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Evaluation of A Simplified Downdraft Gasifier for Fuelling Internal Combustion Engines for Agricultural Operations

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Abstract: The aim of this study was to evaluate the effect of throat size and air flow rate on the efficiency of a simplified downdraft gasifier, the heating value, and the percentage composition of the produced gas from the gasification of cassava rhizomes and rice husks. The throat size of the gasifier was varied at 100, 150, 200, and 250 mm, while the air flow rate introduced into the gasifier was varied at 1, 2, 3, and 4 m^3/hr, respectively. The produced gases from selected biomasses after the gasification process are CH_4, H_2, CO_2, CO and O_2. After the gasification of the selected biomass, the analysis of the gaseous composition revealed that the percentage gaseous composition of CO is higher compared to other gases, while that of oxygen is low. The maximum percentage composition of CO gas produced is 23.95%, 26.14% at throat diameter and air flow rates of 250mm and 4m^3/hr, while the lowest value of O_2 is produced at throat diameter and air flow rate of 100mm and 1m^3/hr after gasification of cassava rhizomes. The maximum percentage composition of CO gas produced is 23.71%, 25.10% at throat diameter and air flow rates of 250mm and 4m^3/hr, while the lowest value of O_2 is produced at throat diameter and air flow rate of 150mm and 1m^3/hr after gasification of rice husks. It was concluded from the study that cassava rhizomes have a better heating value compared to rice husks. The efficiency of the simplified downdraft gasifier is higher for cassava rhizomes compared to rice husks after the gasification process.

Keywords: Gasification, Biomass, Waste to Energy, heating value, internal combustion engine

1.0 Introduction

The bedrock of the development of any nation is electricity. Availability of electricity could transform the lives of human, communities, and nations. In Sub-Saharan Africa, 585 million people have no access to electricity, including Nigeria, with a share of 76.6 million individuals [6]. According to International Energy Agency projections, by 2030, the number of people without access to electricity is not likely to decrease because of population growth [8]. Overuse and misuse of fossil fuels in recent years has triggered an increase in oil prices and reservoir depletion. The conversion of biomass-to-bioenergyis considered a renewable technology that can replace fossil fuel dependency. Biomass can be produced in a short time, with a minor negative impact on the environment. The technology can reduce the dependence on fossil fuel consumption and minimize exhaust gas emissions into the atmosphere [2].

Gasification is a thermo-chemical process that converts solid biomass into a mixture of combustible gases that can be used in various applications. Biomass is primarily composed of carbon (C), hydrogen (H), and oxygen (O), while the main chemical compounds in it are cellulose, hemicelluloses, and lignin. Other composition such as nitrogen (N), sulphur (S), and chlorine (Cl) are detected to be in traces. The thermal energy needed for gasification is generated through partial combustion of the feed material. The complete chemical breakdown of the fuel and internal reactions result in a combustible gascalled producer gas[2]. The main inflammable gases are H_2 and CO, but small amounts of methane (CH_4), ethane (C_2H_4), and acetylene (C_2H_2) are also produced. The effectiveness of gasification process is generally dependent on the specific gasifier used, fuel type, fuel moisture content, and fuel geometry. The main objective of the study was to evaluate the performance of a simplified downdraft gasifier using different feedstocks for fueling internal combustion engines for agricultural operations.

2.0 Materials and methods

2.1 Materials

The rice husk from the variety FARO 11 and cassava rhizomes from variety TME419 were the adopted biomasses used for the gasification process in this study. The rice husk was sourced from Ibo Shade market, Auchi Town, Edo State, while the cassava stem was sourced from one of the local farms within the town. The cassava stem was cut to a length of 15–20mm, while the size of the rice husk was between 5–10mm. The two biomasses were dried to a moisture content below 15%, while the bulk density of the rice husk and cassava stem used for the gasification process was 120 kg/m^3. The downdraft gasifier was loaded with biomass based on their respective bulk densities; they were combusted with paraffin. The throat diameter of the downdraft gasifier was varied at 100, 150, 200, and 250 mm, while the air flow rate through the gasifier was varied at 1, 2, 3, and 4 m^3/hr. The throat diameter of the gasifier was kept at an average of 175mm when the air flow rate was varied, while the air flow rate was kept at an average of 2.5m^3/hr when the throat diameter of the gasifier was varied. The average air temperature at the time of the experiment ranged from 24 to 33^{0}C, and the air humidity ranged from 66 to 74%. The composition of the gaseous products from the biomass gasification process for the selected biomass was measured with the use of a gas analyzer (infrared spectroscopy). The air flow rates were tested based on the orifice plate; this device was used for measuring air flow rates based on the pressure difference within the gasifier. The method was adopted as a result of the portability, durability, and low cost of the adopted device.


