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Original Research

GASIFICATION OF RICE HUSK FOR DOMESTIC ENERGY GENERATION

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Abstract

The study was on the gasification of rice husk of particular specie (*O.glaberima* popularly known as Jamila), for the purpose of generating energy. A downdraft gasifier, with an initial design conditions of 5 kW thermal power output was considered. The design analysis of the gasifier provided the following specifications: reactor hopper volume and height, throat diameter and height, fuel consumption rate, and outlet diameter of gas pipeline, of 0.00334 m^3 and 92 mm, 0.054 mm and 0.08 mm, 1.64 kg/hr, and 19mm respectively. While the design of the blower revealed the following specifications which includes: 8.9 kg/hr air flow rate, 314.2 rad/sec angular speed of blower, 653 N/m torque and 205.2 W power. While the characteristics of the rice husks include 49.21% C, 44.70% H, 3.82% S, 0.79% N_2 and 1.41% O_2 with HHV and LHV of 4.1 MJ/Nm^2 and 3.73 MJ/Nm^2, respectively. While the proximate analysis shows the following contents as 4.38% moisture, 15.44% ash, 60.83% volatile matter and 23.73% fixed carbon. The results obtained from the gasification shows that 4.8 m^3/hr of syngas was generated which composed of 10.4% CH_4, 11.02% CO, 3% H_2, 1.5% CO_2 15% O_2 and 0.0102% S. The efficiency of the gasifier was evaluated at 72%.

Keywords: Gasification, rice husk, syngas, gasifier and design

1.0 INTRODUCTION

The ease with which energy is available, affordable and its steady supply is a representation how advanced and sophisticated a society can be. Nigeria, a country bedeviled by incessant energy crisis needs to refocus attention on the use of conventional fuel resources and alternative sources which could be provided off grid. Based on Olanrewaju, *et, al.*, (2019) assessment on bio-resource, Nigeria had the potential to generate about 62 Mtoe (2.58 EJ) annually. In addition, the energy from these bio-resource was estimated to in year 2015 to be equivalent to more than half and about four times the nation's energy consumption (121 Mtoe) and electricity consumption, respectively (Olanrewaju, *et al.*, 2019).

Amongst the various biomass resources available in the country, agricultural crop residue, was estimated to be more than 76% with an equivalent value of 153.76 MT/year (Olanrewaju, *et al.*, 2019).. However, Simonyan and Fasina (2013) concluded from

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the results of the findings that Nigeria is capable of producing 2.01 EJ (47.97 MTOE) of energy from the 168.49 MT of agricultural residues and wastes that can potentially be generated in a year.

Rice is one of the most staple food in Nigeria. As at 2019, Africa had a total production capacity of 14.6 MT, out of which Nigeria and Egypt alone produced about 55% and 30%, respectively (Statista, 2019). The estimated production of milled rice in Nigeria from 2010 - 2022 (January) was estimated to have grown between 2,818 MT – 5,355 MT (Statista, 2022). Therefore, cultivation and production of milled ~~of~~ rice in Nigeria had recorded significant achievement and development in the last decade.

Two prominent agricultural residue, arising from rice cultivation, which are considered to be potential biomass resources includes rice husk and rice straw. The rice husk, as one of the major by products from rice milling processes constitute about 20% of the rice paddy by weight [Zafar, 2022]. The rice husk mainly consist of lingo-cellulose and silica, which are not usually utilized in any meaningful way. These, however possess high biomass resource potential. Ben-Iwo *et al*., (2016) estimated that the total rice paddy cultivation in Nigeria between the years 2004 – 2013 was 3,334,000 – 4,700,000 T. However, the total residue from rice production stands at 1.19 (million tons), the husk has a lower heating value (LHV) of 19.33 MJ/kg of energy while the residue potential energy value was estimated as 23 PJ. From the foregoing, bioenergy can be described as versatile and to consist of organic originating from plants and animals~~,~~ These can be converted to solid, liquid and gaseous fuels to be used as fuel for heating homes, electrifying communities and fuelling the transport as well as the industrial sectors (Koyama, 2016 and Alhassan *et. al*, 2019).

Gasification reaction is mainly endothermic in which the conversion of solid, organic material to a mixture of combustible gases occurs by partial oxidation at elevated temperatures (500 – 1400~~)~~ ^{o}C (Rajvanshi, 1986, Sivakumar *et. al.*, 2013 and Akhator, *et. al.,* 2019). This conversion is caused by combusting the solid material with limited oxygen to produce an exhaust gas called producer gas or synthesis gas. The producer gas consists primarily of CO, H_2, CO_2, CH_4, and traces of higher hydrocarbons (if air is the oxidizing agent) and various traces of contaminants: char particles, ash, tar, and oil as a result of inappropriate selection of design parameters. It is indicated that the synthesis gas must contain enough CO, H_2, acetylene and other hydrocarbons to be combustible and the produced gas stands to be more versatile than the raw biomass (Koyama, 2016 and Alhassan *et. al*, 2019). The study also show that the gasification process consists of different order of reaction zones. There are five major steps from top to the bottom that are involved: drying, pyrolysis, partial combustion, cracking and reduction (Rajvanshi, 1986, Sivakumar *et. al.,* 2013 and Mustafa *et. al.*, 2017).

