Effect of the Temperature on the product yield during the Pyrolysis of Guinea-Corn stalk

Abstract

This study explain the effect of temperature on the product yield of guinea-corn stalk (Char, tar and Gas). Approximately 0.23kg dried Guinea Corn Stalk (GCS) was introduced into the retort in which the retort was rendered airtight. The retort was placed into the chamber of an electric furnace and the GCS was pyrolysed at a temperature of 400^{O}C at a constant time of 20minutes. This was repeated for temperatures 450,500,550 and 600^{O}C and in each cases, the quantities of char, tar and the bio-gas were determined. Proximate and ultimate analysis were carried out on the sample in other to know the level of moisture content in the sample and also to know if GCS has more contribution to global warming by observing the percentage of the Sulphur and Nitrogen content in the ultimate analysis.

Using the sigma plot application as well as the Microsoft excel bar chart to illustrate the relationship between the temperature and the pyrolysis product. This application depict and shown how the increase in temperature affect the product yield (Gas, Tar and Char). The Char yields a percentage of approximately 17% at 400^{O}C and drastically decreased to 27% at 600^{O}C, the tar yields a percentage of approximately 28% at 400^{O}C and increased to 39% at 600^{O}C and also the gas yields a percentage of approximately 17% at 400^{O}C and increased to 34% at 600^{O}C.

The result shown that GCS can be pyrolyzed at and high temperature to obtaining more yields of bio-gas.

Keywords: Pyrolysis, Guinea-corn stalk, Bio fuels, Gas, Tar, Char and proximate and ultimate analysis.

1.0 INTRODUCTION

An increment in the numbers of the world industrialization and motorization has led to a steep rise for the demand of petroleum-based fuels. Today fossil fuels take up 80% of the primary energy consumed in the world, of which 58% alone is consumed by the transport sector (Nigam S.W, 2008). The high cost of this energy and it environmental impacts has placed enormous stresses on the developing world. The use of fossil fuels (non-renewable) is increasingly problematic from both an economic and environmental point of view. It has been necessary to identify compatible relief strategies to avoid the exhaustion of fossil fuels and minimize the excess of CO_2 emissions related to energy production (Ribeiro et al., 2007). As a result of the fast rising depletion of fossil fuel, different countries are working on an eco-friendly, alternative and renewable means of generating fuel which includes solar, wind, hydroelectricity, geothermal and energy from biomass (biofuel).

Biomass is a promising eco-friendly alternative source of renewable energy in the context of current energy scenarios. It's a fuel that derived directly or indirectly from biological materials (i.e. from living or dead organisms), they are the sources of all biofuels and plays an important role in diversifying the global sources of energy. Also it is recognized as a green and alternative renewable biofuel. It uses most especially agricultural residue products such as guinea corn stalk, maize stalk, rice husk and so-on to generate energy (Lam et al., 2010).

Although biomass is complex in nature, biomass contains a small amount of sulphur, nitrogen and ash. Therefore, combustion of bio-fuel produces less harmful gas emissions such as nitrogen oxides (NO_x), sulphur dioxide (SO_2) and soot compared to conventional fossil fuels(Okekunle, *et al*., 2018). In addition, zero or negative carbon dioxide (CO_2) emission is possible from biomass fuel combustion because released CO_2 from the combustion of bio-oil can be recycled into the plant by photosynthesis (Mohammad et al., 2010).

In the conversion of biomass to bioenergy, several processes can be used which include: chemical, biological and thermal processes. Chemical processes involve the trans-esterification of oil to produce biodiesel, Biological method involves the use of fermentation (bacterial, algae and fungal) while thermal conversion processes include direct combustion, gasification and pyrolysis. Out of all these processes, pyrolysis produces energy fuels with high fuel-to-feed ratios, making it probably the most efficient process for biomass conversion and the method most capable of competing and eventually replacing non-renewable fossil fuel resources (Demirbas, 2006).