A


B


C


D

Plate A and B:Image of cassava rhizomes and rice husk.

Plate C and D: Image of the simplified downdraft gasifier and gasification process.

2.2 Air flow rate (m^3/hr)

Air flow rate can be determined using the equation below;

$$Q_{ac} = \alpha * A_2 * \sqrt{\frac{2 * \rho_{kk}(P1-P2)}{1-m^2}}$$

Where Qac denotes the actual air flow rate (kg/s); flow coefficient; A2 denotes the plate hole area (m^2); kk denotes the density of air (kg/m^3); P = P1-P2 denotes the differential pressure before and after the disk (Pa); and m denotes the orifice plate hole area to tube area ratio.

2.3 Gasification efficiency

Gasification efficiency is a crucial factor when evaluating the actual technical operation, as well as the economic possibility of using a gasifier system. The gasification efficiency of the gas when used for engine applications is:

$$\eta = \frac{\int_{\tau_1}^{\tau_2}(LHV_{gt}.G_{gt})d\tau}{LHV_{nl}.M_{nl}(\tau_2-\tau_1)}.100\%$$ (Cuong et. al. 2014).

Where: τ_1, τ_2: initial and final time of the gasification process, G_{gt}: volume flow of gas (m^3/h), LHV_{gt}: heating value of the gas (MJm^3), M_{nl}: cassava stem or rice husk consumption (kg/h), LHV_{nl}: low heating value of cassava stem and rice husk (MJ/kg). The specific gasification rate (SGR) is expressed as the mass of biomass fuel utilized per unit time per unit reactor area, usually about 110–210 $kg/h/m^2$ [1]. It was expressed as:SGR = G_t/S. Gt denotes the fuel mass flow rate (kg/h), and S denotes the reactor cross-sectional area (m^2).

2.4 Location and duration

The fabrication and evaluation of the downdraft gasifier were conducted at the workshop of the Mechanical Engineering Department, Auchi Polytechnic, Auchi, Edo State. The fabrication and evaluation were carried out between November 12th,2021 and January 3rd, 2022.

2.5 Statistical analysis

Polynomial and linear equations were fitted to the data using the Excel program in the Microsoft Excel software. The fixed "X" variables were the throat diameter and air flow rate as the independent variables; the dependent variables were the percentage gaseous composition, gasifier heating value, and efficiency of the gasifier, which were fixed as "Y" variables. The regression coefficient establishes the relationship between the adopted independent and dependent variables.

3.0 Results and discussion

The proximate and ultimate analysis of both cassava rhizomes and rice husks are evaluated in the laboratory. The value of the analysis is as shown in the table below.

	Proximate analysis (%)	
	Cassava rhizome	Ricehusk

Moisture content	12.37	13.20
Volatile matter	35.96	48.00
Ash content	3.1	16.00
Fixed Carbon	14.32	18.90

	Ultimate analysis (%) Cassava rhizome	Ricehusk
Carbon	43.42	32.70
Hydrogen	8.33	4.83
Nitrogen	38.98	0.39
Oxygen	29.24	32.40
Heatingvalue (MJ/kg)	17.43	15.21

The heating value of a biomass has been defined as the energy available in the biomass fuel per unit mass. The ultimate analysis shown in table 1.0 above reveals that the two biomasses (cassava rhizomes and rice husks) possess an average heating value considerable enough for the gasification process. [4, 5].

