International Journal of Sustainable and Green Energy
2022; 11(2): 35-46
http://www.sciencepublishinggroup.com/j/ijsge
doi: 10.11648/j.ijrse.20221102.11
ISSN: 2575-2189 (Print); ISSN: 2575-1549 (Online)

Performance of a Gasifier Coupled to Internal Combustion Engine and Fired Using Corn Cob Feedstock in Biomass Energy Production

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To cite this article:

Jazuli Sanusi Kazaure, Ugochukwu Okwudili Matthew, Ubochi Chibueze Nwamouh. Performance of a Gasifier Coupled to Internal Combustion Engine and Fired Using Corn Cob Feedstock in Biomass Energy Production. *International Journal of Sustainable and Green Energy*. Vol. 11, No. 2, 2022, pp. 35-46. doi: 10.11648/j.ijrse.20221102.11

Received: November 2, 2021; **Accepted**: March 31, 2022; **Published**: May 26, 2022

Abstract: The performances of renewable energy generation from Corn Cob feedstock in biomass gasification coupled to internal combustion engine (ICE) was implemented as an alternative energy sources to the underserved rural communities where the national grid power supplies are deficient. The biomass feedstock Corn Cob possessed an explicit energy resources that can be utilized in gasification systems for bioenergy creation due to its dense and uniform nature as well as its improved energy composition and its low sulfur and nitrogen concentrations. In this study, the biomass characterizations of Corn Cobs were investigated as energy generating constituent required for off-grid power generation schemes. Theoretical and experimental analysis of ten existing literature on Corn Cob feedstock biomass gasification methodology were reviewed, which helped to form key decisions in the design implementation. As the investigational experimentation of Corn Cob biomass gasification utilizing air as gasifying agent was accomplished, the syngas-based power generation was measured in a characterized gas-ICE. The renewable energy recovery from Corn Cob feedstock gasification in the current study showed an electricity generating capacity of approximately 200KW. The renewable energy formation with respect to solar energy system, wind and hydro together with biomass power gasification implementation are among the contemporary renewable energy alternatives to the dwindling power generating capacity necessitated by growing energy requirements in the developing countries. The combined thermochemical transformation of Corn Cob feedstock gasifier as power generating system characterized a technological paradigm shift to sustainable renewable energy future. The research findings disclosed that the gasification of Corn Cobs have energy potentials for a sustainable biofuel feedstock applications to renewable energy. The research concluded that Corn Cobs feedstock hydrolysed substrate produces certain concentration of bioethanol with high-level anti-knock characterisation as a result of its distinguishable octane composition and prominent latent heat of evaporation that diminishes the compressed gas temperature throughout the compression stroke used in the internal combustion engine as renewable energy sources.

Keywords: Biomass Gasification, Bioenergy, Green House Effect, Carbon Emission, Fossil Fuels, Corn Cob, Internal Combustion Engine, Renewable Energy, Syngas

1. Introduction

Biomass gasification systems are renewable organic materials from plants and animal sources, considered among the renewable energy resources with high capacity to contribute to the world energy requirements [4]. The utilization of biomass can offer a positive solution in renewable energy services, including electrical energy generation, heat energy and transportation fuels, which can condense carbon dioxide (CO_2) emissions, sulphur and heavy metals release into the atmosphere. The world-wide demand for energy is expected to maintain the constant growth and it is extensively acknowledged that its alternative sustainable solutions need to be discovered to address any future eventual deficit. The renewable energy resources like solar energy system, wind, hydro, geothermal and biomass energy are considered renewable because it is naturally inexhaustible [5]. The renewable energy resources have evolved into central discussions of the current society energy sustainability mix, with regard to the supply of fossil fuels which are non-renewable energy in nature and also contribute to the global warming and greenhouse gaseous effects. Beside the inadequate availability of the non-renewable energy sources like the fossil fuels which damages the environmental ecosystem when consumed, its by-products contributes to ozone layer depletion, greenhouse effect and global warming [6]. Consequently, the initial world-wide agreement to limit CO_2 emissions and global warming effects were Kyoto Protocol to the United Nations Framework Convention on Climate Change, the World-wide Accord, assigned to the Japanese city in which it was approved in December 1997 directed towards diminishing the emissions of gases that promote global warming [7].

The Kyoto International Treaty was transformed into a binding document committed towards reducing six gases namely; CO_2, Methane, Nitrous Oxide, Sulphur Hexafloride, Hydrofluorocarbon and Perfluorocarbons as well as reducing ground level ozone by 5% [7]. The adoption of Kyoto Protocol was a pre-emptive measures to counterbalance greenhouse gases effect which were rapidly threatening the global climate, human life and the entire planet. In a similar development, the Paris Climate Agreement was an accord binding the governments of more than 182 nations to moderate greenhouse gaseous emissions and regulate the universal temperature surge lower than 2°C (3.6°F) for environmental ecosystem sustainability [8]. The global decarbonisation agenda was prioritized which implied an economic system that sustainably reduces and compensates the emissions of CO_2 towards a long-term goal of CO_2-free global economy. In achieving those objectives, the renewable energy was given preference for upcoming energy synthesis, along-side other clean sources like solar energy system, biomass gasification, wind and nuclear power [9]. The determination for a global friendly environment in energy invention is to stimulate intensification in opportunities for business innovations in renewable energy manufacturing like solar power, wind, hydro and biomass technology. The renewable energy study throughout the entire human race, indicated that Germany manufactures the topmost quantity of renewable energy technology, amounting to (12.7%) of the country energy requirements, seconded by the United Kingdom (11.95%), Sweden (10.97%), Spain (10.18%), Italy (8.9%), Brazil (7.36%), Japan (5.4%), Turkey (5.26%), Australia (4.76%) and the United States of America (4.33%) in the topmost ranking [10].