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. The word is derived from the Greek words “pyro” meaning fire and “lysis” meaning decomposition or breaking down into constituent parts (Mohammad et al., 2010).

Distribution of pyrolysis products depends on such operating conditions as type of feedstock, reaction time, pyrolysis temperature and sweep gas flow rate and also higher temperature, smaller particle size, and increased heating rate resulted in decreased char yield from pyrolysis of agricultural residues (Itabiyi and Lucas, 2013). To obtain high liquid yield, the pyrolysis conditions require high heating rate, moderate temperature (450-550^{O}C) and short vapor residence time (Mohan *et al*., 2006). Higher proportion of gas product is obtained from applying high temperature, low heating rate and long residence time, while slow heating at lower temperatures and long vapor residence time favor the formation of char product (Mohan *et al*., 2006; Nugranad, 1997; Onay and Koçkar, 2003).

Itabiyi, et al. (2011) revealed that that for particle sizes lesser than 2.03 mm, gas and char yields increases but resulting to a decrement in liquid yield were obtained as the particle size was decreased. Their study suggested that it is likely that the smaller size of biomass particles could affect greater heat transfer because of less temperature inside the particle, thus giving higher yields of released gases and volatiles. The investigation of this work was done, to study the effect of pyrolysis temperature on the product yields during the pyrolysis of Guinea-corn stalk.

2.0 Methodology

2.1 Guinea-corn stalk preparation for experiment

The Guinea-corn stalk (GCS) used for pyrolysis experiment in this study, was procured from isale oyo area, oyo state of Nigeria. The large quantity of the residues causes environmental pollution, thus, it is needed to be removed. The process of cleaning the residues was done so as to remove the unwanted particle or dirt from the sample procured.

The weight of the sample (W1) was measured using Ohaus top loading digital weighing scale of sensitivity ± 0.001 g (Model: PA4102, range: 0-4100g, Ohaus company, Manufactured in Switzerland) and then oven-dried at a temperature of 105^{O}C until constant weight (W_2) was obtained in accordance with official methods of the ASTM D5373-02 (2005).

The proximate and ultimate analysis of the Guinea-corn stalk were experimentally carried out to ascertain if the Guinea-corn stalk were suitable for the thermo-chemical conversion process.

The moisture content of the GCS was determined after sun drying 95% of the GCS for almost 23days until the weight of the GCS remain constant. For reasonable pyrolysis performance, moisture content of less than 7% is recommended (bridgwater et al, 2001).

2.2 Experimental Procedure

The experiments on pyrolysis were carried out to determine the effect of temperature on the product yield of GCS. 223grams of dried CGS were introduced into the retort and then covered, tightened with a gasket incorporated to prevent gas leakage. The retort was placed inside the electric furnace and pyrolysed by varying the temperature from 400^{O}C to 600^{O}C at 50^{O}c interval with a constant resident time of 20minutes. The retort was connected through a galvanized pipe to the condensate receiver which was placed inside an ice-cooling unit to aids the vapour condensation of the pyrolysis product from the retort. The condensate receiver was connected to the gas collection unit through rubber hose and tightened at both ends with clips. The gas collection unit has one inlet pipe which the impure gases from the condensate receiver flows in through and two outlet pipes. The water inside the gas collection unit is to filter the impure gases and the pressure of the gases displace some quantity of water through one of the outlet pipes. The filtered gases will then be tapped from the other outlet pipe into the gas cylinder.

The weight of the char from the retort and the weight of the tar in the condensate receiver were determine using the ohaus top loading weighing balance and the gas weight was determine through subtraction as well as using water displacing method from the cylinder.

2.3 Product Yield

Product yield is the ratio of the product weight to the sample weight in percentage and were determined for the products separately by weighing each product of pyrolysis sample.