For the past two centuries, gasifiers have been used in some extent (Rowlan, 2010). Numerous authors have work on the design and modification of different types of downdraft gasifiers, in particular with the view to enhance performance. Dalmis, *et. al* (2018) design and developed a throatless prototype downdraft gasifier integrated with a stirrer to investigate the performance, using two different airflow from top and tuyers. The authors concluded that with supplied air from the top and at the same equivalence ratio of 2.0 the efficiency obtained was 65.4%, H_2/CO ratio was 1:385 while the gas heating value was 5.047 MJNm-^{3}. Mukunda, *et. al* (1994) based on the output achieved a higher efficiency by allowing air distribution, increasing insulation and recirculating gas within the reactor thereby utilizing the sensible heat in the gas to dry the biomass. Also, Bario *et. al.,* (2001) concluded that by modifying the air distribution system and injecting the air at the centre of the reactor cross section for uniform distribution across the reactor. Also incorporated to design is a perforated grate that used manual actuation to clear the ash contents continuously and to ensure smoother bed movement.

Bukar *et. al*., (2019) conducted a review on the fundamentals and basic formulae adopted while designing a biomass gasifier for energy generation. The authors concluded that physical and chemical characteristics of biomass, as well as the geometry and optimum design parameters play a crucial role in enhancing the performance of the gasifier. Havilah *et. al*., (2022) in their work presented a comprehensive review on advancement in biomass downdraft gasification technologies for high quality synthesis gas. The results evaluated by the authors conformed to those of Bukar *et.. al.,* (2019), but in addition the upgrading and applications of the gas produced were reviewed.

Akolgo *et. al* (2019) examined the different gasification technologies presented for the past three decades, with particular emphasis on Ghana's energy mix. The authors concluded that small-scale, direct heating and fixed bed gasification's are found to be more suitable for meeting the energy requirement.

Mustafa, *et. al* (2017) presented a techno-economic feasibility study of liquid bio-fuel production from biomass to meet the demand for public transport in small communities. The authors found that the potential of producing biofuel is more than three times by adopting a downdraft gasifier of 6.0 MW capacity. From the study, the expected annual quantities of syngas, bio-diesel and bio-hydrogen producible from 27,000 T of biomass are 65,000 T, 3,294 T and 814.7 T, respectively. The payback period of the system in this context is 4 years which is considered to be very attractive to potential investors.

Therefore, the thrust of this paper is on the design, construct and testing of a small-scale biomass gasifier to generate synthesis gas from rice husk. The research output is expected to add to energy mix of small communities, thereby reducing the gap between energy demand and supply and to focus on clean renewable energy resources. This will significantly reduce the adverse environmental effect caused conventional fuels.

2 MATERIALS AND METHODS

2.1 Materials

The biomass used for the gasification is rice husk obtained from rice operating mills within Kaduna metropolis. Although there are several rice species available. The thrust of this research was on particular specie of rice referred to as O.glaberrima (Popularly known as Jamila).

2.2 Analysis of Biomass (Rice Husk)

a. Percentage Moisture Content (PMC)

The moisture content of the rice husk sample was determined based on mass loss after two hours at 105°C under Nitrogen purge, in accordance with ASTM E1756 (2008) standard specification as expressed eqn (1):

$$\%M_c = \frac{(g-x)}{g} \times 100 \qquad 1$$

b. Volatile matter

The volatile matter of the rice husk sample was determined by heating the sample in an oven to dry the sample under Nitrogen purge at 850°C, for 15mins. The determination of property was in accordance with ASTM E872 (1998) standard specification as expressed by eqn (2):

$$V_m = \left(\frac{x-y}{g}\right) \times 100\% \qquad 2$$

c. Ash Content

The ash content of the rice husk sample was determined by heating the same sample to 730°C for 1 hour with atmospheric air using the same muffle furnace. The content was determined in accordance with ASTM E1755 (2001) standard specification expressed by eqn (3)

$$A_c = \left(\frac{x}{g}\right) \times 100 \qquad 3$$

Where g and x stands for the wet and dry weights of the sample in % while y is the weight of residue in %.

d. Percentage Fixed Carbon

The percentage fixed carbon was calculated by subtracting the sum of percentage volatile matter (VM), percentage ash content (AC) and percentage moisture content (MC) from 100 as expressed by eqn (4):

$$F_c = 100 - (VM + AC + MC) \qquad 4$$

e. Ultimate Analysis

The ultimate analysis was conducted in accordance with ASTM D3176 standard specification. The Scanning Electron Microscope energy dispersive X-ray spectroscopy (SEM-EDS) was used to carry out the morphology analysis. The Energy dispersion spectrum scan on the intensity of each of the element present gave the molar concentration in %, and the image was then saved.

f. Calorific Value

The calorific value was conducted in accordance with ASTM D1989 standard specification. The calorific value of the rice husk was carried out using a bomb calorimeter.

