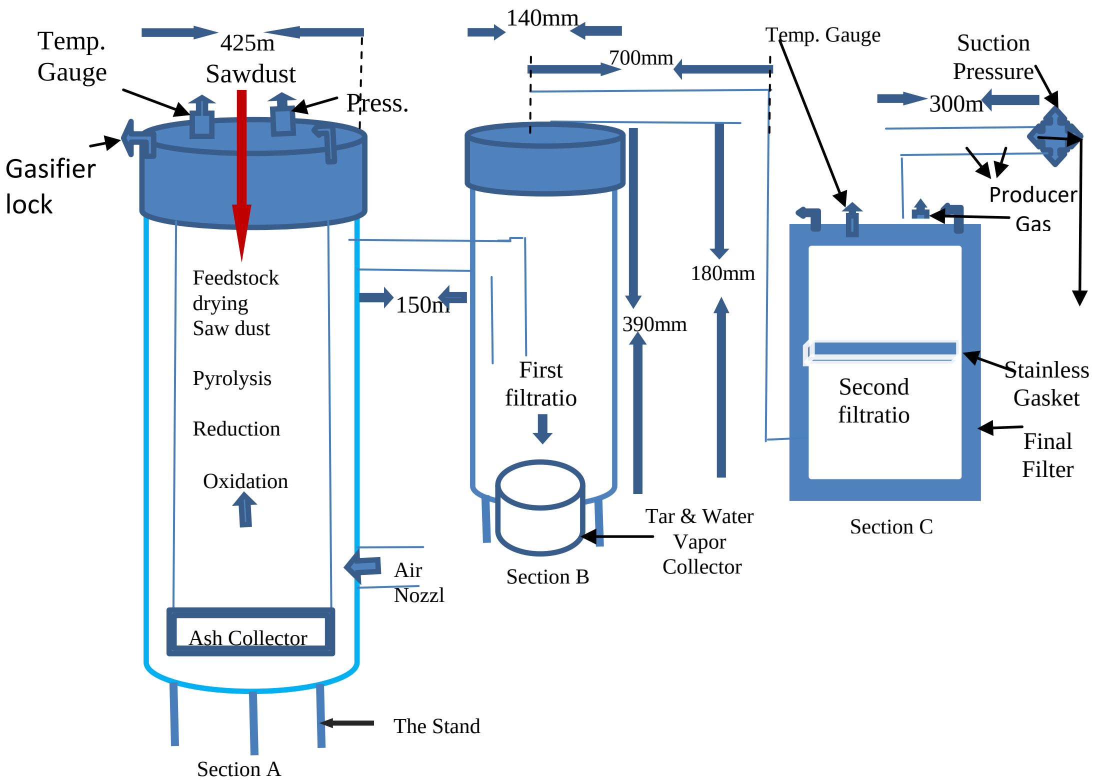

Fig. 2. Schematic of Up-draught Gasifier System.

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C. *Principle of Operation of Up-draught Gasifier System*

Fig. 2 shows schematic of wood (sawdust) gasification system. The section A is the reaction chamber. Sawdust is loaded into it and ignited at the bottom. Controlled amount of air is introduced through the air nozzle, as the wood burns heat is generated. The oxidation process continues to release heat that aids reduction reaction, pyrolysis and drying of fresh wood on the upper chamber. Due to insufficient oxygen the processes produce carbon (II) oxide (CO), hydrogen (H_2) and methane (CH_4). The gases are extracted to section B, for first filtration where water vapor and tar are removed from the gas. Further filtration is done in section C with heat exchange to bring down the temperature of the producer gas.

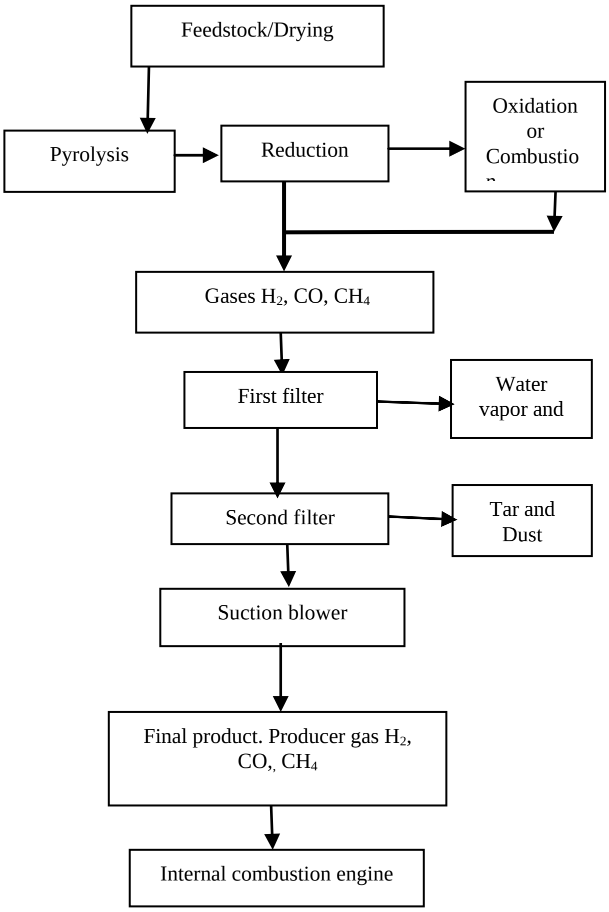

Fig. 3. Block Diagram of Gasification Process

Fig. 3 is the block diagram of the gasification process. It shows the feed stock which is the sawdust being dried and moved to the pyrolysis section. Then, reduction and oxidation. It also shows the gases produced and various filtration stages. The suction blower helps in extracting the final producer gas. The gas is fed to internal combustion engine for electricity generation.