2.4 Char Yield

The weight of the char W_{char}, and the weight of the sample W_s were determined according to the relations given above. Then the char yield was determined accordingly to relation:

$$\text{Char} = \frac{Wchar}{Ws} \text{x } 100 \quad (2.1)$$

2.5 Tar Yield

The determination of tar yield was done using the values of tar weight W_{tar} and sample W_s gotten above. Tar yield is then given as:

$$\text{Tar} = \frac{Wtar}{Ws} \text{x } 100 \quad (2.2)$$

2.6 Gas Yield

Gas yield was determined with the known weight of the gas and the weight of the sample as it is given in the relation as:

$$\text{Gas} = \frac{Wgas}{Ws} \text{x } 100 \quad (2.3)$$

3.0 RESULTS AND DISCUSSION

3.1 Proximate and Ultimate Analyses

As shown on Table 3.1, the proximate analysis of 2grams of the GCS sample by weight, 2.75cm diameter and 5.5cm by length was analyzed experimentally in which 14.58% of fixed carbon, 61.56% of volatile matter, 3.21% of ash content as well as 12.04% of moisture content were obtained. The ultimate analysis of the same weight, length and diameter of GCS was analyzed in which 52.67% of carbon, 5.76% of hydrogen, 42.17% of oxygen, 0.58% of nitrogen and 0.04% of Sulphur were obtained according to ASTM 3174-76.

Due to low percentage of Sulphur and nitrogen shows that the pyrolysis of guinea-corn stalk has little or no contribution to the global warming. According to ASTM 3174-76, the heating value of the guinea-corn stalk was 19.95kJ/g. while that of pyrolysis products used calculating the energy yield on average basis are as follows:

Char = 27.5 MJ/Kg; Tar = 16 MJ/Kg; Syngas = 20.44MJ/Kg (Jones et al, 2009).

Table 3.1: shows the result of the Proximate and Ultimate Analysis of the GCS

PROXIMATE ANALYSIS	**Fixed Carbon** 14.58%	**Volatile Matter** 61.56%	**Ash Content** 3.21%	**Moisture Content** 12.04%	
ULTIMATE ANALYSIS	**Carbon** 52.67%	**Hydrogen** 5.76%	**Oxygen** 42.17	**Nitrogen** 0.58%	**Sulphur** 0.04%

3.2 Results of Pyrolysis Products

The following results were obtained during the process after the weight of 223grams of GCS was introduced into the retort at a temperature of 400 ^{O}C at a constant time of 20mins to produce 123.45 g of char, 62.45 g of tar and 37.10 g of gas.

At a temperature of 450 ^{O}C the weight of char reduced to 92.86 g and that of the tar increased to 76.50 g and the weight of the d gas increased to 53.64 g.

At a temperature of 500 ^{O}C, the char had drastically decreased to 75.26 g, the weight of the tar increased to 81.52 g and the weight of the gas increased to 66.22 g at the same duration of 20mins.

At a temperature of 550 ^{O}C, the char decreased to 65.91 g, the weight of the tar increased to 87.28 g and the weight of the gas increased to 69.81g at the same duration of 20mins. At a temperature of 600 ^{O}C, the char had slightly decreased to 60.43 g, the weight of the tar decreased slightly to 86.17 g and the weight of the gas increased to 76.40 g at the same duration of 20mins as shown in Table 3.2 below.

The bar chart in Figure 3.1 shows the relationship among the pyrolysis products in which at 400^{0}C, char possess the highest bar with the gas having the lowest bar. At a temperature of 600^{0}C, the tar possess the highest bar with the char having the lowest bar which illustrate that as the temperature increases the char weight decreases, tar weight and the gas weight increases.

Table 3.2: Result of the Pyrolysis of GCS within Temperature ranges of 400^0C to $600\ ^0C$.