2.3 Design of the downdraft gasifier

The type of gasifier adopted for this study is the downdraft gasifier because there are no complexities in its design, the operation process is simple and tar formation is low. The gasifying agent used is air because it is inexpensive and readily available. The initial design conditions were made according to the recommendations by the research output of the following authors: Venselaar, (1982), Zhongqing, *et al.*, (2015) and Bukar *et.at. al.*, (2019), as shown in table 1.

Table 1: Selected Design Parameters

S/N	PARAMETERS	VALUE
1	Thermal output power	5kW
2	Equivalent ratio (ER)	0.35
3	Specific gasification rate (SGR)	2000m^3/m^{2}hr
4	Reactor tube capacity (RTC)	250kg/m^{2}hr

a. **Throat Design (A_{th})**

The gasifiers throat diameter is designed from specific gasification rate (SGR) value.

$$SGR = \frac{SG}{A_{th}} \qquad 5$$

where SG is the synthesis gas generated, A_{th} the throat diameter. However area of a circle is obtained as: $A_{th} = \frac{\pi d^2}{4}$

where d is the throat diameter. However, flow stability of biomass inside the gasifier, ratio of throat height to throat diameter was taken as 1.5 as quoted by Venselaar (1982) as:

$$(H_{th}) = diameter\ of\ throat \times 1.5 \qquad 6$$

b. **Specific Gasification Ratio (SR)**

The specific gasification rate (SGR) is the volume flow rate of gas per unit area based on throat diameter, the gas volume being measured at standard conditions expressed by Akhator et al (2019) as:

$$SGR = \frac{weight\ of\ feedstock}{Grate\ area} \qquad 7$$

c. Fuel Consumption Rate (FCR)

Expressed the ratio of energy to be generated to the calorific value of the feedstock:

$$FCR = \frac{q}{CV \times \eta} \qquad 8$$

Where q is the amount of heat to be generated by the gasifier (5kW), CV the calorific value of the fuel and η is the efficiency of the gasifier as expressed by Kumar, *et al.*, (2018) and Akhator *et. al.*, (2019) as:

d. Grate Area (A):

It is described as the cross-sectional area of the reactor, obtained as the ratio of FCR to SGR:

$$A = \frac{FCR}{SGR} \qquad 9$$

e. **Gasifier Efficiency**

The efficiency of the gasifier is what determines the actual technical operation, as well as the economic feasibility of using a gasifier system, as expressed by Kumar *et. al.*, (2018)

$$Efficiency\ (\%) = \frac{Calorific\ Value\ Gas \times Volume\ of\ Gas\ production\ rate}{Calorific\ Value\ of\ Fuel \times Fuel\ Consumption\ Rate} \qquad 10$$

The calorific value of fuel (gas) could be expressed as lower or higher heating value (MJ Nm^{-3}). The compounds of the gas that actually affected the calorific values are H_2, CO, and CH_4 (Waldheim and Nilsson 2001).

$$LHV(MJ/Nm) = 10.8\ (\%H_2) + 12.63\ (\%CO) + 35.8\ (\%CH_4) \qquad 11$$

$$HHV(MJ/Nm) = 12.76\ (\%H_2) + 12.63\ (\%CO) + 39.75\ (\%CH_4) \qquad 12$$

f. Height of the Reactor Hopper

The height of the reactor hopper was obtained using equation 3.18 given by Akhator *et. al.*, (2019).

$$H = \frac{V}{A} \qquad 13$$

where V is the volume of the gasification chamber in m^3 and A is the area of the reactor hopper in m^2. The volume of the gasification chamber was expressed as:

$$V = \frac{M}{\rho} \qquad 14$$

where M, is the mass of rice husk in kg per batch or flow rate, ρ is the density of rice husk in kg/m^3. The area of the reactor hopper was expressed by Akhator *et. al.*, (2019).

$$A = \frac{FCR}{RCT} \qquad 15$$

where FCR is the fuel consumption rate in kg/hr and RCT is the reactor tube capacity in kg/m^2hr.

g. Gas outlet pipe diameter

The diameter of syngas exit pipe was obtained from the expression of Akhator *et. al.*, (2019) as:

$$D = \sqrt{\frac{4 \times SG}{\pi}} \qquad 16$$

where SG is the syngas generation rate.

