DEVELOPMENT OF A BIOMASS PYROLYSER FOR SAWDUST AND RICE HUSKS CONVERSION TO ENERGY

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ABSTRACT
Renewable energy sources are climatic condition dependent. Likewise, bio-digester does not produce biogas instantly. Against these backdrops, a biomass pyrolyser was designed, fabricated, and evaluated. The machine comprised of a reactor, furnace, and a moisture removal cylinder. The pyrolytic gas was produced by thermal decomposition of biomass waste in the reactor. The pyrolyser was evaluated using a 2 x 5 x 5 factorial experiment in a Completely Randomized Design (CRD) with feedstock, moisture content and retention time of feedstock in the reactor as factors. Measured parameters during evaluation were total gas yield, rate of gas yield and reactor conversion efficiency. The data obtained were analyzed statistically with Statistical Package for Social Science (SPSS) 20 software. At a moisture content of 12 % dry basis, the proportion of methane (CH_4) in the pyrolytic gas obtained from sawdust and rice husks were 57.3 % and 54.3 %, respectively. It was observed that the total gas yield, rate of gas yield and reactor conversion efficiency decreased as the moisture content of the biomass material (sawdust and rice husks) increased. However, as the retention time increased, all the measured parameters increased. After a retention time of 100 minutes, 2 kg of sawdust produced 1146 g of pyrolytic gas at the rate of 0.191 g/sec and 57.3 % reactor conversion efficiency. While 2 kg of rice husks produced 1124 g of pyrolytic gas at the rate of 0.187 g/sec and 56.2% reactor conversion efficiency. In less than 2 hours, a biomass pyrolyser produced fuel for operations. Therefore, it is a quick, simple and cheap method of converting biomass wastes into useful gas and it is not climatic condition dependent.

KEYWORDS: Biomass, Pyrolytic Gas, Biomass Pyrolyser, Sawdust, Rice husk

1. INTRODUCTION

The interest in using renewable energy resources has been on the increase recently because the known fossil resources (oil, natural gases and others) are considered almost exhausted, the only chance of human kind for the near future remains the renewable resources. Even if governments adopt dynamic policies to conserve energy, the demand will continue to increase (Cubiota -Rosie *et al*., 2008). Energy problems are so acute at the international level that it is no longer possible to satisfy the world's constantly growing needs by continuing to exploit, the limited range of resources. This growth of energy demand must be increasingly satisfied by diversified energy resources which include sustainable and renewable sources (Buzdugau and Tripsa, 2006).

Biomass energy-based system is reliable and can be extensively used for transportation and generation of heat for domestic uses. Agricultural activities generate a lot of biomass wastes which are difficult to manage and may result into harmful effects such as health hazards and environmental pollution. In view of these, an alternative renewable source of energy that does not require wind velocity, high amount of sun rays and constant water availability will be helpful. Biomass is widely considered as an important potential fuel and best alternative energy resources for the future (Panwar, 2009). It is an efficient energy source that can turn waste into useful energy, produce fuel almost immediately for operations and reduces greenhouse effect. It is reliable, cheap, environmental friendly and has low maintenance cost. Some researchers have conducted series of research works in recent years to develop and promote biogas production in Nigeria using different biomass sources and some fraction of municipal solid waste.

Biomass pyrolysis could be done all year round and is independent of climatic conditions like other renewable energy source such as solar, wind and hydropower. Biomass pyrolysis produces pyrolytic gas immediately which is far better than the bio-digester which produces gas in minimum of nine days. Likewise, biomass gasification has only bio-gas as its product and it is produced at a temperature of 1000 °C. However, biomass pyrolysis has pyrolytic gas, bio-oil and biochar as its products and produces them at a low temperature of 600 °C. This research was conducted to design, fabricate and evaluate a simple low-cost biomass pyrolyser for pyrolytic gas production using sawdust and rice husk as both the feedstock and energy source.