Some of the important reactions that takes place in the system are:

$$C + ½\, O2 \rightarrow CO\ (-111\ kJ/kmol) \tag{13}$$

$$CO + ½\, O2 \rightarrow CO2\ (-283\ kJ/kmol) \tag{14}$$

$$H_2 + ½\, O2 \rightarrow H2O\ (-242\ kJ/kmol) \tag{15}$$

Other important gasification reactions include:

$$C + H_2O \rightarrow CO + H_2(+131\ kJ/kmol) \tag{16}$$

$$C + CO_2 \leftrightarrow 2CO(+172\ K9J/kmol) \tag{17}$$

$$C + 2H_2 \leftrightarrow CH_4(-75\ KJ/kmol) \tag{18}$$

IV. IMPLEMENTATION

A prototype of gasifier plant is implemented. Fig. 4 is the picture of experimental setup of the prototype and sawdust. Little quantity of charcoal is charged up to 300^0C before introducing the sawdust. Airflow meter measures the amount of air supply and gas produced. Thermocouple is used to measures the temperature.

Fig. 4. Picture of the Implemented Gasifier Plant and sawdust

The 12.56kg of saw-dust heats to about 500^0C to 600^0C where pyrolysis occurs to give carbon monoxide, hydrogen gas and methane. Above 600^0C gives more of hydrogen gas and carbon with little methane but below this temperature range, has more of methane formation.

V. EXPERIMENTAL RESULT AND ANALYSIS

A. *Comparison of Experimental and Theoretical Results*

Comparison of the experimental results to calculated results is shown in Table IV. Due to leakages in gasifier process variable such as air flow ratio, pressure and temperature that are not under control; the experimental result is less than the calculated values. 1kg of saw-dust gave 2.5kg (Nm^3) of producer gas and 12. 56kg of saw-dust will give 31.4kg.

TABLE IV
EXPERIMENTAL AND THEORETICAL RESULTS ANALYSIS

Gas Composition	Experimental Results (kg)	Theoretical Results(kg)	Difference (%)
Carbon-Monoxide	9.106	29.26	68.88
Hydrogen	1.419	4.14	65.72
Methane	0.502	1.670	69.94
Total Gas Generated	11.027	35.07	68.55

The heating value of 1kg of producer gas produces is 17.01kJ = 17010J;

$$2.5 \times 17010J = \frac{42525J}{1000} = 42.525KJ \tag{19}$$

but if 1kg of saw dust burns per second, then 42525 watts is produced i.e. (42525/1sec)w and if it takes 1kg of saw-dust

1 minute to burn, the power produced will be 42525/60=708.75w.

B. Electrical Energy Conversion

The electrical power produce from sawdust depends on the quantity that burns per unit time. For an internal combustion engine of 1500 rpm, maximum gas intake of $0.0214\,m^3/s$ and assumed volumetric efficiency of 0.8 (% efficiency), therefore, the real gas intake (grin) is

$0.0214 \times 0.8 = 0.017\,m^3/s$

Thermal power on the gas is $P_g = P_{in} = g_{rin} \times heat\ value$

$\frac{17.01\mathrm{kJ}}{\mathrm{m}^3/\mathrm{S}} \times \frac{0.017\,\mathrm{m}^3/\mathrm{S}}{1} = 0.289\mathrm{kJ} = 289\ \mathrm{J/S} = 289\mathrm{VA}$

Engine efficiency P_m, depends on the compression ratio. For a compression ratio of 9.5:1, efficiency is estimated to be 28% [12].

$P_m = P_g \times \mathrm{efficiency} = 80.92\mathrm{VA}$

Electrical power $P_e = P_m/\mathrm{efficiency}$ gives 289VA

Real power = $P_{in} \times \mathrm{Cos}\emptyset = 289 \times 0.8 = 231.2$ watts

Energy produced $231.2 \times 60 = 13.872\ KJ$

VI. CONCLUSION

This work presents gasification of sawdust as alternative means of electricity generation. Sawdust is found to be in large quantity as waste material in Nsukka Nigeria. A prototype gasifier plant is built and sample of sawdust gasified. The result shows 82.6% carbon mono-oxide, 12.9% of hydrogen and 4.6% of methane in the synthetic gas produced. Comparing the gas produced to the calculated value shows wide margin which is attributed to leakages on the plant and implemented control limitations. Conversion of the gas to electrical energy indicates that the process is useful to generate electricity.

VII. RECOMMENDATION

Conversion of sawdust to electricity is advantages for the generation of electricity, thermal applications and environmental sanitation. This work has shown that it is possible to gasify sawdust. To increase the quantity of producer gas, it is recommended that the sawdust be pelleted and the gasifier plant of larger size built to enhance burning rate. Also, robust control method can be used to monitor and control temperature, air and gas flow as well as to maintain the system at optimal condition for maximum gas production

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