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Development of a Dawndraft Gasifier for Effective Utilization of Bagasse for Production of Gas

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Abstract: *Energy production is one of the most important economic factors in the development of modern society. Nigeria is purely an agrarian nation and the people depend on Agriculture for their survival. Agricultural waste has been proposed as an alternative energy resources to meet fossil fuel crisis. The sustainable use of this bagasse for bioenergy applications such as electricity generation at low cost and mitigate greenhouse gas emissions is imperative. Conversion of bagasse feedstock to palletization and briquetted could improve the quality of the solid fuel in terms of higher energy density per unit volume and promotes less biomass bridging in a downdraft gasifier. The study was aimed to evaluate the downdraft gasifier using bagasse as feed stock for production heat and gas generation. The experimental factors considered in this studies were bagasse biomass at three level were namely; (pelletized, briquetted and control) respectively, while the particle sizes considered were namely (0.6mm, 1.86 mm and 2.36 mm) respectively, the treatments were laid out in a complete randomized design (CBD) with three replications. The collected data were subjected to the analysis of variance (ANOVA) and the results of the investigation revealed that, briquetted feedstock at all particle sizes had a significant influenced and gave maximum temperature values of 104 ^oC, 467 ^oC and 1194 ^oC during the gasification processes, while pelletized feedstock exhibited closer to the briquetted than control feedstock. Similarly, as affected by particle size bagasse at 2.36 mm produced the highest temperature during the gasification process than all other experiment. Similarly, the finding also discovered that combination briquetted biomass and 2.36 mm particle size have significantly influenced the gasification temperature of the gasifier at the thermocouples (T_1, T_2 and T_3) throughout the experimented period. Based on the findings, a community could generate gas using bagasse husk briquetted to meet demand in most economical way, thereby reducing emission, waste and saving cost which translates to sustainable development.*

Keywords: *Gasifier; Gas; Blower; Energy; Bagasse; Briquetted and Pelletized*

1.0 INTRODUCTION

Biomass represents one of the largest sustainable energy resources in the world and has been perceived as an attractive source of power and fuels. The history of gasification dates back to the seventeenth century. Since the conception of the idea, gasification has passed through several phases of development. During the 1840s, the first commercially used gasifier, which was an updraft style, was built and installed in France. Gasifiers were then developed for different fuels, industrial power and heat applications (Quaak *et al*., 1999). The 1970s brought a renewed interest in the technology for power generation at small scales due to oil crisis (Stassen and Knoef, 1993). Since then, fuels other than wood and charcoal have been applied as feedstock materials. As a century old technology, gasification flourished quite well before and during World War II. Gasifiers were largely used to power vehicles during that period. Many of the gasoline and diesel driven vehicles during the war were converted to producer gas driven. Today, because of increased fuel prices and environmental concerns, there is a renewed interest in gasification. The use of downdraft gasifiers fueled with wood or charcoal to power cars, lorries, buses, trains, boats and ships have already proved their worth (Turare,2002). Gasification has become a more modern and quite sophisticated technology. Most of the development work was carried out with common fuels such as coal, charcoal and wood. The key to a successful design of gasifier is to understand the properties and thermal behavior of the fuel fed into the gasifier system. It was recognized that fuel properties such as Surface area, size, shape as well as moisture content, volatile matter and carbon content affect gasification performance (McKendry, 2002). Abubakar et al., (2018a) tested and evaluated the performance of a forward curved blower for thermal applications. They determined the performance characteristics of the blower. A peak temperature of 891^{o}C was recorded at 3111 rpm and an air velocity of 23.8 m/s. Major characteristics of the blower such as the power output were found to be 0.56 kW while the mechanical efficiency was varying between 55% and 62% respectively. Abubakar et al., (2018b) designed and developed a forward curved Blower for Downdraft Gasifier Reactor. The geometric parameters, operating conditions and the performance characteristics were determined. It was found that the blower can sufficiently supply air for a gasifier operation even at high temperature. It is against this background that this study was conceptualized to develop a gasifier that will effectively utilize bagasse for the production of combustible gas for electricity generation.

1.2 Current Status of Gasification Technology

Gasification was discovered independently in both England and France in 1798, and through 1850 technology had been developed to the point that it was possible to light much of London with manufactured gas or "down gas" from coal and manufactured gas soon crossed the Atlantic to the United State and through 1920, most American cities and downs supplied gas to the residents for lighting and cooking through the local "gas works" (Doherty *et al*, 2008).