2. MATERIALS AND METHODS

2.1 Design Considerations

The biomass pyrolyser comprises of a reactor which has a feedstock inlet, perforated base furnace whose side are lined with clay for burning of wood waste to generate heat needed for the system and a moisture removal cylinder to remove moisture from the produced gas. The design was based on the following considerations:

i. The system was to be airtight which was achieved by making sure all welded joints were properly done without leakages. Body filler and gasket were used at the required places to ensure that thermal decomposition takes place in the reactor.
ii. In order to produce a clean pyrolytic gas for energy and power generation a moisture removal cylinder was included.
iii. Mild steel materials were used in the construction to withstand the high temperature.
iv. To ensure that the developed pyrolyser is easy to operate, the height was kept low to allow easy loading of feedstock.

2.2 Description of Machine Parts

The machine consists of a reactor, furnace, moisture removal cylinder, galvanized pipes, metallic couplers, and control valves. Figures 1 and 2 show the orthographic projection and exploded view of the designed biomass pyrolyser respectively.

Reactor

A 220 mm diameter, 600 mm height and 40 mm thickness, mild steel iron pipe were used as the reactor. A mild steel iron was used because of its ability to withstand high temperature. The reactor has a tight cover with a gas outlet.

Furnace

A 370mm diameter and 630 mm high drum with 40 mm clay internal lining was used as furnace. It has net underneath for ease of air flow into the furnace. This served as a heat source to the chamber where wood wastes are loaded to fire the reactor. The clay lining helped to conserve the heat produced and protect the wall of the furnace.

Moisture Removal Cylinder

A gas cyclone was used to remove moisture from the generated gas. Rotational effects and gravity are used to do the separation. It can also be used to separate fine droplets of liquid from gaseous steam. A cyclone filter of diameter 250 mm and height 340 mm was used in the system. The pyrolytic gas from the pyrolyser was collected in tyre tubes and taken to laboratory for analysis. The volumetric percentage of the gas composition produced was analyzed using a gas analyzer. Multi Gas Analyzer model Exibd I (accuracy of ± 5 %) was used for the analysis of the pyrolytic gas. The gas produced were for Hydrogen (H_2), Methane (CH_4) and Carbon monoxide (CO).

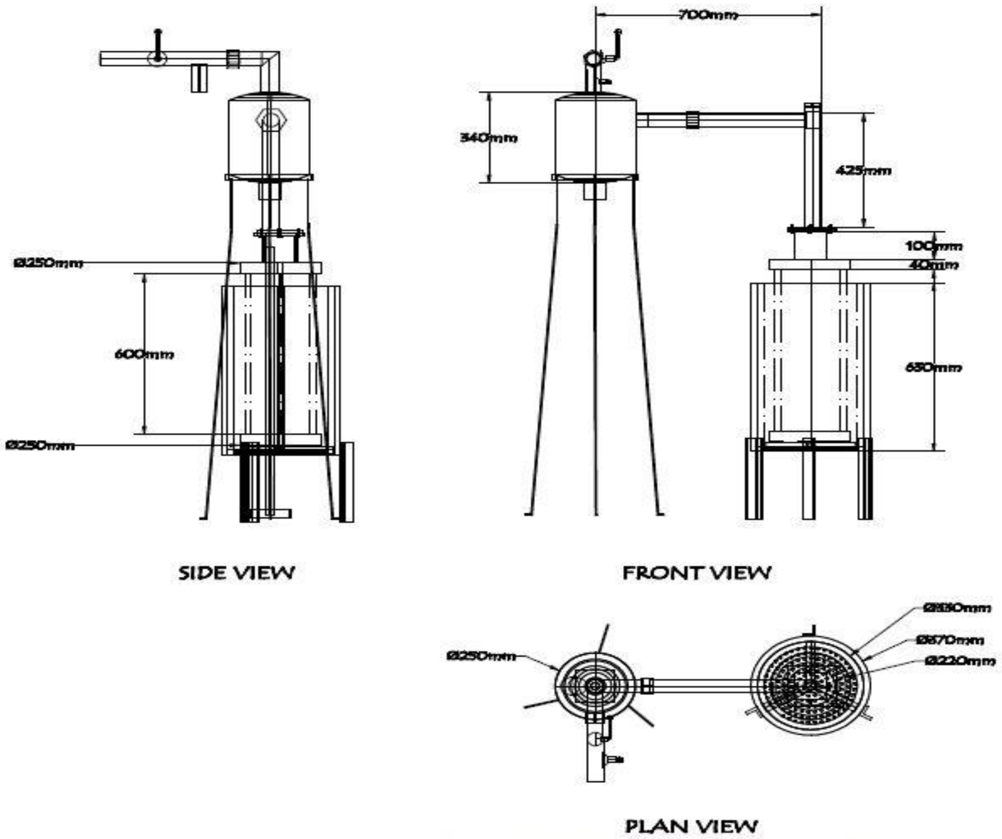
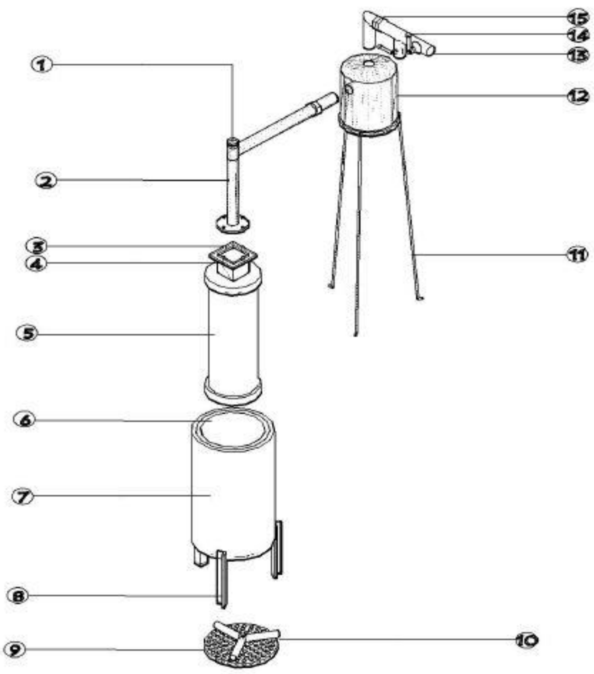