h. Volume of the gas receiver tank

The volume of the gas receiver tank was obtained from the expression of Akhator *et. al.*, (2019).

$$V = H \times A \qquad 17$$

Where H is the height of the gas receiver tank in mm, A is the area of the gas receiver tank in mm^2 and Area (A) was obtained as:

$$A = \frac{\pi}{4} d^2 \qquad 18$$

i. Volume of the cooling chamber

The cooling chamber is cylindrical in shape as shown in figure 3.1. The volume of the cooling chamber was obtained as:

$$V = \pi r^2 h \qquad 19$$

j. Critical thickness

The critical thickness $r_c$was obtained using equation provided by Holman (2002)

$$r_c = \frac{k}{h_o} \qquad 20$$

Where k is the thermal conductivity of the material in w/mk and h_o is the convective heat transfer coefficient in w/m^2k. h_o was obtained from Holman (2002)

$$h_o = \frac{Q}{A(t_s - t_f)} \qquad 21$$

where Q is the conductive heat transfer in W, A is the area exposed to heat transfer in m^2, t_s is the surface temperature in kand t_f is the fluid temperature in k. Q was evaluated from the expression given by Holman (2002).

$$Q = -KA\left(\frac{T_2 - T_1}{x}\right) \qquad 22$$

Where K is the thermal conductivity of the material in W/mk, A is the surface area in m^2, T_2 is the temperature of the outer surface of the gasification chamber, T_1 is the temperature of the inner surface of the gasification chamber and x is the material thickness. The temperatures of the outer surface and inner surface of the gasification chamber can be obtained using an infrared thermometer.

k. Air / fuel ratio

The stoichiometric air – fuel ratio was obtained using equation 3.29given by Akhator *et. al.*, (2019)

$$\text{Stoichiometric air fuel ratio} = \frac{Ma}{Mf} \qquad 23$$

where M_a is the mass of air and M_f is the mass of fuel.

l. Sizing of blower

Blower is an equipment or a device which increases the velocity of air or gas when it is passed through the impellers. For gasifiers design, low pressure blowers are often used. The sizing of the blower is actually a function of the gasification chamber, and also on the air/fuel ratio requirements.

The mass air flow rate (M_a) was expressed by Akhator *et. al.*, (2019)

$$Ma = Actual\,\frac{air}{fuel}\,ratio \times FCR \qquad 24$$

where FCR is the fuel consumption rate in kg/hr, expressed by Ibrahim *et. al.*, (2018)

$$FCR = \frac{M_b}{t} \qquad 25$$

where Mb is the mass of the rice husk in kg,t is the total time of operation in hr.

Equivalent ratio (ER) is expressed by Akhator *et. al.*, (2019) as:

$$ER = \frac{\text{Actual air/ fuel ratio}}{\text{Stoichiometric air/fuel ratio}} \qquad 26$$

The volume flow rate (Va) is the volume of fluid which passes per unit time expressed by Akhator *et. al.*, (2019) as:

$$Va = \frac{Ma}{\rho} \qquad 27$$

where Ma is the mass air flow rate in kg/hr while ρ, is the density of air gives as 1.2754 kg/m^3

The power and torque required to drive the blower were obtained from Musa [53] as

$$P(kw) = T \times \omega \qquad 28$$

and for the torque,

$$T = \frac{373 \times 5252}{N} \qquad 29$$

Where N, is the speed of the blower in rev/min and ω is the angular speed of the blower in rad/sec obtained as

$$\omega = \frac{2\pi N}{60} \qquad 30$$

m. Gasifier Efficiency

The efficiency of the gasifier is what determines the actual technical operation, as well as the economic feasibility of using a gasifier system as expressed by Ibrahim *et. al.*, (2018)

$$Efficiency\ (\%) = \frac{lower\ heating\ value\ of\ gas \times gas\ flow\ rate}{calorific\ value\ of\ fuel \times fuel\ consumption\ rate} \quad 31$$

o. Assembling

The gasifier consists of the hopper, throat, reduction zone, gas collector, ash-discharge plate and air blower. The gasifier design was carried out in three parts; the combustion chamber, the gas collector chamber and the cooling chamber. An orthographic working assembling drawing of the gasifier is shown in Figure 2.1.