1.3 Biomass

A generally accepted definition of biomass are defined by the United Nation Framework climate change which emphasized that biomass is a non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms that also includes products, by products, residues and waste from agriculture, forestry and related industries (Diana, 2012).

1.3 **Biomass as a Fuel**

Biomass simply refers to organic materials originated from plants (wood, crops etc.) and animal wastes. Different biomass conversion processes produce heat, electricity and fuels. Among all biomass conversion processes, gasification is one of the most promising (Mavukwana, et *al*, 2013).

1.4 Component of Biomass

Cellulose, hemicelluloses, lignin and extraises are found to be the main compkonents of biomas. Cellulose and hemicelluloses are formed by long chains of carbohydrates (such as glucose, whereas lignin is a polymeric lignin has a close relationship with hemicelluloses as it exist as a glue fixing the bunches of cellulose chains and plant tissues together. This is gives mechanical strength to the plant. Lignin is rich in carbon and hydrogen, which are the main heart producing element. Hence lignin has a higher heating value than carbohydrates (Diyoko, *et al*., 2012).

1.6 Gasification Process

Biomass gasification is the conversion of an organically derived, carbonaceous feedback by partial oxidation into a gaseous product, synthesis gas or "syngas", consisting primary of hydrogen (H2) and carbon monoxide (Co), with lesser amount of carbon dioxide (Co_2), water (H_20) methane (CH4), higher hydrocarbons (C_2+), and nitrogen (N_2) (Diana, 2012).

1.7 Drying

In this stage, the moisture content of the biomass is reduced and occurs at about 100 – 200^0C with a reduction in the moisture content of biomass of less than 5% (Jamilu, 2016) Resulting water vapour together with water vapour formed at combustion zone partly lead to production of hydrogen and remaining is going with producer gas (Ramzan, *et al*, 2011).