Figure 1: Orthographic view of the pyrolyser



ITEM NO	ITEM	QTY
1	FEEDSTOCK INLET	
2	METTALIC PIPE	
3	GASKET	1
4	BOLT AND NUT	4
5	REACTOR	1
6	CLAY LINING	
7	FURNACE	1
8	FURNACE STAND	3
9	PERFORATED BASE	1
10	REACTOR SEAT	1
11	MOISTURE REMOVAL STAND	1
12	MOISTURE REMOVAL CYLINDER	1
13	GAS OUTLET	2
14	CONTROL VALVE	2
15	METALLIC COUPLER	2

Figure 2: Exploded View of the Pyrolyser

2.3 Design Calculations

Airflow Rate design for the Furnace

The airflow rate is the rate at which the pyrolytic gas flows out of the reactor. According to Ojolo and Orisaleye (2010), the velocity of flow ranges between 6 and 10 m/s. Therefore, using a pipe of 50mm diameter, the airflow was calculated as:

$$Q = \frac{1}{4} \times \pi \times (pipe\ diameter)^2 \times velocity \quad (1)$$

where,

Q = Airflow rate (m^3/s)
Velocity = 10 m/s (estimated)
Pipe diameter = 0.05 m (estimated)
Hence, airflow rate was calculated as 0.00625 m/s = 6.25×10^{-3} m^3/s

Volumetric Capacity of the furnace

The reactor volume was determined by considering the size and density of the selected biomass. The reactor is the actual place where the conversion of biomass takes place. A known mass of biomass was used to determine the volumetric and gravimetric capacity of biomass required for the pyrolysis process. According to Vidian *et al.* (2017), the bulk density of sawdust is 100 kg/m^3. The volume of the biomass required was determined by selecting a cylinder of height 630 mm and diameter 370 mm (based on availability), the volumetric capacity of the furnace was calculated using the formula:

$$V = \frac{\pi}{4} d^2 h \quad (2)$$

where,

V = volume of the cylindrical drum, (mm^3)
d = diameter of the cylindrical drum, (estimated as 370 mm)
h = height of the cylindrical drum, (estimated as 630 mm)