The renewable energy investments are very important as they have the capability to deliver all set of power supplies without consuming the natural energy resources [11]. To lower the risk of environmental degradation such as gas spillages and minimizing issues associated with fossil fuel emissions, in addition to reducing the need for imported fuels made renewable energy more appreciable. The renewable energy diversification could enable the developing countries like Nigeria to meet the energy requirements for years to come as the innovations bring down the costs and the promise of a clean energy future. The American solar energy, wind and biomass generation are progressively increasing into an integrate-able national electricity grid ecosystem without compromising reliability and energy efficiency [12]. This implies that renewable energies are progressively succeeding dirty fossil fuels in the power sector, advancing the profits of lowering gas emissions of CO_2 and several other environmental pollutants. The renewable energy sources offered the most suitable energy substitute with regard to the diminishing power generating capacities imposed by intensifying energy requirements due to urbanization and population surge in the developing countries [13]. Nigeria is among the developing nation often regarded as the third world countries with several rural communities associated with energy deficiencies due to impediments in expanding the national electricity grid for every household consumption. In the current research, Corn Cob was used as biomass feedstock in the internal combustion engine (ICE) with substantial energy resource potentialities required for gasification systems for commercial energy fabrication in the range of 150KW-200KW [14]. The Corn Cob has certain degree of desirability above other biomass feedstocks taking into account its fermentable carbohydrate concentrations and unchanging characterizations together with its improved energy composition and little point nitrogen and sulphur constituent used as gasifiers. Corn cob is an agricultural waste product produced from cereal crops like maize usually disposed and destroyed by fire on the farms if not recycled, refer to Figure 1. The heaping and incineration of Corn Cobs on the farmlands naturally amount to gross air pollution, hence the need to recycle them into renewable energy formulation [15]. In Nigeria, cereal crops (maize-corn) are essential food component for countless number of people and it remains the most desirable agricultural harvest for above 100 million rural dwellers in the various rural communities in Nigeria.

Figure 1. *Corn Cobs collected from a harvested maize field for use as an energy source in biomass gasification feedstock for renewable energy generation.*

Corn Cob is an agricultural residual lignocellulosic biomass feedstock substance with immense capacity for bioethanol manufacture through fermentation of lignocellulosic biomass material into ethanol which complement the fossil fuel usages [16]. The production of bioethanol through this process is a favourable alternative to carbon loaded fossil fuels which pollute the environment when they are burnt. Improving the environmental efficiency and economic profit of bioethanol production from lignocellulosic biomass, requires recycling the Corn Cob through pre-treatments, enzymatic hydrolysis, fermentation and distillation through the down draft gasification approach. Naturally, the biomass gasification systems are carbon neutral renewable energy sources, required for outright carbonaceous fossil fuel elimination. Corn Cob contained carbohydrate sources, a rich supplier of lignocellulosic substances that are abundantly available, inexpensive and renewable, characterizing the cellulosic biomass raw material for ethanol (biofuel) production with several improvements in bioethanol transformation [17]. Corn Cob deposits are adequately obtainable in Nigeria as they are delivered in substantial amounts by the maize processing farmers, which turn out to be among the biggest producers of agricultural residues in Nigeria as nearly 11million metric tons and above of Corn Cob are generated annually [18]. The bioconversion of Corn Cob into energy delivering gas recognized as syngas via biomass down draft gasification techniques is a sustainable non-carbonaceous renewable electricity production requirements for the ever-increasing energy desirability in the rural communities. The biomass gasification of Corn Cobs feedstock produces hydrogen, syngas and thermal energy that are used in generating electrical power to support the socio-economic activities of the rural citizens. The biomass gasifier function adequately within a specified selections of feedstock properties, to that effect, the understanding of the attributes of the feedstock to be utilized at the moment of gasification is very essential in order to calculate the performances before and after gasification synthesis. The gasification performances together with the impressions of biomass compositions, the biomass element sizes, the gasifying agents, the operating condition of gasification process with respect to pressure and temperature on the gasification effectiveness and type of gasifier were presented. The current design produced a medium-scale biomass gasification systems with power generating capability of 150–200 KW biogas power plant as an alternative renewable energy sources to the rural communities. The paper is structured into introduction, objectives of the study, statement of problem, literature review, methodology, implementation and conclusion.

2. Objectives of the Study

The current design focused on the renewable energy production, utilizing biomass energy from the synthesis of Corn Cob feedstock as gasifier to produce power required to drive the internal combustion engine for rural electrification. The application of biomass for energy generation depend on certain conditions such as feedstock availability, land availability, environmental ecosystem sustainability and atmospheric conditions. Considering the generator engines that should be associated with the system required to consume the energy carrier produced for electricity, the internal combustion engines (ICE), micro turbine engines (MTE), Externally fired gas turbines (EFGT) and Stirling engines (SE) can be adopted to achieve the purpose [19]. In the current design, the following objectives were realized;

i. Development of an applicable medium-scale biomass gasification systems to generate alternative energy source in the range of 150KW-200KW biogas power plant.
ii. Establishment of sustainable renewable energy mix, utilizing Corn Cob feedstock gasifier with air to accomplish energy generating system as alternative to fossil fuel consumption which causes environmental warming and greenhouse effects.
iii. Accomplishment of a medium-scale biomass gasification system using Corn Cob as feedstock gasifier obtained from agricultural waste product.
iv. Advancement of a medium-scale biomass gasification system to drive the internal combustion engine, creating potential renewable energy market in developing countries like Nigeria with insufficient national grid electricity distributions.
v. Promotion of socio-economic life of rural communities through creation of Corn Cob supply chain as organic agricultural raw material for biomass renewable energy production.
vi. Strategic waste management mechanism and renewable energy recycling for environmental biodegradation safety management..