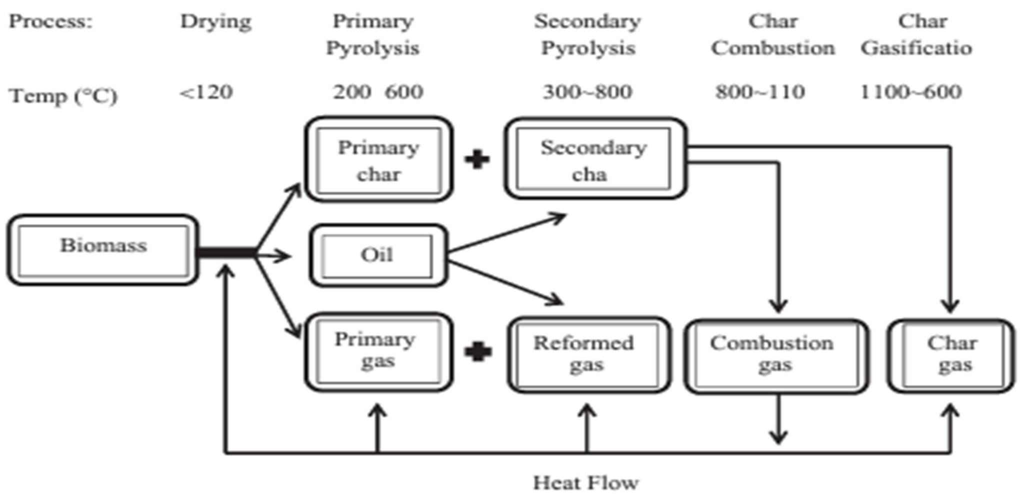

Fig.1 Heat and mass flows in a gasification process

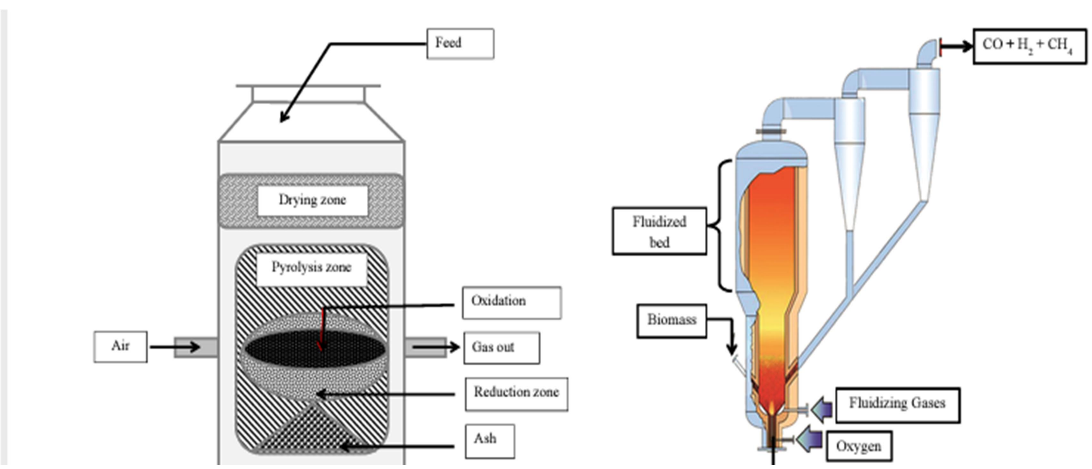

Fig.2 Heat and mass flows in a gasification process

2.0 Materials and Methods

2.1 Site Description

The study was carried out in the Entrepreneur Centre of the University of Maiduguri, the capital of Borno State. It lies between latitudes 11° 45`N and 11° 51`N, Longitudes 13° 2`E and 13° 9`E and 345m above mean sea level with a mean annual rainfall of about 625mm and annual temperature of 28-32°C Abubakar et al (2019).

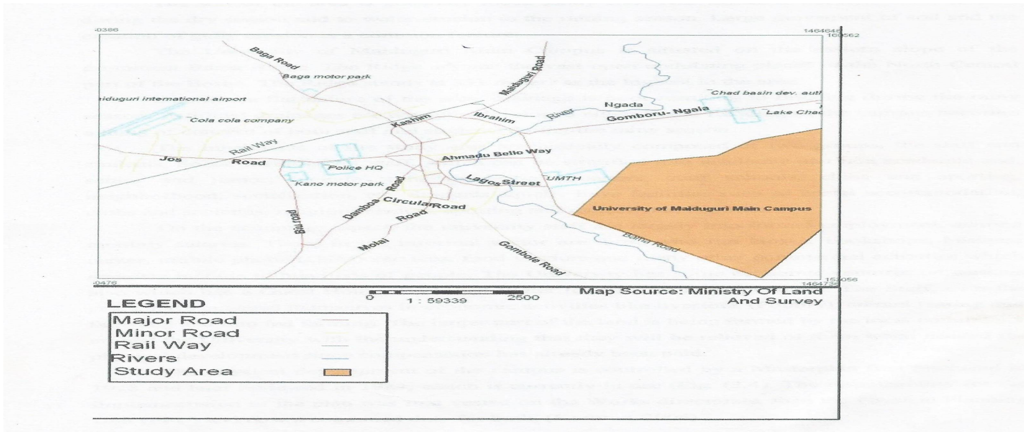

Figure 3.1 Maiduguri Road Map Showing the Study Area (Abubakar., *et al* 2019)

2.2 Treatment and Experimental Design

The experimental factors considered in this studies were feedstock (bagasse) and particle sizes, each at three level, the feedstock selected were namely; (pelletized, briquetted, and control); while the particle sizes considered were namely (0.6mm, 1.86 mm and 2.36 mm) respectively. The treatments were laid out in a complete randomized design (CBD) with two replications.

2.3 Gasification rectors

In the present study, a downdraft fixed-bed gasification reactor was simulated two-dimensionally using the Eulerian method. By considering two-dimensional modeling, the effects of the reactor geometry and gasification properties can be investigated along vertical and horizontal directions. Fluid flow was assumed to be steady (Zhang., 2011) and turbulent [Gerun., 2008) similar to previous studies. Feedstock entered the reactor from the upper part of the geometry, and air inlet nozzles were located on both sides of the reactor. Outlet syngas were discharged from the bottom of the reactor. Mass, momentum, and energy equations were solved using the first-order upwind scheme. Species transport was solved by the Eddy dissipation method. Radiant heat transfer was significant because of the high temperature of the reactor; thus P1 model was used for this type of heat transfer, similar to the literature

2.4 Fuel properties and reactions

Bagasse pellets initially have a moisture content of more than 50%. This moisture should be reduced by pre-drying. Bagasse with higher moisture content requires more energy to begin the gasification process; therefore, pre-drying and decreasing the moisture content of bagasse is necessary. In the present study, sugarcane bagasse properties were introduced to ANSYS Fluent and defined by proximate and ultimate analyses. Different properties are reported for different types of woods in the literature. The properties used in the present study are shown in Table 1.