Hence, volumetric capacity of the furnace was calculated as 67,747,018.5 mm^3 = 67,747.02 cm^3

2.4 Performance Evaluation of the Machine

The sawdust used for the experiment was obtained from a sawmill in Tanke, Ilorin while the rice husk was obtained from a local rice processor at Oja-gboro, Ilorin both in Kwara State of Nigeria. Both sawdust and rice husks were sun-dried to obtain their stable moisture contents of 6.5% (dry basis). The moisture content was measured with Moisture Meter TK100S with accuracy of ± 0.5 % (China). An electronic weighing scale with model number LT30KA (China) was used to measure 2 kg of sawdust at 6.5% (dry basis) moisture content and loaded into the pyrolysis system reactor. Approximately 5kg of wood waste was ignited inside the furnace to serve as heat source. The reactor was placed in the furnace when the wood waste was red hot. According to Adejumo and Abayomi (2012), to achieve a desired moisture content, Equation (3) should be used to determine the quantity of water to be added to the sample.

$$Q = W_i \frac{Mf - Mi}{100 - Mf} \qquad (3)$$

where,

Q = quantity of water added (g)
W_i = initial mass of sample (g)
M_f = final moisture content of sample (% dry basis)
M_i = initial moisture content of sample (% dry basis)

Hence equation (3) was used to achieve the other moisture content levels. The experiment was repeated for moisture content at 12, 17, 22, and 27 % dry basis. An infra-red thermometer model UT302D with accuracy of ± 2°C and temperature range of -32 to 1050°C was used to measure the outer temperature of the reactor at an interval of 5 minutes during the process. A by-product (biochar) obtained from the first experiment was used as heat source for the second experiment, that of the second experiment was used for the third experiment and it continued in that order. This same process was repeated for 2 kg of rice husks. The produced gas was collected in a set of tyre tubes. Initial weight of the empty tubes was taken. The weight of the tyre tubes was measured using an electronic weighing machine to obtain the total gas yield. A sample of 30 g was used for analysis using a gas analyzer. The time for each experiment was monitored with a stopwatch (KingL, USA).

The rate of gas yield was obtained using Equation (4).

$$Rate\ of\ gas\ yield\ Rate = \frac{Total\ gas\ yield\ (g)}{Time\ of\ gas\ yield\ (s)} \qquad (4)$$

The reactor conversion efficiency was therefore obtained using equation (5).

$$Reactor\ Conversion\ Efficiency = \frac{Total\ gas\ yield\ (g)}{Initial\ biomass\ weight\ (g)} \times 100\% \qquad (5)$$

2.5 Experimental Design and Statistical Analysis

The experimental design adopted for the machine performance evaluation was a 2 x 5 x 5 factorial experiment in a Completely Randomized Design with three replicates. Two levels of feedstock, five levels of moisture content and five levels of retention time of feedstock in the reactor. The stable moisture contents for sun-dried sawdust and rice husks were obtained as 6.5% (dry basis). Likewise, the pyrolyser did not begin to produce pyrolytic gas until after 20 minutes. Hence, to investigate the effects of feedstock, moisture content and retention time on total gas yield, rate of gas yield and reactor conversion efficiency, samples of feedstock were conditioned to obtain moisture content of 6.5, 12, 17, 22 and 27 % moisture content (dry basis). Total gas yield, rate of gas yield and reactor conversion efficiency was obtained at the retention time of 20, 40, 60, 80 and 100 minutes. The whole experiment was replicated three times. The data obtained was analyzed statistically with Statistical Package for Social Science (SPSS) 20 software. The Analysis of Variance was used to check the effect of each factor and interactions on the total gas yield, rate of gas yield and reactor conversion efficiency. Duncan's New Multiple Range Test (DNMRT) was used to analyze the difference between the means of the total gas yield, rate of gas yield and reactor conversion efficiency.