3. Statement of Problem

Burning of coal and other fossil fuels used in domestic and commercial consumptions have negative impact on the environmental ecosystem sustainability, with consequential impressions on global warming and greenhouse gaseous effect. The discovery of biomass together with other renewable energy sources with respect to solar energy system, wind and hydro power systems are fundamental aspect of the energy requirements for cleaner environment with regard to power generation. The biomass gasification is an advanced technology fabrication designed to manage processes relating to heat, steam and oxygen to transform biomass to hydrogen and several gaseous formations, with no combustion. To that effect, mounting biomass energy system removes carbon dioxide from the atmosphere, making the net carbon emissions of this method low, especially when coupled with carbon capture and storage in the long term. The biomass renewable energy system are the clean sources of energy that aids in bringing down the residual waste of CO_2 from burning fossil fuel, methane released from decaying organic substances, nitrogen and sulphur which are responsible for global warming, greenhouse effect and environmental pollution.

In the current research, attention was given to the rural communities' renewable energy requirements where national grid electrification were in short supply. The biomass renewable energy was coupled and deployed in the rural community to provide between 150KW-200KW worth of electricity for domestic energy consumption thereby improving life and socio-economic activities of the rural dwellers.

4. Literature Review

Biomass gasification is a scientific or chemical transformation of solid biomass energy constituents into a gaseous combustible substance often regarded as producer gas through sequences of thermochemical synthesis [20]. The gasification method produces gas fuels required for power generation which is believed to be ultimate alternative to fossil fuels that accounted for 80% of domestic energy and industrial consumption with consequential impressions on global warming and greenhouse gaseous effects [21]. The effective consumption of biomass energy in the rural communities are expected to utilize medium-scale biomass gasifiers having the power generating capability less than 200 KW for public and household electricity requirements. The technology utilized a well-coordinated process, requiring heat, oxygen and steam to convert biomass to hydrogen and several chemical substances without combustible gaseous emission. Base on the growing interest in the biomass renewable energy investment, the process eliminates CO_2 from the atmosphere and ensures that the net carbon emission is brought low particularly when connected to carbon capture and storage in the extended duration. According to Aseffe et al., (2021), the fit in thermochemical transformation of Corn Cob feedstock gasifier as power generating system symbolizes a technological substitution required for environmental renewable energy management which provided a holistic energy formulation and biomass power systems for electricity generation [22].

Gasification process transforms fossil fuel based carbonaceous constituents or biomass feedstock gasifiers into synthetic gases, containing considerable proportion of carbon monoxide, nitrogen, hydrogen and carbon dioxide in a sequence of successive endothermic reactions [20]. There are several thermochemical transformations that occurred at the stance of biomass gasification processes [15]. The first thermochemical reaction naturally happened in the combustion region of the gasifier at the temperature beyond 1200°C which also triggers an oxidation reactions of the gasification system regarded as combustion zone reactions. The second chemical reaction describes the intermediate product of incomplete oxidation, which implied the biomass constituents not completely combusted in the first reaction. The reaction represented the red-hot bed of charcoal designed to reduce the gas temperature of the endothermic reactions. The third reaction represented the outstanding water-gas shift reaction, which indeed serves as the determining factor in the quality and yield of the syngas manufactured through the gasification arrangement. The final gasification process is actually the hydrogasification that happened in the hydrogen sufficient environment, frequently exploited in the manufacture of synthetic natural gas from Corn Cob biomass feedstocks gasifier [23].

Renewable energy investment in Nigeria holds the opportunity for energy security and in reducing the environmental gaseous pollution and greenhouse gas effects [24]. The progressive investment in renewable energy can help to reduce energy imports and diminish fossil fuel consumptions which is the largest source of carbon dioxide emissions in Nigeria. The excessive burning of fossil fuels produces carbon dioxide gas, which is destructive to the environmental ecosystem sustainability and is making the earth warmer than necessary. At present, eighty percent of global energy demand and sixty six percent electrical energy generation are contributed through the fossil fuels consumptions, accounting for sixty percent of the greenhouse gas emissions blamable to the global climate transmutation [25]. As conversion to cleaner energy mix kick start in several countries, in addition to novel technology inventions targeted at reducing renewable energy cost and ensuring energy efficiency, it is likely that renewable energy will still contend with exceedingly supported carbon-intensive energy technology inventions as time progresses [26]. The renewable energy inventions may perhaps be speedily implemented supposing the energy policies will handle mutually the impactful fossil fuels generating systems while accelerating additional funding for renewable energy developments. The requirements for renewable energy improvements have necessitated several applicable regulations in relation to accomplishing the renewable energy sector developmental aspirations in the sub-Sahara African countries [27]. Whereas regulations are of essence to renewable energy development, there is necessity for authorizations through legislative instruments within the cosmopolitan laws to device methods mandatory towards accomplishing national renewable energy enhancement objectives. To that effect, the renewable energy master plan (REMP) demanded intensifying allocation to renewable energy generating capacity from 13% of the overall power generating capability in 2015 to 23% in 2025 and 36% by 2030 [28]. It has been anticipated that renewable energy generating capability of Nigeria will account for 10% of the total energy consumption by 2025 [27]. Nigeria as a country is at present building up requirements for enormous power distribution and demand for expanded grid dependability and energy security required to drive all key infrastructures necessary for socioeconomic reengagement. In this study, the biomass characterizations of Corn Cobs feedstock were utilized as energy generating constituent required for off-grid power generation methodologies. The renewable energy resources like solar energy system, hydro and wind together with biomass power generating system are among the best appropriate renewable energy supply to the declining energy producing capacities enforced by intensifying electricity requirement in the developing countries [29]. Due to capital intensive nature associated with solar power system installation, wind and hydropower system, energy generated from biomass gasification were considered the highest economical method of supplying renewable energy to the rural communities. In this manner, the biomass gasification power systems were used to generate current from the chemical energy composition in the organic materials (Corn Cob) utilized as feedstock gasifier in the bioenergy conversion process.