Table 1 :Proximate and ultimate analyses of bagasse

Moisture content	1.14%
Volatile matter content	69.99%
Fixed carbon	16.39%
Ash	1.42%

Nitrogen (N)	0.20%
carbon (C)	44.10%
Hydrogen (H)	5.70%
Sulfur(S)	2.30%
Oxygen(O)	47.70%

2.5 Feed Sock Preparation

The Bagasse was collected from mills in Maiduguri, Borno State. The performance evaluation of the adopted gasifier was carried out at the center of entrepreneurship development university of Maiduguri. Initially the Bagasse was sorted, cleaned and sun dried, followed by sieving to the required particle sizes using a sieve obtained from the Civil Engineering Department of Ramat Polytechnic. The feed stock was sieved into different particle sizes such as 2.36 mm, 1.86 mm, and 0.6 mm respectively. The feedstock (rice husk) were divide into three equal each at 2.0 kg respectively. Pelletized and briquetted machine were used for making the Bagasse biomass into pelletized and briquetted was accomplished by the use of bender (bentonite) mixed up with water before pelletized and mounded. Fuel properties and reactions Bagasse pellets initially have a moisture content of more than 50%. This moisture should be reduced by pre-drying. Bagasse with higher moisture content requires more energy to begin the gasification process; therefore, pre-drying and decreasing the moisture content of bagasse is necessary. In the present study, sugarcane bagasse properties were introduced to ANSYS Fluent 16.2, defined by proximate and ultimate analyses. Different properties are reported for different types of woods in the literature. The properties used in the present study are shown in Table 1.

2.6 Thermal Decomposition of Bagasse

There are two distinct stages in the decomposition of Bagasse- carbonization and decarbonation. Carbonization is the decomposition of volatile matter in Bagasse at temperature greater than 300°C and releases combustible gas and tar. Decarbonation is the combustion of fixed carbon in the Bagasse char at higher temperature in the presence of oxygen (Fig. 2.1) [Maeda et al., 2001]. The melting temperature of RHA is estimated as 1440°C, that is, the temperature at which silica melts (Bronzeoak, 2003).

2.7 Gasification in Fixed Bed Reactors

They are sometimes called moving bed because the gasifying agents passes through a bed of solid fuel. If the gasifying agent is fed from the top of the reactor with the biomass, it is term downdraft while if the gasifying agent is feed from the bottom moving counter currently with the biomass the gasifier is called updraft. These reactors are easy to construct, operate and suitable for small scale applications. They are widely available in developing countries but in general have limited scale up properties.

2.8 Downdraft gasifier

In the downdraft gasifier, its upper cylindrical port of gasifier acts as a collection device for wood chips or other biomass fuel and the geometry of the down draft gasifier nearby is a radially directly air nozzle, which permits air to be down into chips as they move down to be gasified and this nozzle constitutes combustion and reduction zones as shown in figure 2.1 below. After the air contact the pyrolyzing biomass before that the flame gas riches as pyrolysis proceeds. Next so the end of pyrolysis zone, the gases consist mostly of CO_2, H_2O, CO, and H_2 and the throat ensures that gaseous products pass through the soothes: hydrocarbon so produces relatively clean gas. Designed for the application of producer gas in CI engine, downdraft gasifier is more suitable as it produces very less tar (Sanjay, 2015 and Jamilu, 2016.

2.8.1 Classification of Biomass Gasifier

Gasifiers are mainly classified according to their design as fixed bed fluidized bed and entrained flow bed. However, gasifiers can also be classified as:

i. According to gasification agents
ii. According to heat for gasification (isothermal or autothermal) and
iii. According to pressure in the gasifier (atmospheric or pressurized).