3. RESULTS AND DISCUSSION

The summary of the Analyses of Variance for total gas yield, rate of gas yield and reactor conversion efficiency is shown in Table 1. Likewise, the results obtained using Duncan's New Multiple Range Test (DNMRT) in evaluating the difference in means of total gas yield, rate of gas yield and reactor conversion efficiency for different parameters showed that each factor level was significantly different from the other at 5% significance level.

3.1 Total Gas Yield

Figure 3 shows the effect of moisture content on total gas yield for sawdust and rice husks. It was observed that increase in moisture content resulted in decrease in total gas yield. After 100 minutes, the sawdust gave highest average total gas yield of 1146 g at 6.5 % moisture content (db) and had the lowest value of 982 g at 27 % moisture content (db). In the same vein, rice husks gave highest average total gas yield of 1124 g at 6.5 % moisture content (db) and had the lowest of 975 g at 27 % moisture content (db). This may be due to the presence of high percentage of moisture which decelerates the rate of particle heating and hence slow down gas production kinetics. Similar trend was reported by Okekunle *et al.* (2016) on the pyrolysis of cassava chaff establishing the fact that increase in drying temperature enhanced the yield of pyrolytic gas.

Table 1. Summary of Analyses of Variance: F-values for all Measured Parameters

Source	Total Gas Yield	Rate of Gas Yield	Reactor Conversion Efficiency
MC	.0001*	.0001*	.0001*
F	.0001*	.012*	.0001*
RT	.0001*	.0001*	.0001*
MC * F	$.439^{ns}$	$.867^{ns}$	$.422^{ns}$
MC * RT	.0001*	.0001*	.0001*
F * RT	.034*	$.570^{ns}$	.043*
MC * F * RT	$.591^{ns}$	$.244^{ns}$	$.624^{ns}$

* Significant at $P < 0.05$; ^{ns}Not Significant at $P < 0.05$; MC = moisture content; F = Feedstock; RT = Retention Time

Figure 4 shows the effect of retention time on total gas yield for sawdust and rice husks. It was observed that increase in retention time resulted in increase in gas yield. At 6.5 % moisture content (db), the sawdust produced an average total gas yield of 82 g at 20 minutes and increased to 1146 g after 100 minutes. However, rice husks produced an average gas yield of 80 g at 20 minutes and increased to

1124 g after 100 minutes. This may be due to greater decomposition that took place at higher retention time as a result of increase in temperature i.e. devolatilization of the cellulosic and hemi-cellulosic material. Similar results were reported by Natarajan and Sundaram (2009) and Ibrahim *et al.* (2012). Pichestapong *et al.* (2013) reported that during pyrolysis of soya bean cake, increase in retention time and temperature increased gas yield from 25.24 to 50.81% From the Analysis of Variance (ANOVA) for the total gas yield. It was found that the moisture content, feedstock, retention time, the interaction of moisture content and retention time, and interaction of feedstock and retention time are significant at 5 % level of significance.

3.2 Rate of Gas Yield

Figure 5 shows the effect of moisture content on rate of gas yield for sawdust and rice husks. At 6.5 % moisture content (db), both sawdust and rice husks rate of gas yield was 0.191 g/sec and 0.187 g/sec. After 100 minutes the rates decreased to 0.16 g/sec and 0.158 g/sec at 27 % moisture content (db), respectively. This may be due to more time required for drying of moisture in feedstock of higher moisture content. This is in similar trend with Aquino *et al.* (2007). Figure 6 shows the effect of retention time on rate of gas yield for sawdust and rice husks. It was observed that increase in retention time resulted in increase in rate of gas yield till a point before it started decreasing. After 20 minutes retention time, for both sawdust and rice husks at 6.5 % moisture content (db), their rate of gas yield was 0.07 g/sec which later increased to 0.22 g/sec. After 60 minutes retention time, decrease in rates of gas yield was observed. This may be due to the fact that the feedstock was attaining bio-char state.