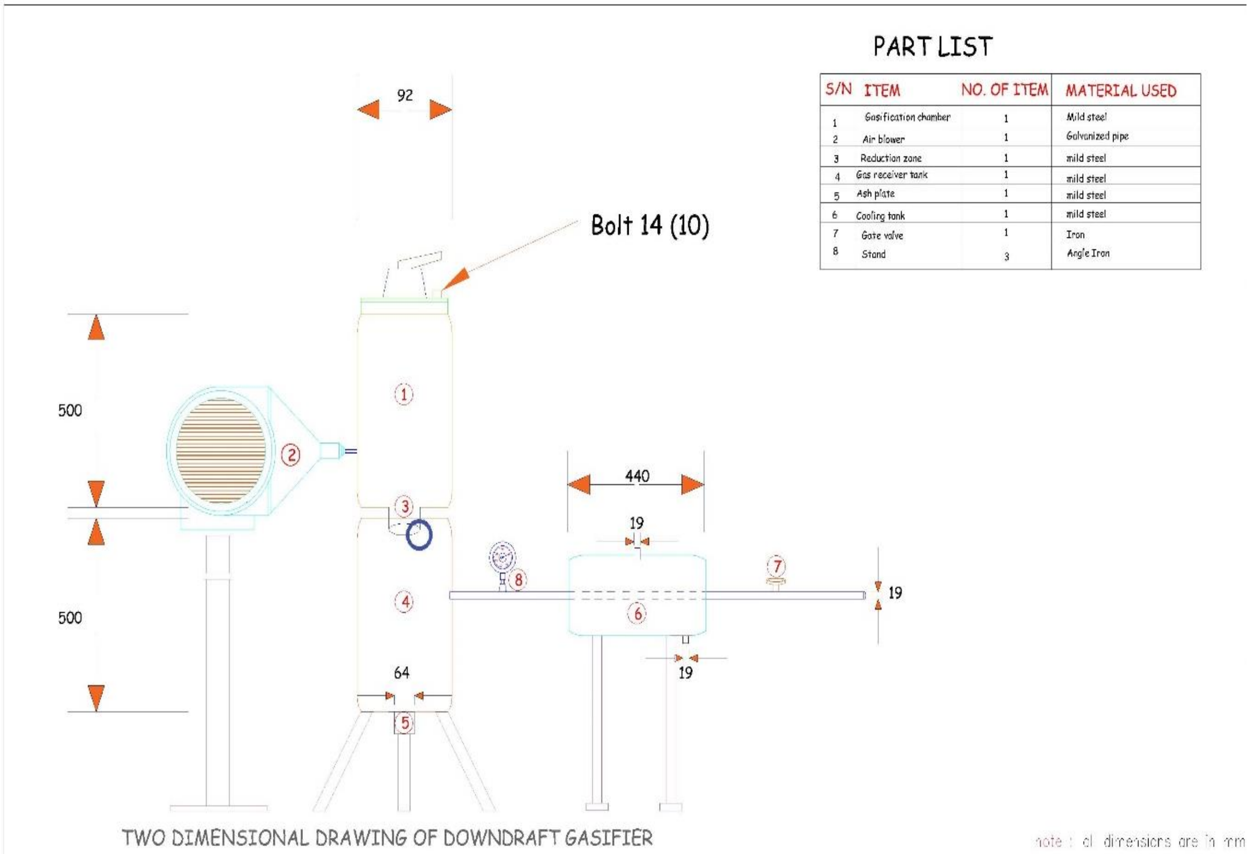

Fig. 1: An orthographic working assembly drawing of the downdraft gasifier

2.4 Experimental Setup and Testing of the Gasifier

The experiment began with loading the gasifier hopper with 3kg of the rice husk and igniting it with a piece of paper and kerosene. It took about three minutes for the rice husk to start burning. The blower was switched on to supply air into the combustion chamber. The gasifier was tested at the Mechanical Engineering Workshop, NDA. Leaks detected during the operation from the reaction chamber were amended. While, the reduction zone had to be insulated and the gasifier was tested again using the same quantity of the feedstock. The quantity of syngas generated was observed to be low due to leakages from the gasifier lid, the dimension and size of the gas outlet pipe (i.e. OD=44 mm), temperature loss in the reduction zone and excess air supplied from the blower. Therefore, the gasifier was modified such that the outlet pipe was replaced with a smaller bore steel pipe diameter (OD=12mm) and the reduction zone was insulated using an insulating material to reduce heat loss. The top cover of the gasifier was sealed with a paper gasket and eight bolts and nuts to ensure there were no leakages. Another important modification was reducing the amount of air inlets pipes to a single air inlet pipe for air supply from the blower. Also, the air suction pipe of the blower was reduced to regulate the amount of air entering the gasifier hopper. With these modifications, the gasifier was fired up for the third time using rice husk as the feedstock. The temperature measured at the gasifier hopper was of 99℃ and a stable flame was observed inside the gasifier hopper for about 90 minutes. The gas produced was analyzed using a bio-portable gas analyzer. Plates 1 and 2 show the assembled downdraft gasifier and the experimental setup.