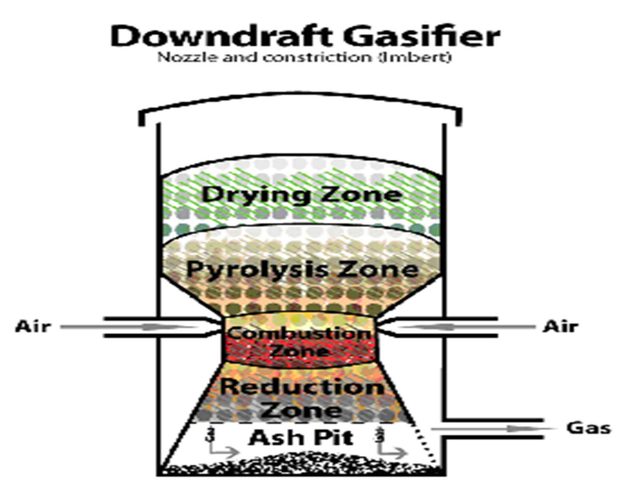

Figure 2.1 Down draft gasifier source (Sanjay, 2015)

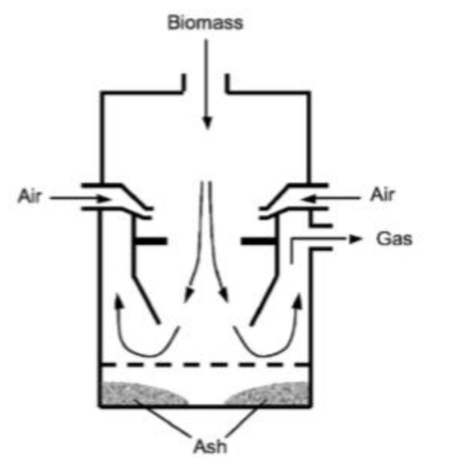

Fig. 2.2: Imbert downdraft Gasifier (Jamilu, 2016).

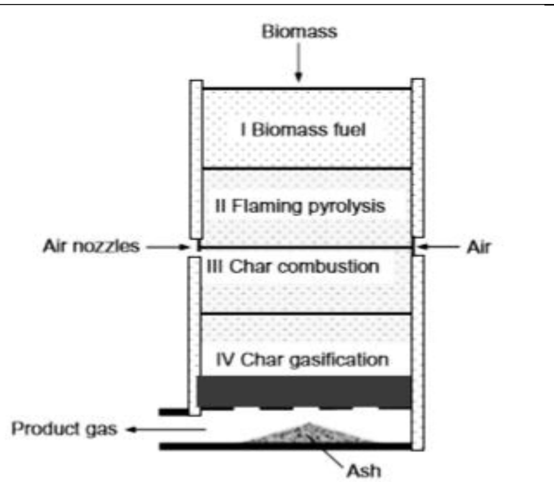

Fig. 2.3: Stratified Downdraft Gasification Design (Jamilu,.2016)

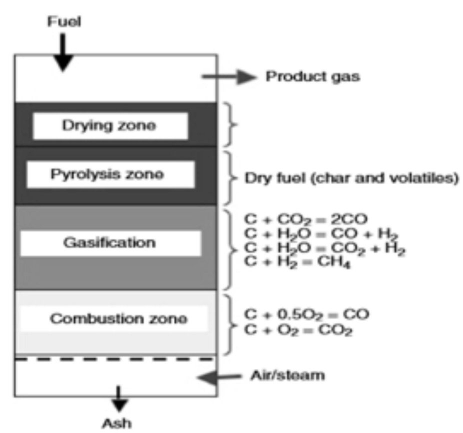

Fig 2.4: updraft gasifier Source: Sanjay, 2015

4.0 RESULTS AND DISCUSSION

The experimental results on effect of pelletized and briquetted bagasse biomass on different particle sizes on the temperatures of downdrafts gasifier were analysed using the Analysis of Variance one-way (ANOVA) as presented in the following tables below.