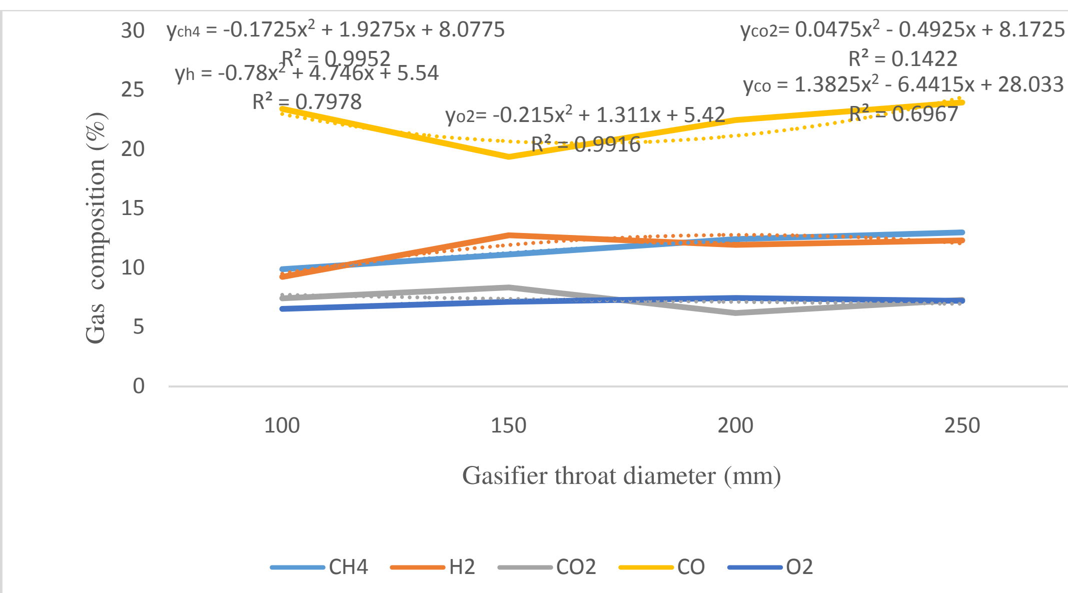

Fig1: Effect of throat diameter on the percentage composition of the produced gas from cassava rhizomes

Fig 1 reveals the variation in throat diameter of the gasifier during the gasification procedure for cassava rhizomes. The percentage gaseous composition of carbon monoxide compared to other gases is high with a value of 23.41–23.95%, while that of oxygen and carbon IV oxide is reported to be the lowest with a percentage composition of 6.53–8.33%. The regression coefficient proved that there is consistency in the production of methane gas during the gasification process. It reveals that the higher the value of the throat diameter of the gasifier, the higher the value of the methane produced.

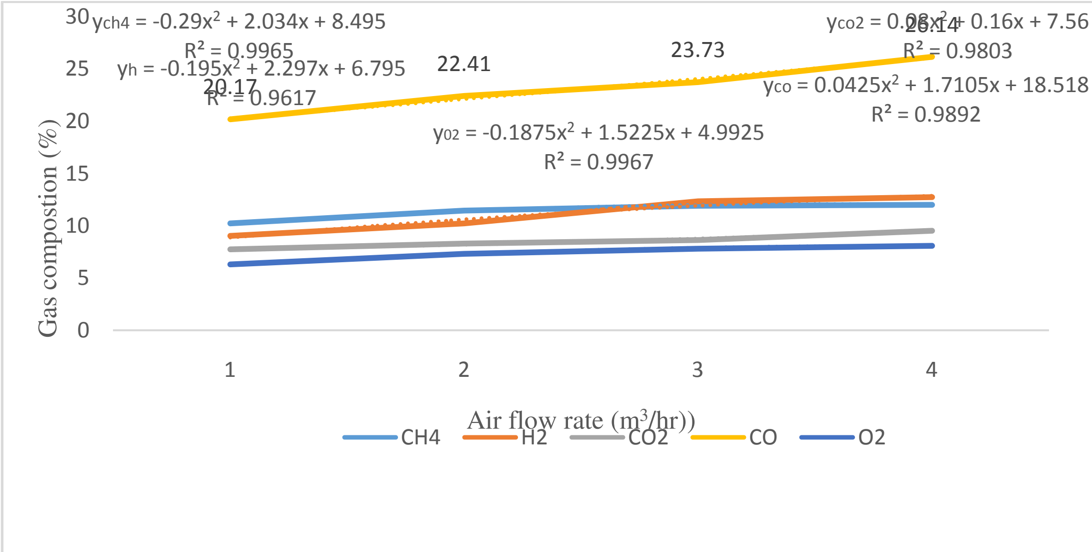

Fig2: Effect of air flow rate on the percentage composition of produced gas from cassava rhizomes

Fig. 2 reveals the variation in air flow rate during the gasification of cassava rhizome. It is therefore deduced that the higher the air flow rate introduced into the gasifier, the higher the value of the gaseous composition of the produced gas. The percentage gaseous composition of carbon monoxide compared to other gases is high, with a range of 20.17–26.14%, while that of oxygen has the lowest value, ranging from 6.31–8.10%. The regression coefficient reveals that at varied air flow rates, there is consistent production of methane gas compared to other gases.

