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PYROLYSIS OF LOCALLY SOURCED SCRAP TYRES FOR THE PRODUCTION OF CHAR

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ABSTRACT

With respect to the environmental problems and health hazards caused by countless scrap tyre piles around Nigerian cities, pyrolysis of scrap tyre was carried out to examine its potential as a viable source of energy. A thermo chemical reactor furnace of 17.4 litres capacity was designed with temperature specification of 1,200^{o}C at a pressure of 2.3 MN/m^{2}. Scrap tyres from light duty vehicles were processed by washing them in water to remove dirt, cut into sample sizes of 20 mm x 30 mm and then weighed in various portions of 1 kg each. 1 kg mass of the processed scrap tyres was pyrolysed in each batch of pyrolysis experiment to obtain char at different pyrolysis temperatures of 250^{o}C, 350^{o}C, 450^{o}C, and 600^{o}C. Proximate and ultimate analyses of the char resulting from the pyrolysis were carried out. The pyrolysis process produced char with average composition of 83.30% carbon, 5.45% hydrogen, 0.52% nitrogen, 1.17% sulphur and 1.90% oxygen. The analysis of percentage composition of the raw scrap tyre samples gave 79.86% for carbon, 7.35% hydrogen, 0.39% nitrogen, 1.57% for sulphur and 6.50% for oxygen. The 79.86% carbon which is primarily made of char indicated that the adoption of pyrolysis for processing of scrap tires can contribute immensely to the production of char which can further be processed into activated carbon, compressed into charcoal briquettes, used as soil amendment etc.

Keywords: *Pyrolysis, char, scrap tyre, temperature, furnace, elemental analysis.*

INTRODUCTION

The world is turning towards renewable energy as an alternative source of energy sequel to the gradual depletion of non-renewable energy sources. Therefore, it is necessary to diversify into the available renewable energy resources in other to avoid the prevalent energy crisis in Nigeria and the world at large. Unlike other energy sources, fuel derived from waste materials (bio-fuel) is sulphur-free and biodegradable (Aziz *et al.*, 2005). Cheah (2004) highlighted the major advantage bio-fuel has over fossil fuel, since it is derived from renewable sources, to include clean burning as well as little or no contribution to the increase of carbon monoxide in the atmosphere. The carbon monoxide is an essential factor to be considered in any environmentally inclined researches because of its effects on ozone depletion and climate change which the entire world is working towards minimizing (Sivasakthivel and Reddy, 2010). Aziz *et al.* (2005) also noted that the oxygen content in bio-fuel can help improve its combustion efficiency, thus, fewer greenhouse gases such as carbon monoxide are released into the atmosphere. The approach of reducing, re-using, recycling and recovery of solid wastes is still not a common practice in some third world countries where used tyres constitutes a major part of the wastes materials disposed in the environment (Hopewell *et al.*, 2009). The generation and disposal of tyre wastes from human activities is becoming an increasing environmental problem in recent times, particularly in developing countries. It is estimated that 259 million tyres are disposed annually in Nigeria due to wear or severe damage such as puncture (Foraminifera, 2013).Car tyres which are produced from polymerisation process are non-biodegradable because of its complex mixture of very different materials, which include rubbers, carbon black, steel cord and other inorganic compounds (Islam *et al*, 2008; Muzenda, 2014). In attempt to reduce the menace caused by the abundance of waste tyre in Nigeria, the application of scrap tyre rubber as additive in asphalt concrete is gradually receiving a growing attention (Oba *et al.*, 2015). However, the non-biodegradable nature of these tyres have led to recycling either by combustion in a furnace or by pyrolysis which is the primary focus in this study. Pyrolysis is a process that involves thermal degradation (occurs at a temperatures between 400°C and 800°C) of organic substances under anaerobic conditions. The primary products obtained from pyrolysis are char, oil and gas which are energy sources that can contribute to the growth and development of any economy (Katarzyna *et al.*, 2017; Nhlanhla and Muzenda, 2014). Williams (2005) noted that the amount of waste tyres throughout the world is estimated to be 1billion tons tyres per year. It is estimated that the world production of tyres in 2007 reached 1.3 billion (Quek and Balasubramanian, 2012). One common way of disposal of car tyres is land filling, but land filling of used tyres needs a large space because the volume of tyres cannot be compacted (Islam *et al.*, 2008). United States Environmental Protection Agency (USEPA) in a report released in 1991, noted that about 242 million of automobile tyres and off-road tyres are discarded in the United States each year. This is approximately equal to one waste tyre per person per year. In the report, about 33.5 million tyres are rethreaded and an estimated 10 million are reused each year as second-hand tyres. It is estimated that 7 percent of the discarded tyres are currently being recycled into new products and 11% are converted to energy. Nearly 78% are being land-filled, stockpiled, or illegally dumped, with the remainder being exported. However, this is largely almost the case is every developing countries resulting in a larger chunk of the scrap tyres being stockpiled, land-filled or illegally dumped (EPA, 2010). Due to the environmental problems and health hazards caused by countless scrap tyre piles around the globe, most industrialized countries have instigated legal guidelines addressing this issue (Kurt, 2008). The legal guidelines which are stringent in some cases are all geared towards finding a better alternative to land filling and stockpiling of scrap tyres. However, recycling of solid wastes to useful end products is a sustainable and reliable approach for solving such environmental and energy need. Different recycling processes are being used such as reclaiming, incineration, rethreading, grinding etc. but these different recycling processes have some drawbacks (Rodriguez *et al*., 2001). However, most third world countries such as Nigeria, India, Ghana, Brazil etc. are not left out in its share of the global menace of indiscriminate disposal of solid waste. These countries are littered with a host of scrap tyres. Used tyres constitute a major part of such wastes which must be recycled in order to create a clean and healthy environment for habitation. The aim of this paper is to pyrolyse locally sourced scrap tyres for char production.