From the Table 4.1, it was seen that the temperatures of the gasifier increased with increase in mass. Higher temperatures at T_1, T_2 and T_3 were observed with briquetted bagasse biomass with maximum temperature values of 117 ^oC, 471 ^oC and 1109 ^oC respectively. It was narrowly followed by pelletized with corresponding temperature values of 111 ^oC, 452 ^oC and 920 ^oC respectively. Finally, the least gasification temperatures were observed with control biomass. this should also be expected to the fact palletization could improve the quality of the solid fuel in terms of higher temperature and promotes less biomass bridging in a downdraft gasifier as reported by Yoon *et al.* (2012). for more details, see figure 4.1 and table 4.2

Table 4.1: Effect of pelletized and briquetted feedstock on gasification temperatures of bagasse at 2.36 mm particle size

Treatments	Thermocouple 1 (^oC)	Thermocouple 2 (^oC)	Thermocouple 3 (^oC)
Control	87	327	653
Pelletized	111	452	920
Briquetted	117	471	1109

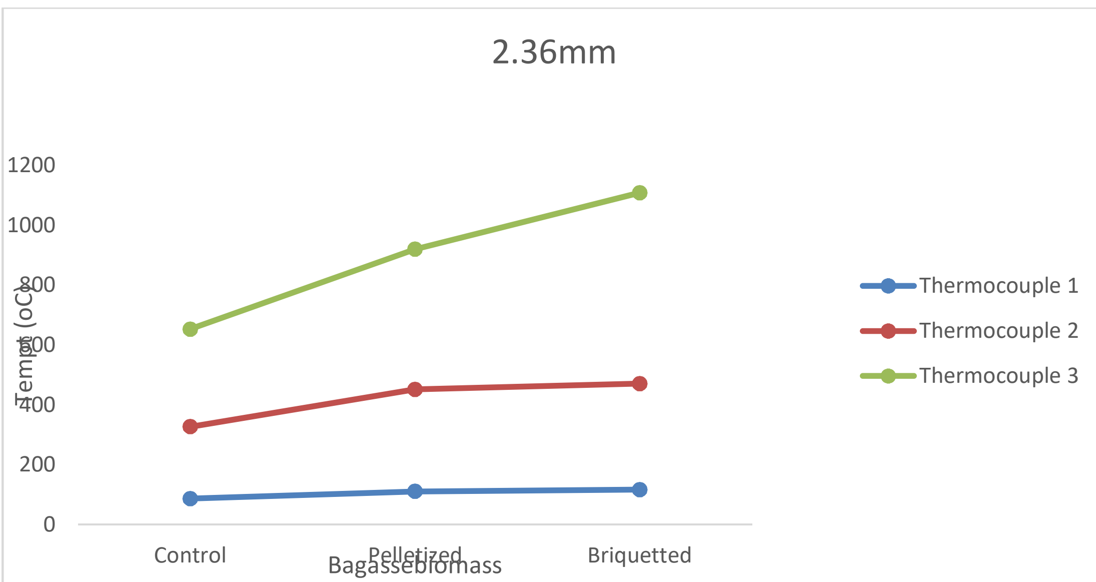

Figure 4.1 Showing the effect of pellet bagasse biomass on gas flow temperatures at 2.36mm particle size

Table 4.2: Shows The Analysis of Variance of the Experiment

ANOVA						
Source of Variation	SS	Df	MS	Fstat	P-value	F crit
Between Groups	947504.2	2	473752.1	24.14502	0.00135	5.143253
Within Groups	117726.7	6	19621.11			
Total	1065231	8				

From the result/summary fstat>fcript. There is a significant difference among the treatments at P>0.05

Table 4.3, shows the result of gasifier temperatures as affected by pelletized and briquetted bagasse biomass at1.86mm particle size. The maximum temperatures values of 104 °C, 467 °C and 1194 °C for T_1, T_2 and T_3 were remarkably observed with briquetted biomass, it was followed by pelletized bagasse during gasification period, while the lowest gasification temperatures at thermocouples T_1, T_2 and T_3 was recorded with control with corresponding gasification temperatures values of 102 °C, 433 °C and 910 °C respectively and similar result was reported by Abubakar., et *al* (2019). For more details, see figure 4.2 and table 4.4

Table 4.3: Effect of pelletized and briquetted feedstock on gasification temperatures of bagasse at 1.86 mm particle size

Treatment (Feedstock)	Thermocouple 1 (°C)	Thermocouple 2 (°C)	Thermocouple 3 (°C)
Control	80	314	634
Pelletized	102	433	910
Briquetted	104	467	1194