Trials	Initial Wt (g)	Final Wt (g)	Temperature (^0C)	Char (g)	Tar (g)	biogas (g)
1.	250	223	400	123.45	62.45	37.10
2.	250	223	450	92.86	76.50	53.64
3.	250	223	500	75.26	81.52	66.22
4.	250	223	550	65.91	87.28	69.81
5.	250	223	600	60.43	86.17	76.40

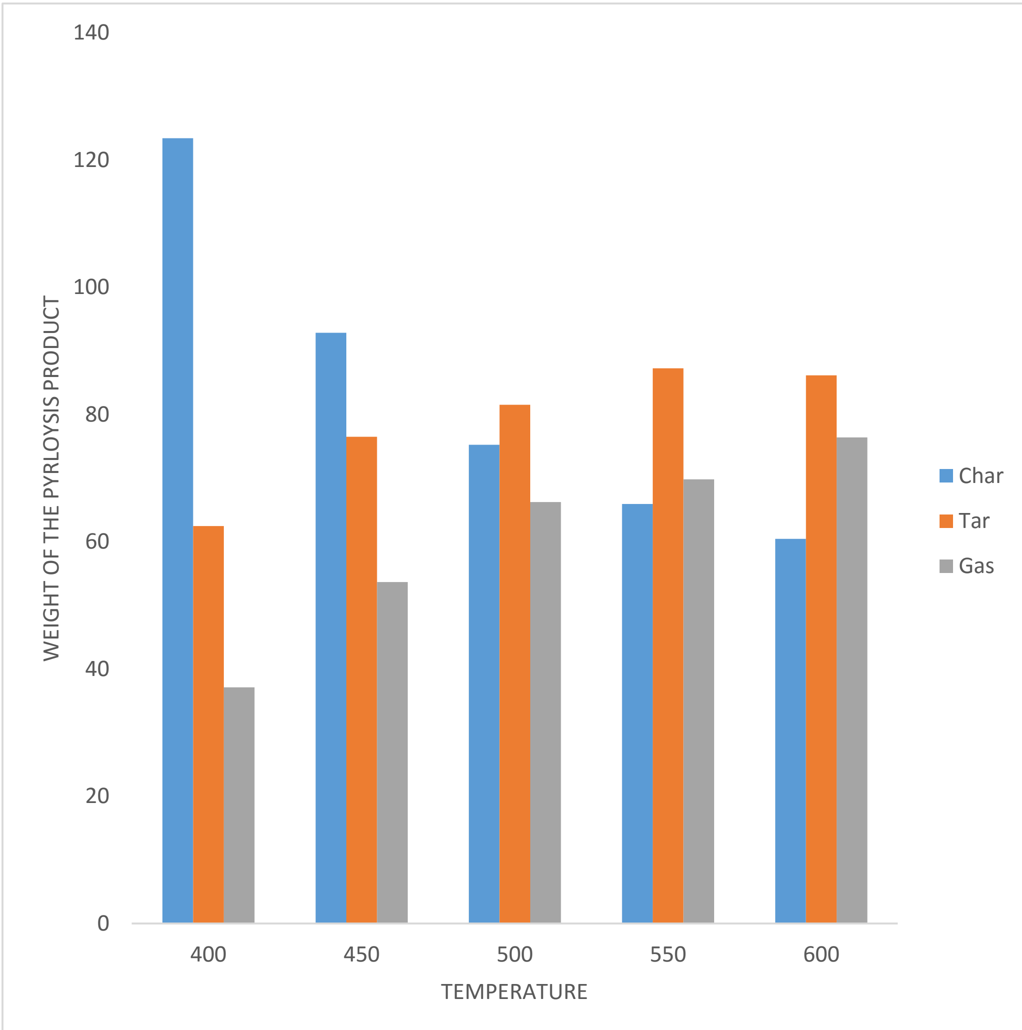

Figure 3.1: Shows the relationship between temperature and the pyrolysis product using bar chart.

3.3 Result of the Product Yields

The Pyrolysis product include the char, tar and syngas

3.4 Bio-Char

From Table 3.4, the result shows that at 400^{0}C, the weight of the char was 123.45grams which represent 55.36% of the char yield. Between the pyrolysis temperature of 550 and 600 ^{0}C, there were no further steady decrease in the char yield i.e. 29.56% and 27.10% which indicates the region where formation of ash begins as shown in Figure3.2. At approximately 650^{0}C, there is a mixture of char and ash.