MATERIALS AND METHODS

Materials

The scrap tyre that were cut into sample sizes of 20 mm × 30 mm manually were weighed into various portions of 1 kg each. A portion of the samples were taken for proximate and ultimate analysis (elemental analysis) to ascertain the chemical content of the sample that has not undergone pyrolysis. 1 kg of the sample was introduced into the heating chamber; the chamber was covered and the covers were tightened and the surfaces secures with asbestos gaskets to prevent leakage of gas from the heating chamber. After ensuring that all the connections are tightly fitted, and that all electrical connections were in place, the thermocouple measuring the temperature in the heating chamber is pre-set to 250^oC. The furnace was then heated via electrical means. The system was monitored at interval and the temperature of the heating chamber in the furnace was recorded from the digital displays of the thermocouples as shown in Plate 1.

Pyrolysis reactor

The pyrolysis process was carried out using an existing batch process, fixed bed reactor. The reactor was designed and tested for pyrolysis using wood by Akinola, (2012). The reactor consist of the following: the furnace, the condensate receiver, the gas collection unit, the condensing unit, water reservoir, the water pump, the flow meter, the control valve and the interconnected pipes.

Furnace

The original design of the furnace by Akinola, (2012) provided for the use of clay as the construction material. The furnace was reinforced with cement to block all leakages. The cohesive nature of Clay and its thermal capacity made it a good material for the construction. Clay has low thermal conductivity and high resistance to heat flow. The clay made furnace is contained in a mild steel compartment which was necessary both as the mould and for support. The inner surface of the furnace was lined with two heating elements. The damaged elements were replaced with new elements of 2,500 watts each to provide heat for the furnace. The temperature in the heating zone (reactor) and that within the furnace were regulated by the help of thermocouples. The thermocouples act as both the thermostat (to regulate the pyrolysing temperature) and the thermometer (to measure the temperature). The temperature within the system can be monitored off the digital screen of the thermocouples as shown in Plate 1. The thermocouples were replaced to improve the performance of the set-up. The furnace has the capacity to contain 5 kg mass of shredded tyre per batch. The Asbestos gasket placed between the lid and the bottom of the reactor was replaced to prevent heat loss and provide a tight fit that will prevent vapour leakage from the retort. A pictorial view of the furnace showing also the thermocouple screens is presented in Plate 1.