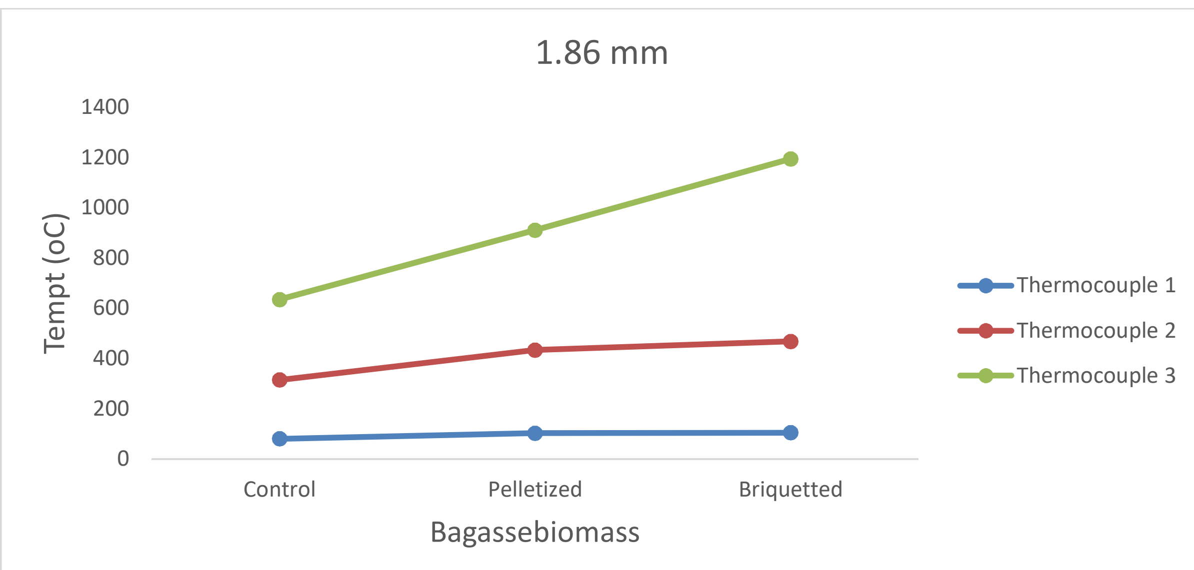

Figure 4.2: effect of pellet bagasse biomass on gas flow temperatures at 1.86mm particle size

Table 4.4: Shows the Analysis of Variance of the Experiment

ANOVA						
Source of Variation	SS	Df	MS	F stat	P-value	F crit
Between Groups	89928.22	2	44964.11	10.244337	0.790653	5.143253
Within Groups	1104152	6	184025.3			
Total	1194080	8				

From the result/summary fstat>fcript. There is a significant difference among the treatments at P>0.05

As shown in table 4.5. Both pelletized and briquetted biomass experimented at 0.6 mm particle size had significantly ($p<0.05$) influenced the temperatures of gasifier. The uppermost T_1, T_2 and T_3 were still observed best with briquetted, it was closely followed by pelletized and the least was obtained with control feedstock throughout the period of the experimentation and result of the experimented is tallied with the work of Abubakar *et al*., (2019). For more details, see figure 4.3 table 4.6

Table 4.5 Effect of pelletized and briquetted feedstock on gasification temperatures of at 0.6 mm particle size

Treatment	Thermocouple 1 (^oC)	Thermocouple 2 (^oC)	Thermocouple 2 (^oC)
Control	54	221	621
Pelletized	92	422	680
Briquetted	96	452	721