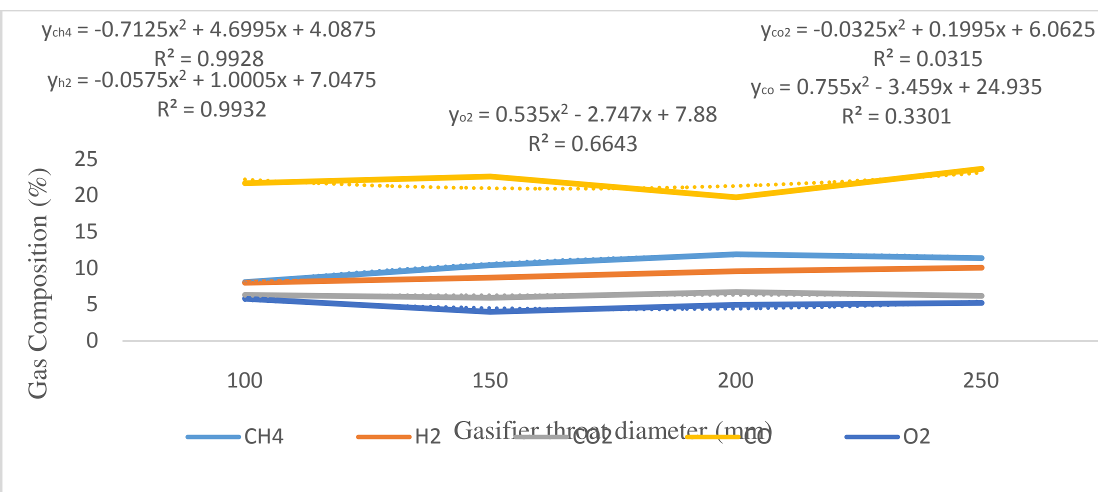

Fig3: Effect of throat diameter on the percentage composition of produced gas from rice husks

Fig 3 reveals the variation in throat diameter of the gasifier during the gasification procedure for rice husk. The percentage gaseous composition of carbon monoxide compared to other gases is high with a value of 21.70–23.71%, while that of oxygen was reported to be the lowest with a percentage composition of 5.84–5.28%. The regression coefficient proved that there is consistency in the production of hydrogen gas during the gasification process. It shows that the higher the value of the throat diameter of the gasifier, the higher the value of the methane produced from the gasification of the rice husk.

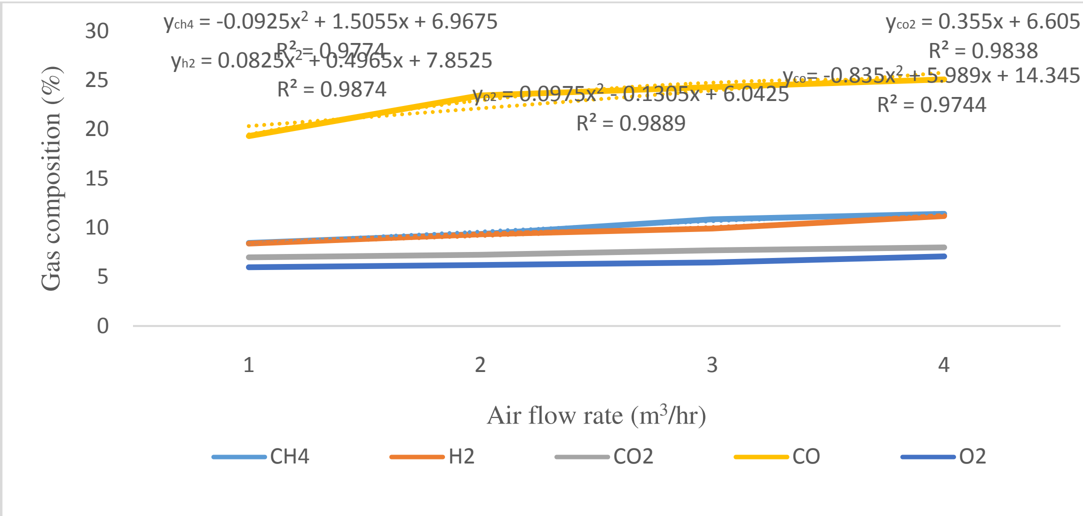

Fig4: Effect of air flow rate on the percentage composition of produced gas from rice husks

Fig. 4 reveals the variation in air flow rate during the gasification of rice husk. It is deduced that the higher the air flow rate introduced into the gasifier, the higher the value of the gaseous composition of the produced gas. The percentage gaseous composition of carbon monoxide compared to other gases is high, with a value of 19.34–25.10%, while that of oxygen has the lowest value, ranging from 5.99–7.10%. The regression coefficient reveals that there is consistent production of oxygen gas compared to other gases when the air flow rate introduced into the gasifier is varied.