Plate 1: Reactor furnace

Condensing unit

The condensing unit consists mainly of the heat exchanger, the water reservoir, the pump and the connecting hoses. The water reservoir is made of cylindrical drums and fitted with an outlet at the base which serves the pump. The heat exchanger is well insulated to increase its effectiveness. As the mixture of condensable and non-condensable gases moves from the heating chamber (the furnace), the heat exchanger receives the hot gases. The heat exchanger is served cold water from a cold water reservoir via a pump. The water is pumped in a direction opposite the flow of the hot gases to produce a counter flow heat exchanger. The hot water resulting from the interaction of the cold water and the hot gases continues back into the water reservoir. To put the pump in useable condition, the rotor shaft was lubricated with grease to ameliorate the stiffened shaft for effective performance. Plate 2 shows the picture of the condensing unit including the support for the heat exchanger which puts it in correct position to receive the hot gases from the heating chamber. Plate 2 shows the picture of the condensing unit including the support for the heat exchanger which puts it in correct position to receive the hot gases from the heating chamber.

Plate 2: Pyrolysis condensing unit

Condensate receiver

The Condensate receiver which is opened on two ends receives the condensed gases from the heat exchanger. The mixture from the heat exchanger consists of non-condensable gases and condensed liquid and another portion which is condensable gas. The remaining portion of condensable gases is expected to be condensed by the ice bath within which the condensate receiver is located. The other open end on top of the condensate receiver delivers the non-condensable gases into the gas collection unit. To enable adequate heat transfer, the condensate receiver was made of rubber for high corrosion resistance.

Methods

Ultimate Analysis

The elemental analysis was carried out to determine the percentage composition of the samples by weight. The values for carbon, Hydrogen, Oxygen and Sulphur was obtained using a Leibig-Pragle Chamber containing magnesium percolate and sodium hydroxide. The determination was done in accordance with the ASTM D5373 standards in the laboratory (Krotz and Giazzi, 2017). The Nitrogen content was determined using the Kjedahl method (Blamire, 2003).

Proximate Analysis

All the samples collected (both pyrolysed samples and raw sample) were tested for: volatile matter, ash content, moisture content and fixed carbon content. The determination of volatile matter, ash content, moisture content and fixed carbon content was done according to ASTM D5373 standards in the laboratory (Krotz and Giazzi, 2017).

RESULTS AND DISCUSSIONS

The results obtained from this study include; result of the proximate analysis of raw scrap tyre samples, result of the Ultimate analysis of raw scrap tyre samples, pyrolysis of scrap tyre samples for 30 mins at temperature range of 250°C to 600°C, Char yield in % from the pyrolysis of scrap tyre samples for 30 mins at temperature range of 250°C to 600°C, Effect of Temperature on Char Yield from the Pyrolysis of Scrap Tyres.

Analysis of Tyre Samples

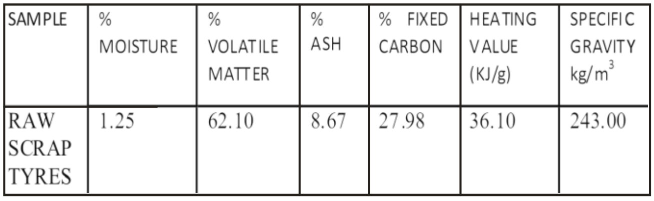
The raw tyre samples to be subjected to pyrolysis were taken into the laboratory for chemical analysis. This was necessary to help study the composition of the scrap tyre after pyrolysis process.