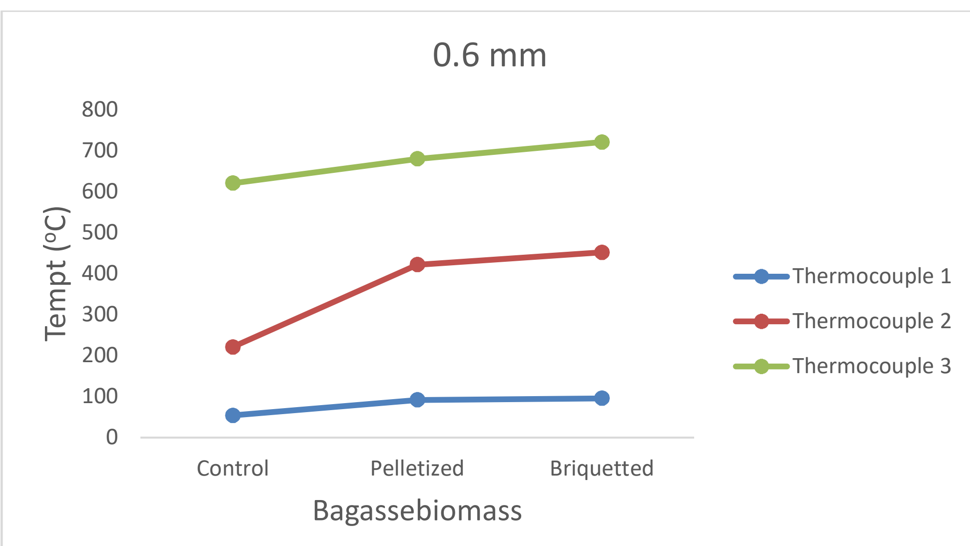

Figure 4.3: Showing the effect of pellet bagasse biomass on gas flow temperatures at 0.6 mm particle size

Table 4.6: Shows the Analysis of Variance of the Experiment

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	25950.89	2	12975.44	0.144144	0.868673	5.143253
Within Groups	540102.7	6	90017.11			
Total	566053.6	8				

From the result/summary fstat>fcript. There is a significant difference among the treatments at P>0.05

4.2 Effect of bagasse particles size on pelletized, briquetted and control sample on gas flow temperatures

As presented in the figure 4.1, The plots revealed that briquetted bagasse experimented produced the uppermost temperature of the gasifier during gas flow process at thermocouples T_1, T_2 and T_3 respectively. It was then closer by pelletized biomass at same thermocouples, and the least gas flow temperatures recorded with control bagasse (unammended).

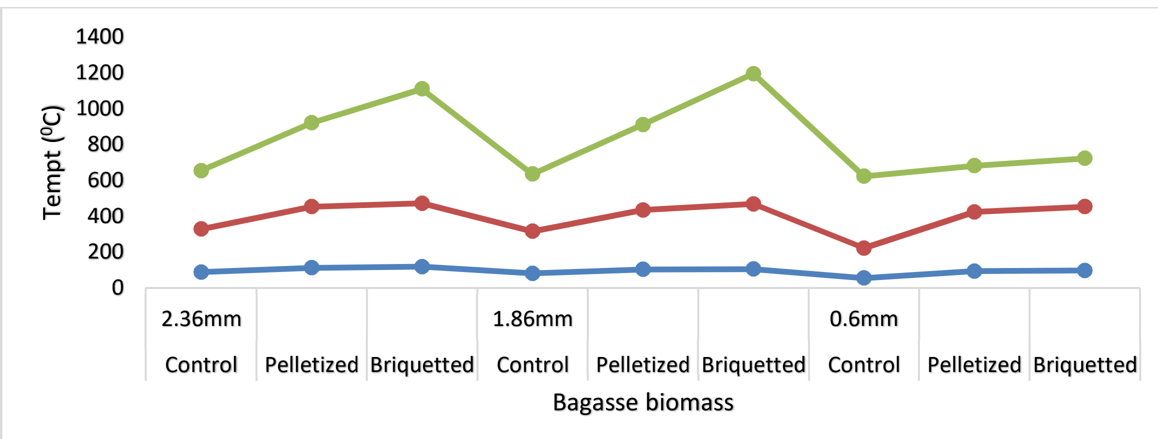

Fig 4.4: Temperatures of the gas flow at different pellet of bagasse biomass and particle sizes

5.0 Conclusion and Recommendations

The study was aimed to evaluate the performance of the existing gasifier to identify the most effective pelleted and particle sizes of bagasse on the temperatures and time of the combustible gas production from the gasifier for effect electricity generation. The collected data were subjected to the analysis of variance (ANOVA) and the result were as follows:

(i) Results of this investigation showed that briquetted bagasse biomass at all particle size experimented had a significant influence on the temperature of the gasifier during the gasification processes and was followed by pelletized and control at all particle size

(ii) Among all particle size experimented, 2.36 mm particle size produced the highest temperature during the gasification process and could be capable for mass syngas generation in the country.

(iii) The highest temperature among thermocouples (T_1, T_2 and T_3) was significantly recorded best with briquetted bagasse biomass.

(iv) In view of the foregoing, it is recommended that briquetted bagasse biomass and 2.36 mm particle size could be used effectively for production as in this region.

(v) It is recommended that, further studies should also be carried out on other agricultural waste using or adopting this approach with a view to re- validating the outcome of this

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