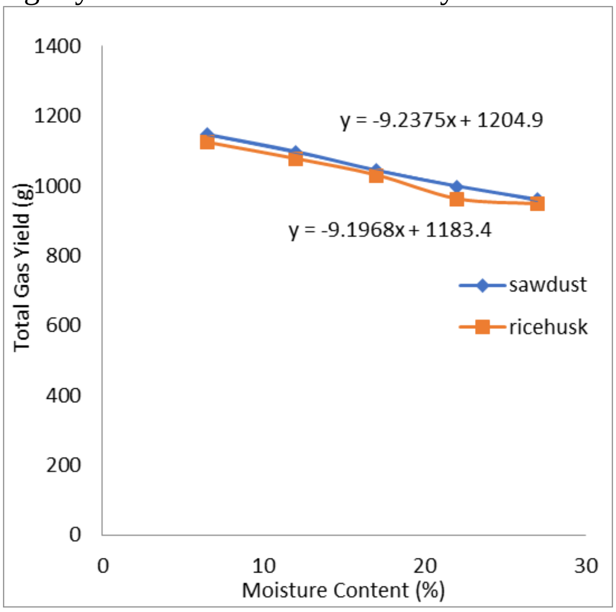


Figure 3. Effect of Moisture Content on Total Gas Yield for Sawdust and Rice husks

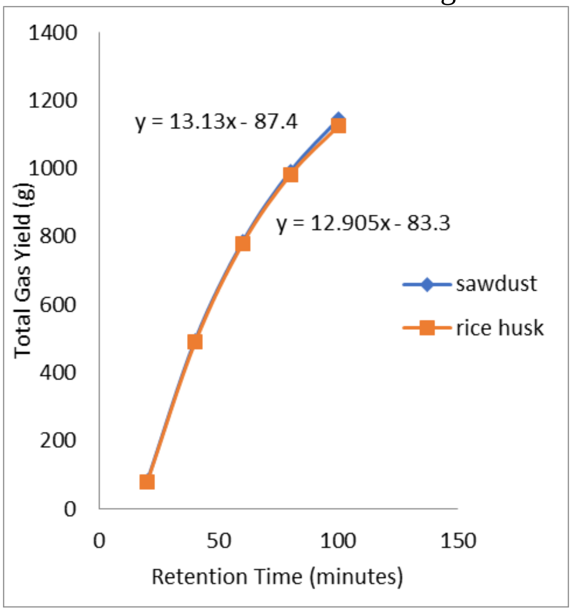


Figure 4. Effect of Retention Time on Total Gas Yield for Sawdust and Rice husks

This is in similar trend with Aquino *et al.* (2007). From the Analysis of Variance (ANOVA) for the rate of gas yield, it was found that the moisture content, feedstock, retention time and the interaction of moisture content and retention time are significant at 5 % level of significance.

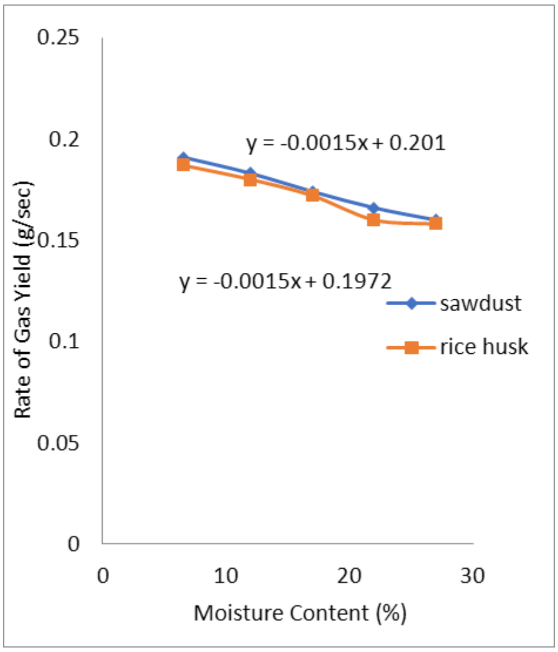


Figure 5. Effect of Moisture Content on Rate of Gas Yield for Sawdust and Rice husks