Plate 1: Assembled downdraft gasifier

Plate 2: Experimental setup

3.0 RESULTS AND DISCUSSION

Proximate Analysis

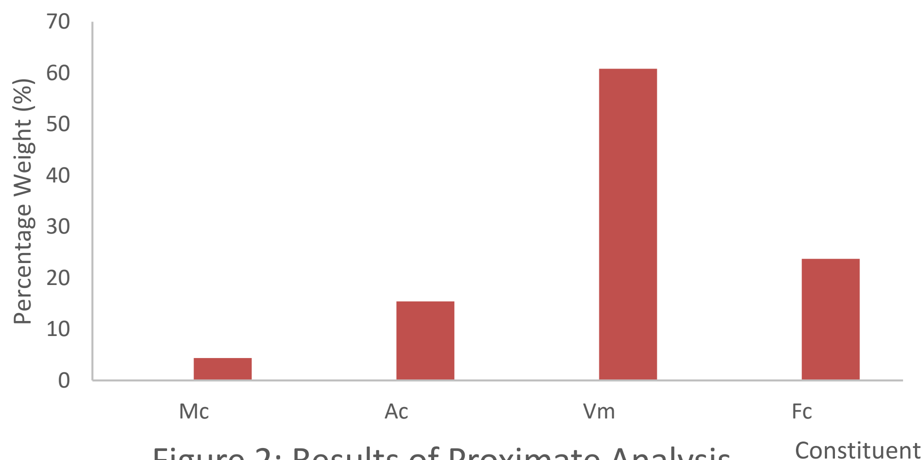

Figure 2: Results of Proximate Analysis

From fig 2, the results of proximate analysis of the rice husk was provided. The rice husk had a moisture content (M_c) of 4.35% from the analysis. The result obtained is in agreement with results found in the literatures: Jinar *et. al.*, (2012), Zhongqing *et. al.*, (2015), Dalmis *et.al.*, (2018), and Osei *et. al.*, (2020) reported moisture content of 8.85%, 4.55%, 7.01%, and 9%, respectively. The recommended value of moisture content in a biomass feedstock was estimated to not be higher than 20% as reported by Sukthang *et. al.*, (2017). Lower moisture content signifies easy gasification of biomass and better or higher energy yield from biomass whereas high moisture results in difficult and low energy yield.

The rice husk was also characterized by high ash content as shown in figure 2. The ash content recorded was 15.44% which is higher than 6% recommended in the literatures (Quaak and Knoef, 1999 & Bukar *et. al.*, 2019). Biomass gasification is not favored by high ash content due to technical issues such as slagging and fouling that may result from the presence of ash in the producer gas. High ash content also results in decrease in the gasification efficiency. For this reason, a good ash discharge plate was incorporated in the gasifier to control this problem.

Higher volatile matter in a feedstock, increases its reactivity thus liberating more fixed carbon. From figure 2, the volatile matter recorded was 60.83%, while that of fixed carbon is 23.73%. The obtained results are comparable to those deduced by Anthony and Rhodes (1997) who reported 65.1% and 21.3% respectively. However, the volatile matter obtained is slightly lower, while fixed carbon is a little higher. The obtained variation may not be unconnected to nature of the feed stocks known to vary with geography of the place where the feed stock is cultivated. The value of the volatile matter content of the rice husk would lead to better combustion and carbonization process of the feed stock.

Result Ultimate Analysis

Fig 3 shows the results obtained from ultimate analysis of rice husk. The percentage composition of carbon and hydrogen were analyzed and found to be 49.21% and 44.76%, respectively, while the percentage of other elements: sulphur, nitrogen and oxygen in the rice husk analyzed were found to be low. As can be seen from the figure 3, the carbon content is observed to have the highest percentage by weight which is in agreement with most findings in relevant literature.