It was observed that the quantity of char produced decreases with increase in pyrolysis temperature. This shows how the weight of the residue reduces as the volatile matter (tar and gas) were produced. However, at temperature above 600^{0}C, there were no further increase in the production of volatiles which symbolizes the end of the pyrolysis process.

Table 3.3: Result of char yield between temperature ranges of 400^0C and 600^0C.

Trials	Dried Sample (g)	Temperature (^0C)	Char Weight (g)	Char Yield (%)
1.	223	400	123.45	55.36
2.	223	450	92.86	41.64
3.	223	500	75.26	33.75
4.	223	550	65.91	29.56
5.	223	600	60.43	27.10

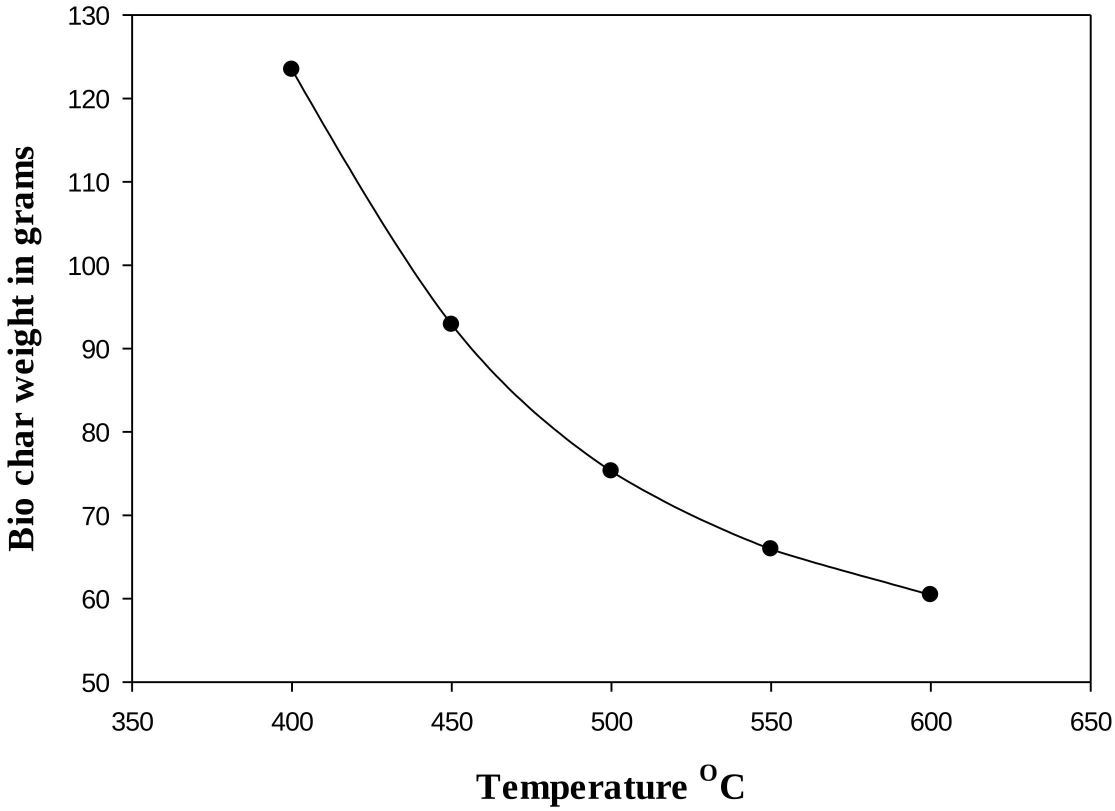

Figure 3.2: Shows the relationship between temperature and the bio-char weight.