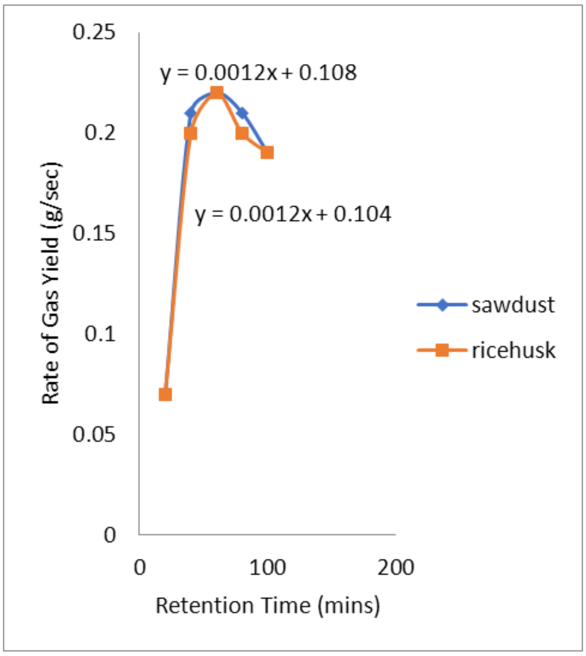


Figure 6. Effect of Retention Time on Rate of Gas Yield for Sawdust and Rice husks

3.3 Reactor Conversion Efficiency

Figure 7 shows the effect of moisture content on reactor conversion efficiency for sawdust and rice husks. It was observed that increase in moisture content resulted in the decrease of the reactor conversion efficiency. At 100 minutes retention time, sawdust had reactor conversion efficiency of 57.3 % at 6.5 % moisture content which reduced to 48 % at 27 % moisture content. In the same vein, rice husks had reactor conversion efficiency of 56.2 % at 6.5 % moisture content and reduced to 47.4 % at 27 % moisture content. This may be due to delay in drying process of feedstock with high moisture content. Similar trend was reported by Akinola (2016). Figure 8 shows the effect of retention time on reactor conversion efficiency of sawdust and rice husks. It was observed that increase in retention time resulted in increase in reactor conversion efficiency. At 6.5 % moisture content (db), the sawdust produced an average conversion efficiency of 4.1 % after 20 minutes retention time and increased to 57.3 % after 100 minutes retention time. In the same vein, rice husks had an average gas efficiency of 4 % after 20 minutes retention time and increased to 56.2 % after 100 minutes retention time. This may be due to the fact that an increase in retention time led to temperature increase thereby accelerating the rate at which thermal decomposition took place. Similar trend was reported by Sha *et al.* (2013). From the Analysis of Variance (ANOVA) for the reactor conversion efficiency, it was found that the moisture content, feedstock, retention time, the interaction of moisture content and retention time, the interaction of feedstock and retention time are significant at 5% significance level.

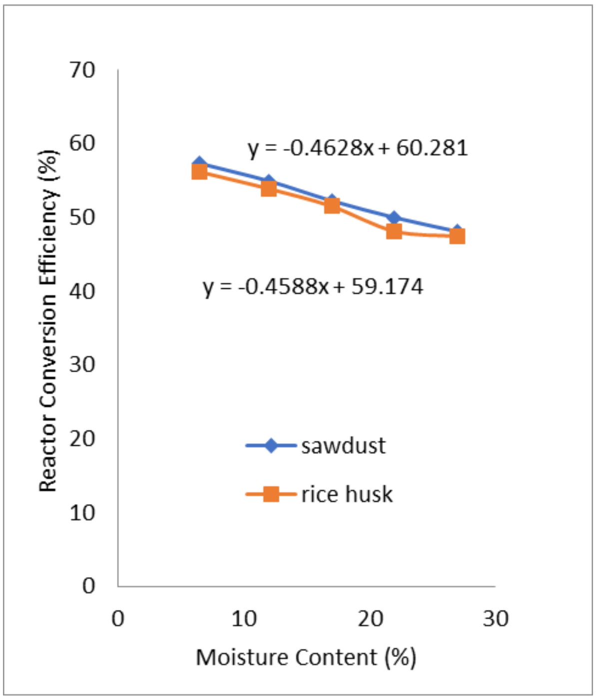


Figure 7. Effect of Moisture Content on Reactor Conversion Efficiency for Sawdust and Rice husks