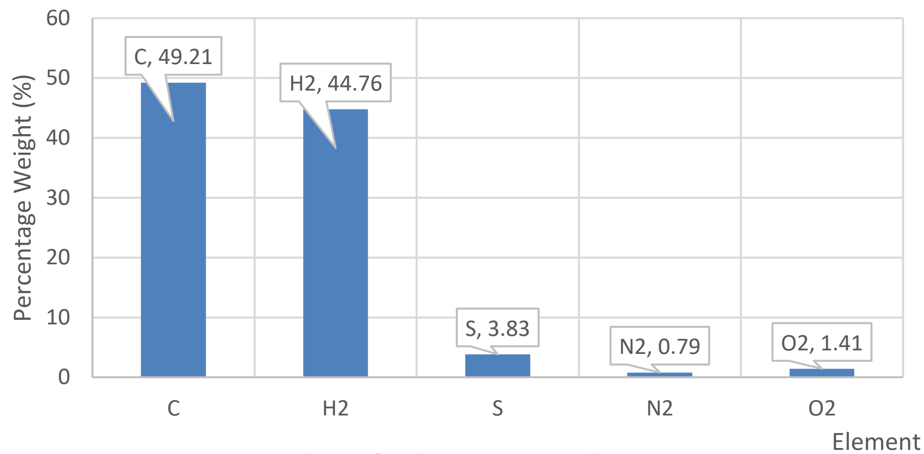

Figure 3: Results of Ultimate Analysis

The carbon content recorded was 49.21% which is relatively high as compared to findings from relevant literature where values obtained by Jinar *et. al.*, 2012) and Akhator *et. al.*, (2019) were found to be 42.22% and 57.54%, respectively. On the other hand, the oxygen content recorded was found to be 1.41%, which when compared with other results: 55.4% and 35.27% as reported by and Zhongqing *et. al.*, (2015) and Dalmis *et. al.*, (2018). In their work, Bukar *et. al.*, (2019), reported that the major components of biomass are carbon, hydrogen and oxygen. Gasification process is usually executed under starved oxygen supply.

High hydrogen content is desirable because it results in a higher heating value of the syngas produced. The hydrogen content of about 44.76% was found to be higher from those obtained by Dalmis *et.al.*, (2018) and Akhator *et. al,*. (2019) who recorded 5.89% and 5.21%, respectively. The sulphur and nitrogen values obtained were observed to be relatively low compared to that deduced by Zhongqing *et. al.*, (2015) and Dalmis *et. al.*, (2018). The low values result in the production of lower contaminants such as H_2S, NH_3 and SO_2. The inorganic elements usually end up as the ash content.

Results of Syngas Analysis

Table 2: Results of syngas Analysis

Serial	Constituents	% Composition
1	CH_4	10.4
2	CO	11.02
3	H_2	3.0
4	CO_2	1.5
5	O_2	15
6	S	0.0102

The result of the various components of the syngas obtained from the gasification rice husk is presented in Table 2. From Table 2, methane composition (10.4%) was found to be in close agreement with findings of Jinar (2012),and Hendriyana (2020), who obtained 11.92% CH_4 and(10.6%) respectively, while lower percentages below 10% were obtained Lanh *et. al.*, (2018) and Dalmis *et. al.*, (2018). While the CO obtained was found to be below the results of Jinar (2012), Lanh *et. al.*, (2018) Dalmis *et. al.*, (2018) and Hendriyana (2020). However, the hydrogen conent of the syngas was found to be lower than those obtained from the results of Hendriyana (2020), Lanh *et. al.*, (2018) (at ER of 0.3) and Dalmis *et. al.*, (2018) by 71.15%, 83.56 and 60.99, respectively. In comparison to the results obtained, the study shows that the result of the syngas generated is in acceptable range. The value of Carbon dioxide (CO_2) recorded was 1.5%. Carbon dioxide production is not dependent on the feedstock supplied for combustion. A controlled supply of air affects carbon dioxide formation because its formation occurs during complete combustion of the feedstock where the excess oxygen present reacts with the carbon monoxide. In addition the influence of ER on the combustion may have affected the gasification process as a results of leakages experiences during the operation. From the results above, the value of oxygen recorded was high (15.0%). Oxygen is a non- combustible gas, but it is an oxidizer. Based on the values recorded for SO_2 and H_2S, it implies that the producer gas is relatively clean.