Corn Cob feedstocks are biomass renewable organic materials produced from agricultural disposable waste mainly from maize crop [30]. The biomass gasification constituents can be burnt straightforwardly into heat energy or transformed into renewable liquid and gaseous fuels through various technologies, requiring converting renewable biomass fuels into electricity or heat energy through combustion, bacterial decomposition and bioconversion into liquid fuel or gaseous substances. According to Chen et al., (2021), the scientific objective was to advance innovation for biorefinery that can transform biomass feedstock constituents into several advantageous, chemical substances, fuel materials and item for consumption, in a manner closely related to oil refineries and petrochemical [31]. The bioconversion of lignocellulose raw material into biofuels production are predominantly of carbohydrate polymers formation from non-edible disposable agricultural constituents like maize Corn Cob for renewable energy production. According to Ab Rasid et al., (2021), the lignocellulose bioconversion requires a microbial breakdown of glucose molecules by means of acidic thermochemical pre-treatment test, intended to accelerate enzymatic hydrolysis of cellulose into fermentable sugars [32]. In this process, the lignocellulosic feedstock slows down the enzymatic hydrolysis together with microbial fermentation processes, adjusting the temperature settings throughout the fermentation stages to enable upper limit production of biofuel on commercial quantities. The brewery industries manufacture of biofuel is done through the fermentation of carbohydrate compound in which sugar components are transformed into bioethanol with water and CO_2 formation as the end products [33].

The domestically produced corn ethanol is ethanol manufactured from corn biomass system which also is the major source of bioethanol energy in the United States of America [34]. Industrially, corn ethanol is manufactured as a result of ethanol fermentation and distillation to enable bioethanol production at higher temperatures, whereas the most favourable temperature for upper limit production occurs at 32°C. The manufactured ethanol are combined into more than ninety eight percent of the United States of America gasoline to condense the environmental air pollutions [35]. According to Bajpai (2020), modifications in the automobile gasoline engines are necessary in relation to the percentage of the ethanol with the gasoline mixtures, denoted as "E" which represented the quantities or the percentages of ethanol composition added to the mixture, as E85 represented eighty five percent (85%) anhydrous ethanol and fifteen percent (15%) gasoline mixture [36]. The Corn ethanol are predominantly utilized in combinations with gasoline to produce combustible energy mixture E10, E15 and E85 in which E10 and E15 could be utilized in all combustible engines with no amendment [37]. On the other hand, combinations such as E85 requiring considerably ethanol concentration demanded substantial amendments to enable the combustible engine to operate the mixture with no damages to the engine [38]. According to Verhelst et al., (2019), the utilization of unadulterated anhydrous or hydrous ethanol in the internal combustion engines are simply workable provided that the engines are modified or constructed to meet those objectives and adopted specifically on the automobiles, motorcycles and light-duty trucks that were originally designed for it [39]. However, the anhydrous ethanol formation could be mixed together with gasoline for use in gasoline engines, although in conjunction with extraordinary ethanol concentrations when inconsiderable engine adjustments are carried out [40]. There are several automobile vehicle engines presently consuming E85 biofuel, also named flexible fuel vehicle including the Toyota Tundra, Dodge Durango and Ford Focus [41].

The performances of the biomass gasification systems are generally influenced by feedstock gasifier type, the gasifying agents, the reaction temperature, the equivalence ratio (ER) and the feedstock particles composition [2]. On the other hand, analyzing the working environments and its overwhelming effects on gasification processes are often developed by means of trials and rigorous experimentations. Generally, there are two types of biomass gasification techniques, namely, kinetic technique and thermodynamic equilibrium technique [2]. The requirements for a comprehensive information on the processes, distinctive gasifier composition and several arithmetical formulations made the system of kinetic technique very problematic to engage. The thermodynamic equilibrium technique centered on chemical balance and mass balance are not as much problematic and can be employed to diverse biomass gasification processes and reactor inputs [42]. However, the thermodynamic equilibrium technique were further classified into two methods; stoichiometric thermodynamic equilibrium technique (established on the condition of unchanging equilibrium constant) and non-stoichiometric thermodynamic equilibrium technique (establish on the instances of decreasing the Gibbs free energy). According to Okolie et al., (2020), the stoichiometric thermodynamic equilibrium technique is generally flexible, because it contained lesser amount of complexity and has been adopted extensively in the study and effects of process parameters on biomass gasification systems [43]. Several researchers used stoichiometric thermodynamic equilibrium technique to predict gasification performances, in demonstrating sufficient conformity in conjunction with experimental data. Although, some other scholars have attempted to remodel those techniques towards improving their accuracy based on certain peculiarities. Ramanam et al., (2008), advanced an equilibrium technique to calculate the gas composition through altering the experimental parameters of ER, moisture content and reaction temperature in the research titled “performance prediction and validation of equilibrium modelling for gasification of cashew nut shell char” [44]. According to the paper, the outcome were contrasted alongside the experimental result and it proved satisfactory which indicated that the ER is sufficiently appropriate to the gasification systems. According to Said et al., (2021), increasing the equilibrium coefficients with constants for estimating the gas composition from solid waste in downdraft gasifier is a thermodynamic equilibrium model for determining gas composition, solid conversion and gasification efficiency [45]. In the current design, an improved equilibrium technique for a comprehensive gasification system was technologically advanced to determine the performances of the combustion gas engine and to analyze the impressions of the operating variables on the gasification process of Corn Cob feedstock in the downdraft gasifier required for bioenergy generation.