3.5 Tar Yield

Table 3.4 shows that 62.45 g which represent just 28.00 % of the product yield at 400^0C (Fig. 3.3) was obtained. The quantity of the tar produced is low compare to other products and the maximum yield is approximately 38.64% which may only be affected by the moisture content present in the sample. Figure 3.3 shows how the weight of the tar increases as the pyrolysis temperature increases.

The quantity of the tar produced during the pyrolysis increases with increase in pyrolysis temperature until when the guinea-corn stalk fully pyrolysed. The tar is the composition of the condensable gases and water present in residue as moisture initially.

Table 3.4: Result of tar yield between temperature ranges of 400^0C and 600^0C.

Trials	Weight of dried Sample (g)	Temperature (^{0}C)	Tar Weight (g)	Tar Yield (%)
1.	223	400	62.45	28.00
2.	223	450	76.50	34.30
3.	223	500	81.52	36.56
4.	223	550	87.28	39.14
5.	223	600	86.17	38.64

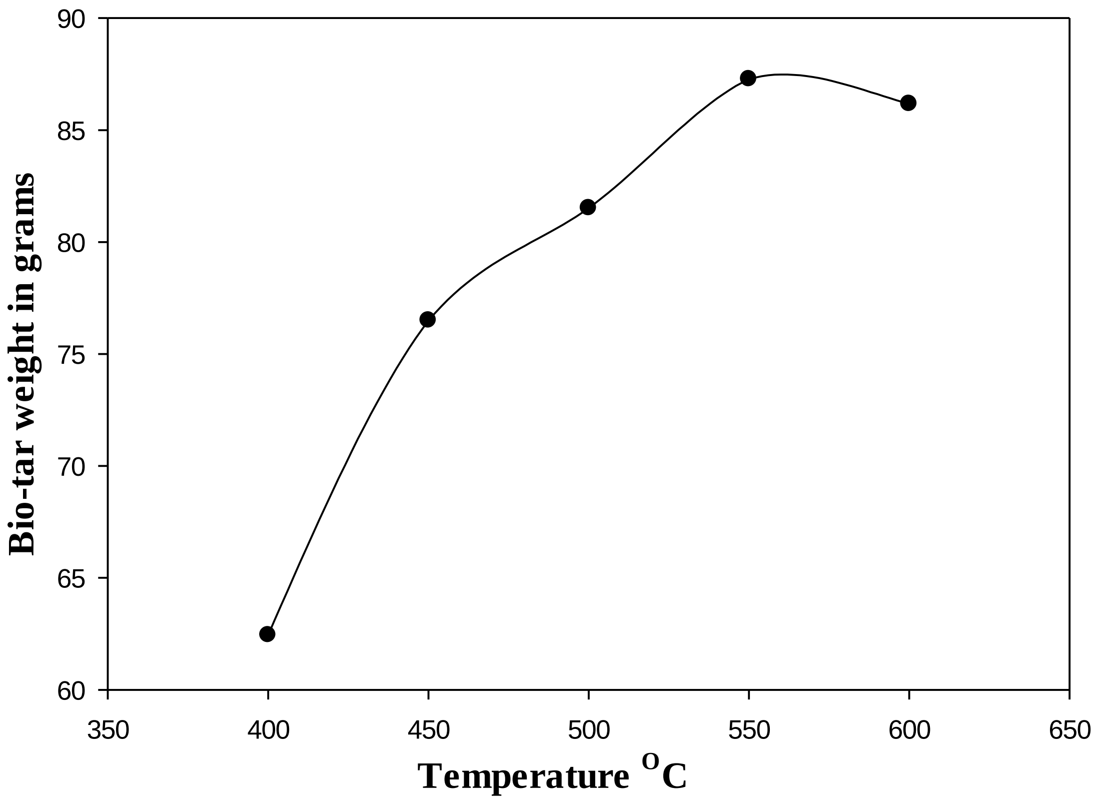

Figure3.3: Shows the relationship between temperature and the bio-tar weight.