Results of Calorific Value of Rice Husk

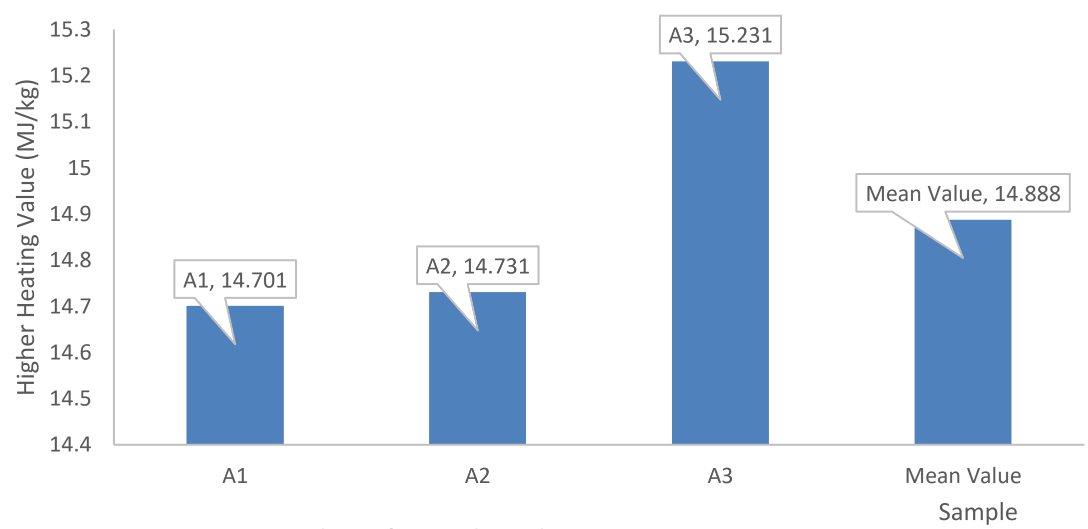

Figure 3.4: Results of Bomb Calorimeter Test

As can be seen from the fig. 3.4, the calorific value of the rice husk was experimentally conducted three times and the results obtained were 14.701MJ/kg, 14.731MJ/kg and 15.231MJ/kg respectively. The mean value of the calorific value or higher heating value (HHV) of the rice husk was evaluated to be 14.888MJ/kg. This value was found to be comparable to those found by Danje (2011), Dalmis *et. al.*, (2018), and Akhator *et. al*,. (2019) who respectively recorded ~~as~~ 19.14MJ/kg, 14.89MJ/kg and 19.85MJ/kg. The higher heating value (HHV) of rice husk ranges from 13.158MJ/kg to 15.217MJ/kg as reported by Yardav and Singh (2015). The obtained result falls within the acceptable range. From the study, it shows that this particular rice husk is suitable for gasification.

Result of blower design analysis

Table 3: Summary of Blower Design Analysis

Serial	Parameter	Result
1	Mass air flow rate (Ma)	8.9 kg/hr
2	Volumetric air flow rate (Va)	6.94 $8m^3/hr$
3	Fuel consumption rate (FCR)	1.67 kg/hr
4	Density (ρ_a) of air at normal temperature	1.2754kg/m^3
5	Angular speed of the blower (ω)	314.2 rad/sec
6	Torque required to drive the blower (T)	653N/m
7	Power required to drive the blower (P)	205.2kW

As can be seen from Table 3, the fuel consumption rate was found to be 1.67kg/hr. This value is comparable to that in the literature. Lanh *et. al.*, (2018) and Osei *et. al.*, (2020) evaluated consumption rate of 6.1kg/hr and 2.37kg/hr, respectively. The fuel consumption rate depends on the quantity of feedstock that is fed into the gasification chamber.

Results of downdraft gasifier design analysis

Table 4: Summary of gasifier design analysis

Serial	Component	Result
1	Syngas generation rate	4.8 m^3/hr
2	Throat Diameter	**0.054 mm**
3	Throat height	**0.08 mm**
4	Lower heating value	**3.73 MJ/Nm^3**
5	Higher heating value	**4.1 MJ/Nm^3**
6	Critical thickness	**3.5 mm**
7	volume of reactor hopper	0.00334m^3
8	fuel consumption rate	1.67 kg/hr
9	Hopper Height	500 mm
10	Hopper Diameter	92 mm
11	volume of gas receiver tank	0.00334 mm^3
12	diameter of the gas outlet pipe	19 mm
13	efficiency of the gasifier	72%

As can be seen from Table 4, the lower heating value (LHV) of the syngas obtained (3.73MJ/Nm^3) was found to be lower by 72.29%, 70. 97%, and 6.75% from those obtained by Jinar (2012), Zhongqing *et. al.*, (2015) and Akhator *et. al*., (2019), respectively. However, the result of the HHV obtained falls within the acceptable range of 4 – 16 MJ/ Nm^3 (Saw and Pang, 2012)

Also, the efficiency of the gasifier was evaluated to be 72%. This value was compared to results of Abdulrahman *et. at.*, (2016), Dalmis, *et. at.*, (2018) and Osei et. al., (2020) which obtained 57.5%, 65% and 38%, respectively. It could be vividly observed that there was a marked improvement in the efficiency of the gasifier. In addition, Birk (2003) reported that the acceptable range of gasifier efficiency falls between 60 – 80 percent.

Also, from Table 4, the value of the critical thickness of the gas cylinder was found to be 3.5mm. This value is less than the outer radius of the gas cylinder which was found to be 46mm. This implies that, heat loss by conduction will decrease as reported by Holman (2002). This will help to increase the thermal efficiency of the gasifier.

The gasifier fulfilled its primary objective very satisfactorily in that it successfully convert the rice husk into producer gas. Also, the performance characteristics such as fuel consumption rate (FCR) and syngas generation rate as shown in table 3 and 4, are in good agreement with previous work on gasifier.

CONCLUSION

The results of proximate reveals that the rice husk has the following content moisture 4.38%, volatile matter 60.83%, fixed carbon 23.73% while the ultimate analysis shows carbon and hydrogen content of 49.21% and 44.76%, respectively. The design of the rice husk gasifier was successfully implemented. The analysis of gas generated from the gasification reaction contain the essential elements of typical syngas: CH_4 (10.4%), CO (11.02%), H_2 (3.0%) CO_2 (1.5%). Based on the fuel consumption rate of 1.64 kg/hr, air flow rate of 8.9 kg/hr and the syngas generated the efficiency of the gasifier was found to be 72%.

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