The corn cob biomass feedstock utilized in bioenergy transformation is required to possess satisfactory energy concentration needed to generate reasonable amount of chemical energy [46]. The energy concentration of feedstock gasifier is expressed as the amount of energy that can be stored in a given biomass system per unit volume or weight [23]. According to García-Freites et al (2021), the volumetric energy density of a bioenergy feedstock is important in studying the volume of biomass required to be collected, stockpiled and applied in the energy manufacture system [47]. Even though Corn Cob biomass feedstock gasifier do not possess extreme energy density like the fossil fuels that is well-known to the society, they have equivalent energy density to other biomass feedstock and less energy density to coals, equally employed as bioenergy feedstocks constituent around the globe.

Table 1. *Analysis of Corn Cob Feedstock Biomass Gasification system Performances from existing literature measured in (wt. %) as Renewable Energy Sources.*

Author & Year of Publication	C	H	N	S	O	HHV (MJ/kg)
[15]	44.4	5.6	0.43	1.3	48.27	15
[2]	45.5	6.2	1.3	-	47.0	6
[48]	47.5	6.7	0.7	-	45.1	5.8
[49]	46.2	5.42	0.92	0.24	47.22	18.36
[50]	50.2	5.9	0.42	0.03	43.5	19.14
[51]	-	-	-	-	-	18.25-19.18
[22]	-	-	-	-	-	744

From Table 1, it is abundantly clear that the energy content of Corn Cobs biomass feedstock gasifier is measured in MJ/kg dry matter which is satisfactory enough to produce significant amount of chemical energy. The Corn Cobs biomass feedstock biochemical attributes together with its physical properties are suitable for numerous techniques for energy manufacture. According to Zych (2008), Corn Cobs contained 32.3 percent to 45.6 percent cellulose, 39.8 percent hemicelluloses greatly comprised of pentosan and 6.7 percent to 13.9 percent lignin [52]. The cellulose is a polysaccharide glucose molecule that functions as the principal constituent of the Corn Cob plant cell walls with high molecular weight of polysaccharide molecule, composed of several lesser monosaccharides [53]. The hemicellulose contained fewer compounds of polysaccharide which are readily decomposed into modest monosaccharides and simple sugars while lignin is the composite, non-carbohydrate and structural constituent that combines into cellulose. The hemicellulose and cellulose in Corn Cobs were broken down through enzymatic hydrolyzed chemical reaction with water into simple sugars and then fermented into alcohol and subsequently converted into biofuel.

5. Design Methodology

Thermodynamic equilibrium technique were applied to formulate the mathematical methodology for predicting the producer gas composition from the biomass gasification mixture. The technique was adopted to establish the biomass composition that could be appropriate to whatever biomass gasification system installation. To that effect, the thermodynamic equilibrium technique formulated on chemical balance and mass balance are applied which has negligible problematical constructions and can be employed to several other biomass gasification systems and reactor inputs [42]. Thermodynamic equilibrium technique are generally classified into two methodologies; stoichiometric methodology (model based on equilibrium constant) and non-stoichiometric methodology (model base on decreasing Gibbs free energy). According to Okolie et al., (2020), the stoichiometric methodology is generally of negligible complexity on the account of its extensively adoption in studying the outcomes of process parameters on biomass gasification system development [43]. Several researchers have used stoichiometric methodology to predict gasification performances which have demonstrated reasonable conformity with experimental data in the biomass gasification system installations. The predicted feedstock in the current research is Corn Cobs biomass gasifier, which its experimental investigation results are shown in Table 2 below.

Table 2. *Essential investigation of Corn Cob Feedstock Gasifier.*

Biomass Type	Experimental Analysis (wt. %)			
	C	H	O	N
Corn Cobs	45.5	6.2	47.0	1.3

The results of the ER (0.55-0.85) and oxygen sufficient air, together with oxygen supply of 22%-51% based on the characterized separation techniques (membrane technology) were anticipated and the expected products were measured up with the experimental data to ascertain maximum compliance. In the experiment, the ER were described to be the ratio of the actual fuel/air ratio to the stoichiometric fuel/air ratio. The stoichiometric thermodynamic equilibrium combustion happened when all the oxygen is combusted in the process and there is no more molecular oxygen left in the products. The gasification temperature were maintained at 400°C-900°C as every further operation specifications were modified for the gasification in a fixed bed gasifier. While the biomass feedstock gasification constituents migrate downward through the fixed-bed gasifiers, it move into zones of increased temperature intensity and varied gas constituents, refer to Figure 2.

This approach involved the design of commercial gasification system that can produce a high quality biofuel syngas for internal combustion engines, turbines and heat applications in a well-coordinated scientific arrangement, refer to Figure 3. The biomass gasification presents an alternative to conventional ways of converting feedstocks like Corn Cob biomass gasifier to produce electric energy and other serviceable gaseous commodities without combustion. The benefits of biomass gasification technology, its applications and conditions, particularly in the renewable clean energy generation, made it increasingly important part of the Nigerian energy and industrial power demand. The unchanging price and plentiful supply of Corn Cob feedstock as an agricultural waste product throughout the supply chain makes it the leading feedstock gasifier. The diagrammatical representation of a gasification process involving corn cob feedstock gasifier is portrayed both on the feedstock flexibility, inherent in the gasification system together with the wide scale gaseous product lines of the gasification technology installation.