3.6 Biogas

Table 3.5 shows how the quantity of biogas produced increases with increase in pyrolysis temperature. At 400^0C, 37.10grams which represent 16.64% yield of the products were produced. In-between 550^0C and 600^0C, yield of about 31.30% to 34.26% of the product was achieved as shown in figure 3.4.

Figure 3.4 Explained how the product yield of biogas increases with the increase in Pyrolysis temperature. At higher temperature, pyrolysis process ends before 20 minutes as no further pressure is built inside the condensate receiver.

The biogas is the combination of gases which include methane, carbon-monoxide, hydrogen and carbon-dioxide. The weight of biogas increase as the pyrolysis temperature increases. They were firstly separated from the vaporized mixture at a very low temperature from condensate receiver and collected over water.

Table 3.5: Result of gas yield between temperature ranges of 400^0C and 600^0C

Trials	Dried Sample	Temperature	Biogas	Biogas Yield
	(g)	(^0C)	(g)	(%)
1.	223	400	37.10	16.64
2.	223	450	53.64	24.06
3.	223	500	66.22	29.69
4.	223	550	69.81	31.30
5.	223	600	76.40	34.26

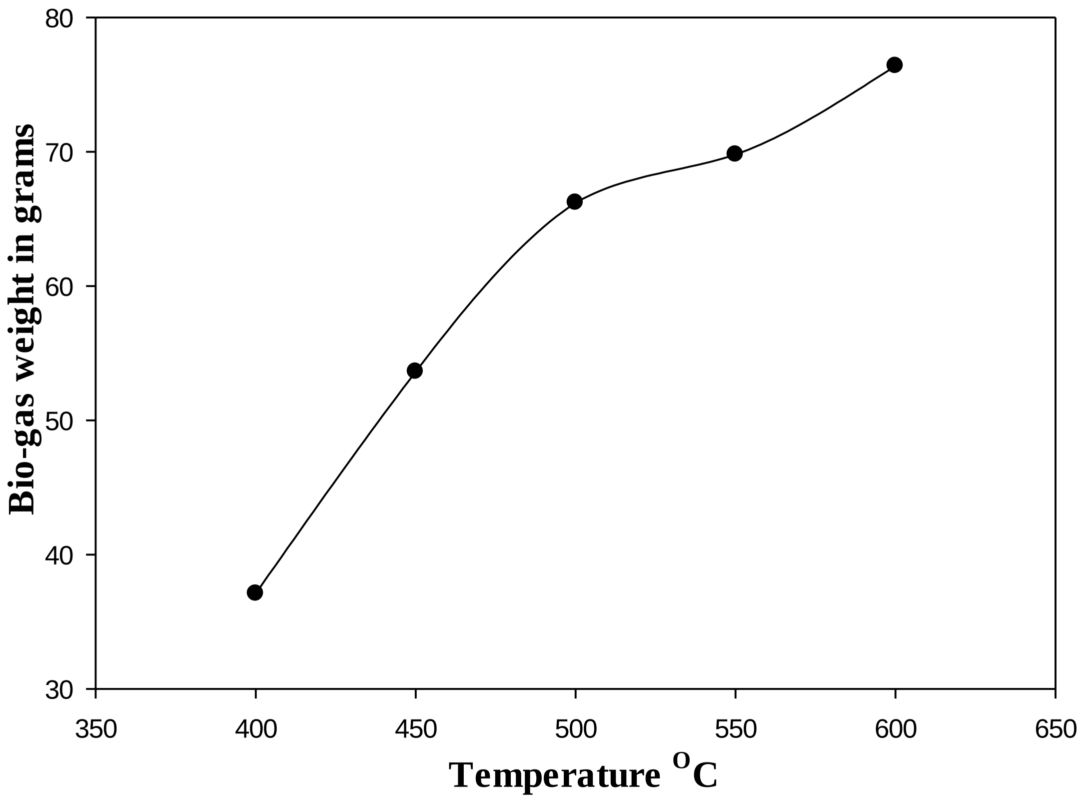

Figure3.4: Shows the relationship between temperature and the bio-gas weight.