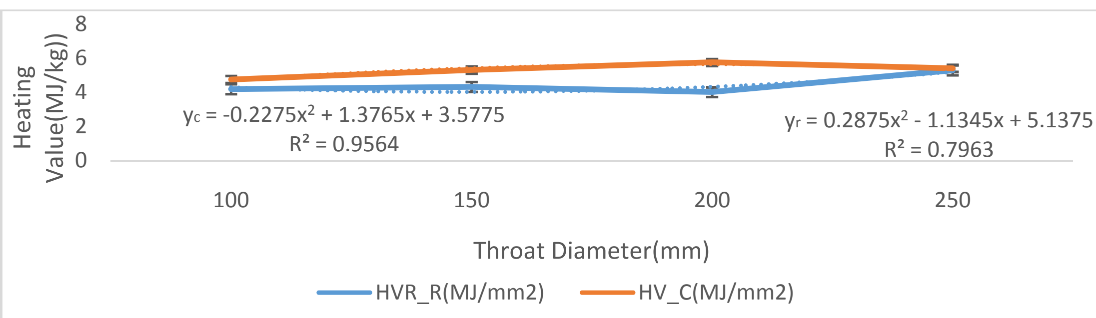

Fig5: Effect of gasifier throat diameter on heating value of the gasifier for cassava rhizomes and rice husk

Fig 5 above shows the effect of throat diameter on the heating value of the gasifier, it was revealed that the heating value of cassava ranges between 4.76-5.41MJ/kg, which is higher compared to that of rice husk with a value of 4.19-5.3MJ/kg. The regression coefficient revealed that the heating value of cassava rhizomes was more consistent when the throat diameter of the gasifier was varied.

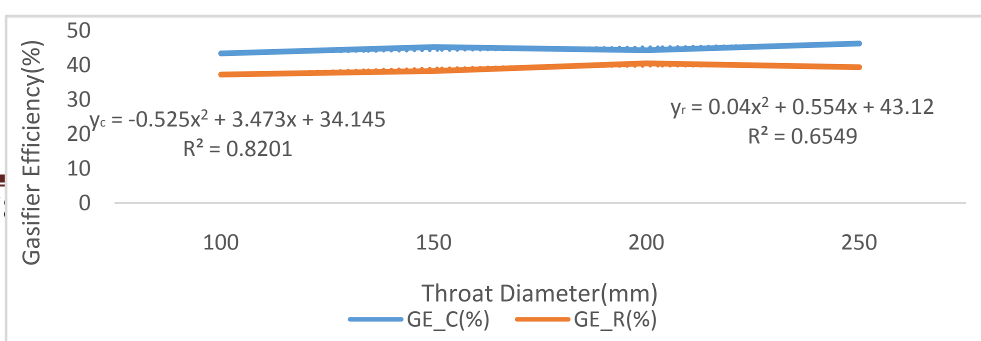

Fig:6 Effect of gasifier throat diameter on the gasifier efficiency for cassava rhizomes and rice husk

Fig 6 above shows the effect of throat diameter on the gasifier efficiency, the efficiency of the gasifier was high for cassava rhyzomeswith a value of 43.44 – 46.25% when compared to that of rice husk which range between 37.32 – 39.41%. The regression coefficient from the figure above also revealed that the efficiency of the gasifier was highwith gasification of cassava rhyzomes.