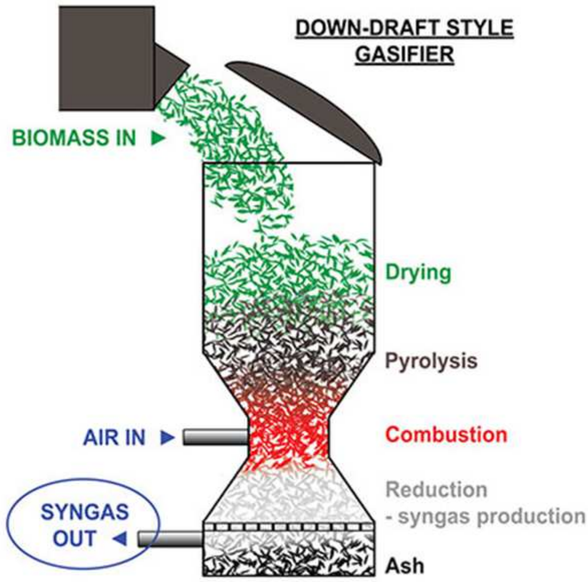

Figure 2. *Biomass feedstock gasification constituents migrate downward through the fixed-bed gasifiers [1].*

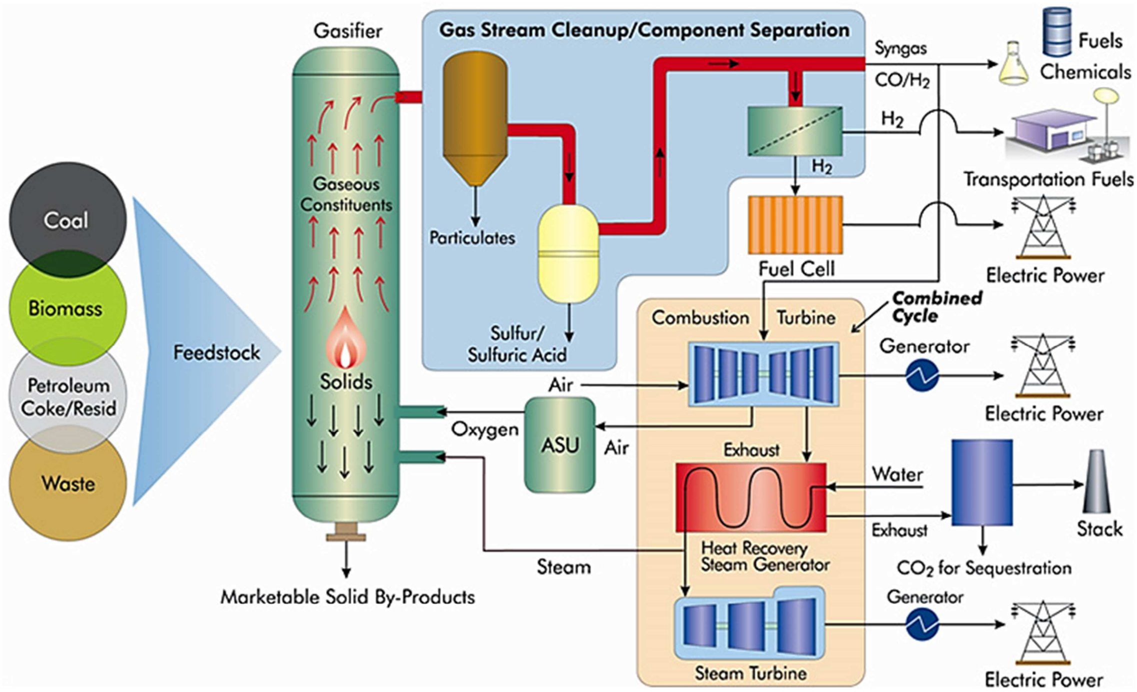

Figure 3. *A synthesized biomass gasification power system using Corn Cob Feedstock as Gasifier [3].*

5.1. Gasification Model Formulation

The thermodynamic equilibrium technique of the current research on biomass gasification renewable energy technology using Corn Cob feedstock as gasifier were established on the following deductions:

i. That reactor (a process where atoms split and release energy) is designed to be constant at the uniform temperature with zero varied measurement.

ii. The total time the gasifier spent in the controlled volume is sufficiently enough to attain equilibrium condition.

iii. Every acquired unbalanced forces on any or entire system must be cancelled out. In attendance to thermodynamic equilibrium, changes due to chemical reactions must be avoided at all cost.

iv. The entire carbon constituent in the biomass gasification system should be transformed into gaseous compound, so that all gaseous compounds produced will only be H_2O, CH_4, CO_2, H_2, CO and N_2 while Tar (black viscous liquid of hydrocarbons materials obtained via destructive distillation) is presumed to be unimportant or waste product.

v. Ash (the alkaline residue after biomass combustion) is presumed to be inert in all reactions.

vi. The entire gaseous compound produced behave as ideal gases.

The ideal biomass gasification chemical composition is expressed as $CH_xO_yN_z$, as it being gasified in the moles of air. The universal gasification reaction according to [54], is expressed followed:

$$CH_xO_yN_2 + m(O_2+{}^{\%N}{}_2/_{\%O2}N)=x_{H2}H_2+x_{CO}CO+x_{CH4}CH_4+x_{CO2}CO_2+x_{H2O}H_2O+(z/2+3.76M)N_2 \tag{1}$$

Where xH_2, xCO, xCH_4, xCO_2 and xH_20 are mole ratio of H_2, CO, CH_4, CO_2 and H_2O respectively and x, y, z are mole ratio of (H/C, O/C AND N/C) established from the definitive investigation of the Biomass composition. If we balance the Carbon, Hydrogen and Oxygen moles of the global reaction can be written as:

$$C : xCO + xCO2 + xCH4 = 1 \tag{2}$$

$$H : x + 2w = xH_2 + 2xH_20 + 4xCH_4 \tag{3}$$

$$O : y + 2m + w = xCO+ 2xCO_2 + xH_2O \tag{4}$$

The conventional reactions that occurred inside the gasification process are as follows:

$$C + CO_2 \rightarrow 2CO \tag{5}$$

$$C + H_2O \rightarrow CO +H_2 \tag{6}$$

$$C + 2H_2 \rightarrow CH_4 \tag{7}$$

The first reactions shown above initial equation (5) & (6) can be combined into equation (8) known as water- gas shift reaction as followed:

$$CO + H_2O \rightarrow CO_2 +H_2 \tag{8}$$

Therefore, equation (7) and equation (8) are used to represent the major reactions that occurred in the gasification process. The equilibrium;

$$K_1 = xCH_4 / (xH_2)^2 \tag{9}$$

$$K_2 = xCo_2xH_2 / {}^{xCOxH}{}_2{}^{O} \tag{10}$$

The value of K_1 and K_2 can be determined by Gibbs free energy as presented in equation (11) and equation (12), because ΔH° and ΔS° determine the magnitude of ΔG° and because K is a measure of the ratio of the concentrations of products to the concentrations of reactants, we should be able to express K in terms of ΔG° and vice versa.