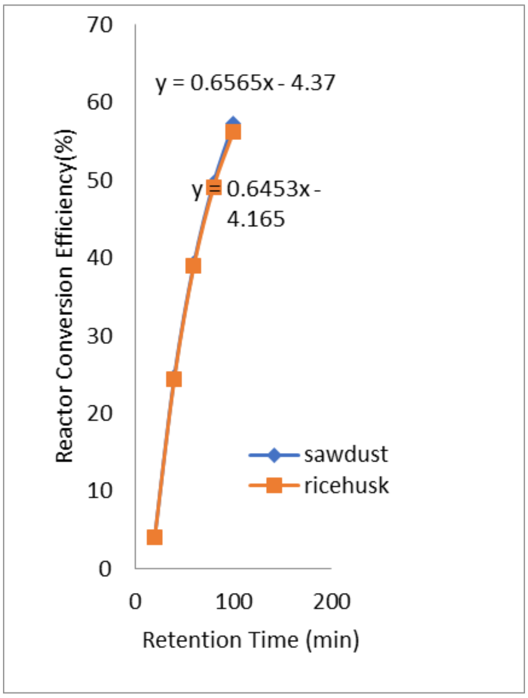


Figure 8. Effect of Retention Time on Reactor Conversion Efficiency for Sawdust and Rice husks

3.4 Gas Analysis and Heating Value

Table 2 shows the results of the pyrolytic gas analysis. it was observed that sawdust at 6.5 % moisture content (db) had the highest percentage of methane gas (CH_4) of 60.60 % per volume and calculated lower heating value of 26.380 MJ/Nm^3 meanwhile sawdust at 12% moisture content (db) had 57.30 % per volume of methane gas (CH_4) and 25.546 MJ/Nm^3 lower heating value. Also, as the moisture content increased, it was observed that hydrogen gas (H_2) percentage per volume increased and methane gas (CH_4) percentage per volume reduced. This is in similar trend with Akinola (2016) who reported that further increase of moisture content is effective for stimulating hydrogen gas (H_2) production, resulting in quality of gas degradation and decline in energy conversion efficiency. At 12 % moisture content (db), sawdust and rice husks had lower heating value of 25.546 MJ/Nm^3 and 24.688 MJ/Nm^3 respectively. The difference in their heating value could be as a result of more methane gas (CH_4) present in sawdust. Tasma and Panait (2012) also worked on sunflower husk and obtained between 6.7 MJ/Nm^3 and 9.8 MJ/Nm^3 as heating values range of the sunflower husk.

Table 2. Results of sawdust and rice husks pyrolytic gas analysis

Gas	6.5 % Moisture content (db) of sawdust	12 % Moisture content (db) of sawdust	12 % Moisture content (db) of rice husks
CH_4 (% by volume)	60.60 ± 0.02	57.30 ± 0.03	54.34 ± 0.07
H_2 (% by volume)	30.71 ± 0.04	34.89 ± 0.10	37.80 ± 0.02
CO (% by volume)	3.47 ± 0.02	2.90 ± 0.05	2.25 ± 0.06
Others gas (% by volume)	5.22 ± 0.10	4.91 ± 0.14	5.61 ± 0.12

4. CONCLUSIONS

A biomass pyrolyser was designed, constructed and tested. Its main components were a reactor, furnace and moisture removal cylinder. It was observed that total gas yield, rate of gas yield and reactor conversion efficiency reduced as moisture content of both sawdust and rice husks increased. However, total gas yield, rate of gas yield and reactor conversion efficiency increased as retention time increased. The results obtained from the performance analysis was that 2 kg of sawdust produced 1146 g of pyrolytic gas at 0.191 g/sec when reactor conversion efficiency was 57.3 %. In the same vein, 2 kg of rice husks yielded 1124 g of pyrolytic gas at 0.187 g/sec and at reactor conversion efficiency of 56.2%. The by-product of the pyrolysis process is biochar which is also a good source of energy. Biomass pyrolyser could be used to convert biomass wastes quickly and cheaply into useful gas for various domestic uses. It is climatic condition independent and could be available all year round.

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