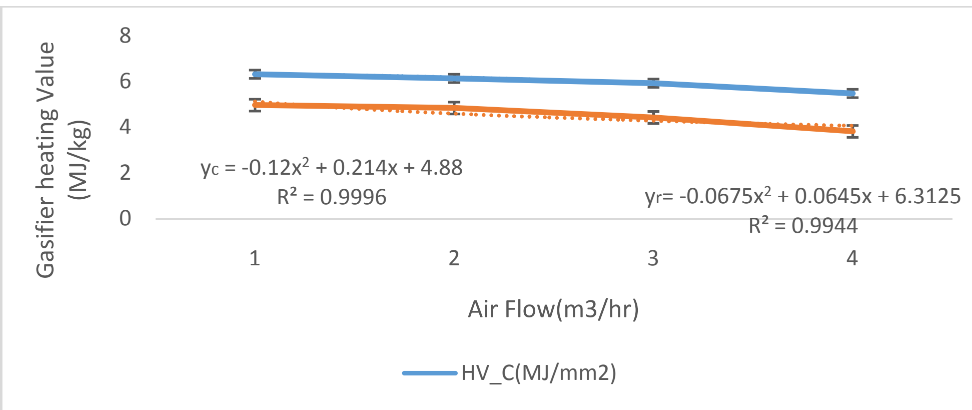

Fig7: Effect of air flow rate on the heating value of the gasifier for cassava rhizomes and rice husk

Fig. 7 reveals that the higher the air flow rate introduced into the gasifier, the lower the heating value of the selected biomass (cassava rhizomes and rice husks) after gasification. The regression coefficient reveals that the consistent reduction in the heating value of cassava rhizomes compared to that of rice husk is close.

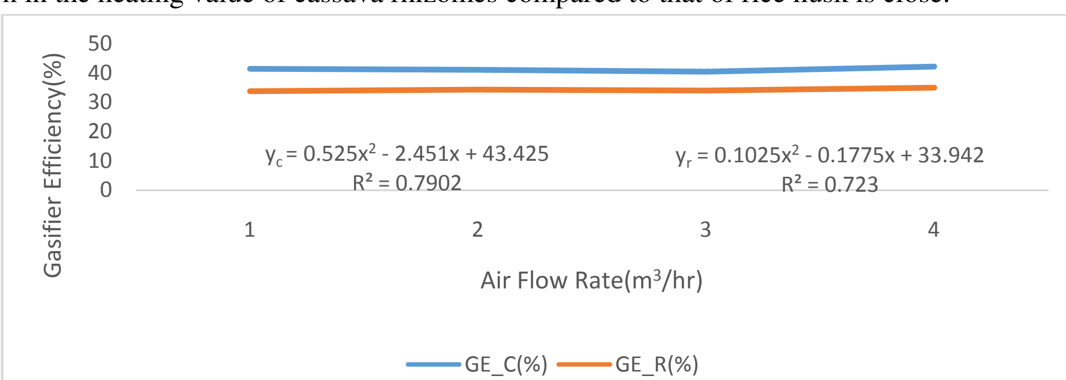

Fig8: Effect of air flow rate on the gasifier efficiency for cassava rhizomes and rice husk

Fig. 7 reveals that the higher the air flow rate introduced into the gasifier, the higher the efficiency of the gasifier on the selected biomass (cassava rhizomes and rice husk, respectively). The efficiency of the gasifier on the gasification of cassava rhizomes and rice husk ranged between 41.37–42.15 and 33.76 and 34.98%, respectively. The regression coefficient revealed that the efficiency of the gasifier during the gasification of cassava rhizomes is higher compared to rice husk.

Tag

Y_{CH4}	-	Percentage gas composition (methane)
Y_{H2}	-	Percentage gas composition (hydrogen)
Y_{CO2}	-	Percentage gas composition (carbon IV oxide)
Y_{CO}	-	Percentage gas composition carbon monoxide
$Y0_2$	-	Percentage gas composition (oxygen)
GE_C	-	Gasifier efficiency for cassava rhizomes
GE_R	-	Gasifier efficiency for rice husk
HV_C	-	Heating value for cassava rhizomes
HV_R	-	Heating value for rice husk.

4.0 Conclusion

The main aim of the present study was to investigate the effects of throat size and air flow rate on the heating value and gasifier efficiency of a simplified downdraft gasifier using cassava rhizomes and rice husk as alternatives to fossil fuel for fueling agricultural machinery. The findings could be concluded as follows:

[1] The production of carbon monoxide from the gasification of cassava rhizomes and rice husk is higher when compared to other gaseous products, while the production of oxygen gas is lower when compared to other gaseous products at a variable throat diameter (mm) and air flow rate (m^3/hr).

[2] It was deduced from the study that cassava has a better heating value (MJ/kg) when compared to rice husks at a variable throat diameter and air flow rate.

[3] The performance or efficiency of the gasifier was higher when cassava rhizomes were used compared to rice husks at a variable throat diameter and air flow rate.

Acknowledgments

All the authors contributed significantly to this study. The authors also thank and acknowledge TETFund for the Institutional Based Research grant (2021) released for the actualization of this study through Auchi Polytechnic, Auchi.

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