Combining terms gives the following relationship between ΔG and the reaction quotient Q:

$$\Delta G=\Delta G^0+RTlnQ=\Delta G^0+RTlnQ \tag{11}$$

where ΔG° indicates that all reactants and products are in their standard states. For a system at equilibrium (K=Q), and as we have learnt from experiment that, ΔG = 0 for a system at equilibrium. Therefore, we can describe the relationship between ΔG° and K as follows:

$$0=\Delta G°+RTlnK \tag{12}$$

$$\Delta G°=-RTlnK \tag{13}$$

If we combine equations (11) and (13), we get the equation

$$\Delta G=RTlnQ/K \tag{14}$$

If the products and reactants are in their standard states and ΔG° < 0, then K > 1, and products are favoured over reactants at equilibrium. Conversely, if ΔG° > 0, then K < 1, and reactants are favoured over products at equilibrium. If ΔG° = 0, then K=1, and neither reactants nor products are favoured at equilibrium.

With particular emphasis to Sittisun et al., (2019), while a-g are constants with specific requirements at 298 K and 1 atm pressure. Noticeably, the Gibbs free energy is the derivative event of the reaction temperature [2] calculated in equation (11) for ln K;

Analyzing the chemical equations from the above expressions, we arrived at five equations: equation (2), equation (3), equation (4), equation (9), and equation (10), in addition to five unknown variables (^xH_z, ^xCO, $^xCO_2$, ^xH_2O, $^xCH_4$). In any case, any computer programming language or MATLAB computer code by means of Newton-Raphson iteration technique can be engaged in solving the nonlinear equations, while lower heating value (LHV) is calculated.

5.2. Model Validation and Modification

According to Sittisun et al., (2019), the thermodynamic equilibrium technique experimental results and gas composition model calculation were contrasted to cross examine its deviation by root mean square error computation [2]. The non-equilibrium conditions are usually present in the actual gasification system, for that reason, the model was formed by increasing the non-equilibrium coefficients A and B to K1 and K2 to decrease computational imperfections. Several scholars on biomass gasification technology often prioritized the exigencies of the methodology in developing their models which had resulted in better energy estimations. On the general note, the correctness of the technique is cross examined through contrasting the projected gas composition from the technique with the experimental results. In the current design, errors were computed using arithmetical variables called root mean square (RMS).

$$RMS = \text{Square Root } ((\sum X_e - X_{p)}^2 / N) \quad (15)$$

Where N, X_p and X_e are number of observations, predicted value and experimental data respectively which must correspond with the theoretical predations.

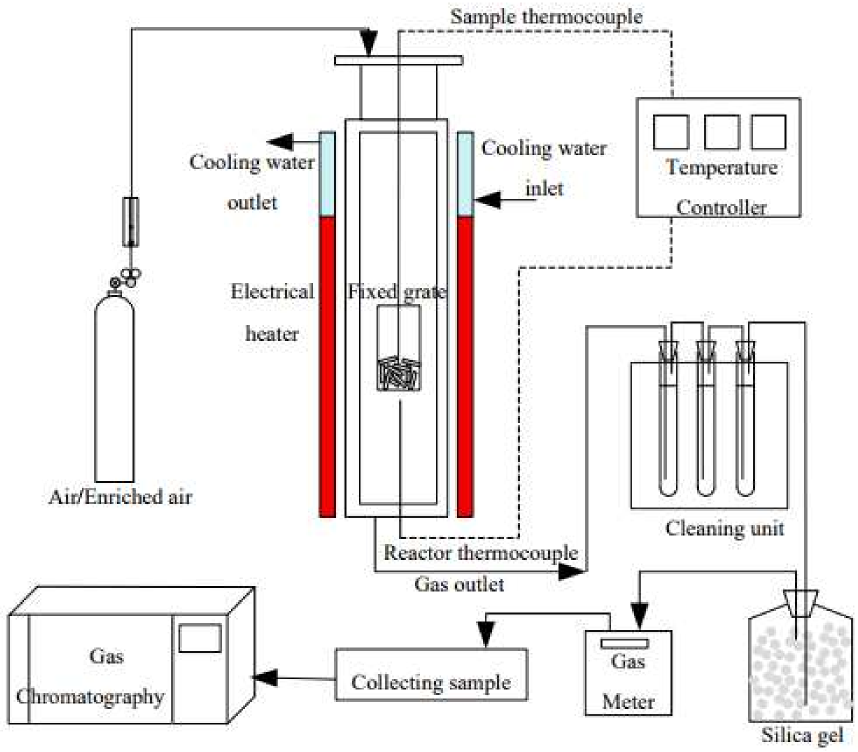

Figure 4. *Experimental setup for biomass gasification using Corn Cob as feedstock gasifier [2].*

5.3. Experimental Setup

The laboratory scale fixed bed gasifier were utilized in the current research to achieve the expected result of the renewable energy mechanization. The diagrammatical representation of the setup is demonstrated as Figure 4 above whereas the coupled workable design is presented as Figure 3. The biomass gasification reactor were encircled with self-controlled 5KW electrical heater with insulated covering. The Chromel and Alumel conductors' temperature sensor (type K thermocouples) was connected to regulate and observe the temperature of the reactor and specimen biomass gasification system. The type K thermocouples are mostly used for applications where temperatures requirements are above 550°C up to the maximum working pressure of the thermocouple. The 150g of biomass feedstock gasifier (Corn Cob) was loaded into the combustion segment through the fixed bed gasifier while regulating the temperature of the system at 800°C. The air and oxygen sufficient air were delivered through the identical environments in model computation. The product gas was cooled, dried, and collected in gas bags. The gas was successively analyzed to determine the composition of CH_4, H, CO_2, N_2 and CO by a reliable Shimadzu GC-8A basic gas chromatography model for dedicated applications. The Shimadzu GC-8A gas chromatography model maintains a specific detection, manual pressure or flow control on column injection port.