Table 3.6: Comparison of Products Yield with Pyrolysis Temperature

Trials	Temperature (^0C)	Char Yield (%)	Tar Yield (%)	Syngas Yield (%)
1.	400	55.26	28.00	16.64
2.	450	41.64	34.30	24.06
3.	500	33.75	36.56	29.69
4.	550	29.56	39.14	31.30
5	600	27.10	38.64	34.26
Average Yield		31.86	37.19	30.49

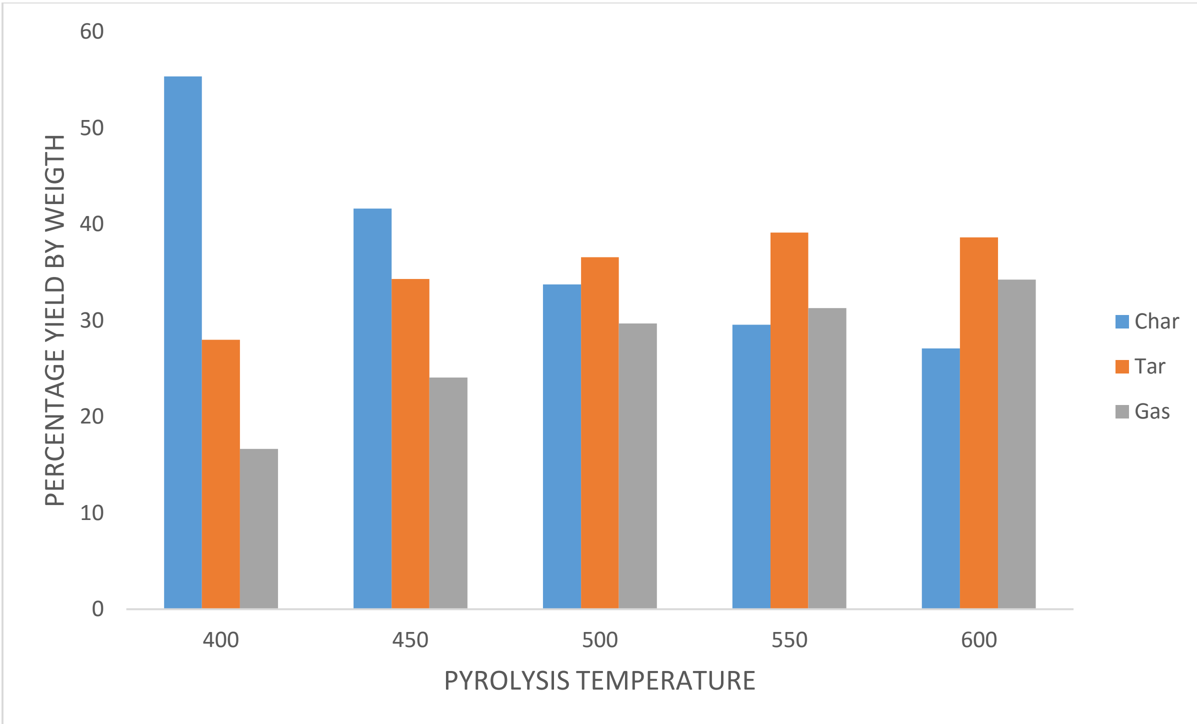

Figure 3.5: Shows the relationship between temperature and the pyrolysis product yield using bar chart.

4.0 **Conclusion**

This study shown that GCS can be used to produce pyrolysis products (char, tar and gas) at variable temperature. Generally, as the pyrolysis temperature increases the bio-char decreases and vice-versa. It's also observed that the bio –tar increases as the temperature increases but once the temperature reaches 550^{O}C, the bio-tar decreases and also, the amount of the gas increases at a high temperature.

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