6. Syngas Composition

The biomass gasification reactions and bioconversions of the corn cob feedstock are clearly distinguished on the impressions of the proportionate composition of syngas. In the same manner, the outcomes may vary considerably depending on the type of feedstock and the gasification technique that was negotiated. On the other hand, the predictable syngas is 30% to 60% carbon monoxide (CO), 25% to 30% hydrogen (H_2), 0% to 5% methane (CH_4), 5% to 15% CO_2. In addition to a lesser or greater quantity of water vapour, smaller quantities of sulfur compounds hydrogen sulfide (H_2S), carbonyl sulfide (COS), and lastly some ammonia and other trace of waste products. The syngas composition remained comparatively invariable regardless of changes in Corn Cob composition in the setup [55]. Even though the gasifier is proficient in managing a wide range of feedstocks, modifications in the Corn Cob used as the design basis for the system can reduce syngas and steam formation (modifications in the production will depend on the Corn Cob feed and how it differs from the design feed). However, any unexpected modifications in feedstock can also cause interruptions in other plant processes. In the production of syngas, the ratio of H_2 to CO is comparatively excessive (>0.7) in all gasification system [56].

7. Expected Results

The percentage of H_2, CO and CH_4 were computed applying the technologically advanced model which centered on the thermodynamic stoichiometric equilibrium computation. The Figure 5 represented the gas manufactured composition and LHV with particular emphasis to the biomass gasification temperature variations. The intensification in oxygen concentration from 22% to 51% increases the intensity of the combustible gas composition, which can equally be understood by the lower nitrogen dilution at the same ER. The reduced amount of nitrogen dilution in the enriched air have an effect on the increased concentration of other gases, including CH_4, H_2 and CO composition. The intensification in the combustible gas concentrations correspondingly build up the LHV performances. The improved oxygen air with 50% oxygen concentration contributed to the maximum LHV output in the experimental setting.

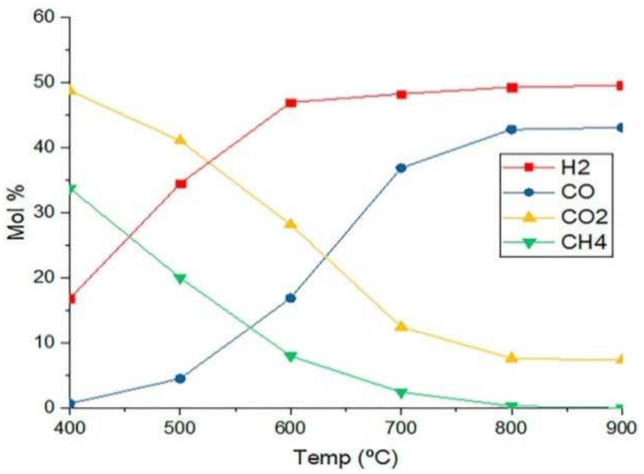

Figure 5. *Effect of gasification temperature on gas production.*

The comparative study of several gaseous characteristics together with the temperature changes have been demonstrated in Figure 5, which shows that CO formation rate and hydrogen production rate become more intense as the temperature increases. However, the CH_4 formation decreases along with temperature increase. The LHV computations have equally been done for several other biomass gasification systems alongside temperature adjustment. The LHV of the experimented model was observed to reduce with increase in temperature, therefore during the gasification process, it will be technically favourable to maintain constant temperature when significant changes have started taking effect.

8. Conclusion

The findings on the Corn Cobs as biofuel feedstock were analyzed in relation to its gasification capabilities obtained from ten bodies of existing literature. The outcomes demonstrated that the gasification of Corn Cobs feedstock have the potential for a sustainable biofuel feedstock applications to renewable energy sustainability. The research concluded that Corn Cobs feedstock hydrolyzed substrate organic specimen having undergone chemical reactions with reagent generate a product with little concentration of bioethanol which contained extreme anti-knock attribute because of its excessive octane composition in addition to high-level latent heat of evaporation, that diminishes the compressed gas temperature at the instances of compression stroke used in the internal combustion engines as renewable energy sources. In this study, an improved thermodynamic equilibrium gasification technique were established to realize the commodity gas product composition as contrasted with the experimental data sample. It was observed that the adoption of the oxygen sufficient air improved the LHV activities. It was also established that the CO manufacture rate and hydrogen formation rate intensifies alongside temperature increase while CH_4 production diminishes with temperature increase.

Availability of Data and Materials

The data and materials for the research were available and interpreted within the body of the work.

Authors' Contributions

The research is jointly carried out. However, Ugochukwu O. Matthew and Engr. Dr. Jazaure S. Kazaure provided a special consultancy services under U&J Digital Consult Limited with Company Registration Number RC: 1692126, Federal Republic of Nigeria.

Ethics Approval and Consent to Participate

The research followed the approved template as required for an academic programme leading to renewable fabrication.

Consent for Publication

All the authors consented to the publication.

Competing Interests

All the authors do not have any possible conflicts of interest.

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