Table 1: Result of the ultimate analysis of raw scrap tyre samples

Element	% C	% H	% N	% S	% O
Raw scrap tyre	79.86	7.35	0.39	1.57	6.50

The result of the analysis shown in Table 1 reveals that tyres are made primarily of carbon products. This possibly accounts for large amount of carbon monoxides produced during burning of tyres as well as the large amount of heat associated with the burning process. The composition of the samples is consequently likely to have effect on the products of the pyrolysis process.

Table 2: Results of proximate analysis of raw scrap tyre samples



SAMPLE	% MOISTURE	% VOLATILE MATTER	% ASH	% FIXED CARBON	HEATING VALUE (KJ/g)	SPECIFIC GRAVITY kg/m^3
RAW SCRAP TYRES	1.25	62.10	8.67	27.98	36.10	243.00

The result of the analysis shown in Table 2 reveals that tyres are made up primarily of volatile matters. This as well as high amount of fixed carbon increases the fuel properties of scrap tyres and may account for the high amount of heat associated with burning tyres.

Pyrolysis of Scrap Tyres

The pre weighed tyre samples were taken and pyrolysed in batches. Each batch of pyrolysed samples contained 1kg of scrap tyres. The weight of the pyrolysed products of each batch of pyrolysis weighed and presented in Table 3. The result presented in Table 3 showed a very small change in weight at 250°C. The weight reduced rapidly at 350°C after which there was a relatively small reduction in weight.

Table 3: Pyrolysis of scrap tyre samples for 30 mins at temperature range of 250-600°C

Temperature (°C)	Initial weight (g)	Char weight (g)
250	1000	936.00
350	1000	637.00
450	1000	581.50
600	1000	519.00

As the pyrolysis temperature increases, there is a corresponding decrease in the weight of the char produced. There was significant reduction in weight at 350°C compared to the weight of char produced at a temperature of 250°C, this may be a precursor to the advent of devolatisation in the samples. Moreover, this may be further confirmed by the chemical composition of the products obtained from the pyrolysis reaction as shown in Figures 2-5. The amount of gases recorded after each experiment may further make a case for the advent of devolatization in the whole process. The char weight obtained from the process is expressed as a percentage of the weight of tyre samples loaded into the pyrolysis reactor and is presented in Table 4.

Table 4: Char yield from pyrolysis of scrap tyre samples for 30 mins at 250˚C to 600°C

Temperature (˚C)	Initial weight (g)	Char weight (g)	Char yield (%)
250	1000	936.00	93.60
350	1000	637.00	63.70
450	1000	581.50	58.15
600	1000	519.00	51.90

Out of 1000 g of scrap tyre samples, 936 g of char weight was obtained after undergoing pyrolysis at a temperature of 250°C. The change in weight which is about 64 g is smaller as a result of insufficient heat to adequately pyrolyse the scrap samples within 30 minutes pyrolysis time employed in the experiment. Out of 1000 g of scrap tyre samples, 637 g of char weight was obtained after undergoing pyrolysis at a temperature of 350°C. The change in weight which is about 363 g is significant as a result of optimum heat supply to adequately pyrolyse the scrap samples within 30 minutes pyrolysis time employed in the experiment. From pyrolysis temperature of 350°C, slight reduction of 581.50 g and 519 gin terms of char weight were further recorded at pyrolysis temperature of 450°C and 600°C. This indicates that the char weight decreased as the pyrolysis temperature increases, and vice versa (Williams *et al.,* 1990; Zhao *et al.,* 2017). The result in percentages of the char yield and the nature of the graph obtained by plotting percentage yield of char against pyrolysis temperatures indicated that as the pyrolysis temperature increased, the char yield decreases.

The decline in char yield is rapid between 250°C and 350°C and continues till around 400°C where the decrease in char yield takes a somewhat less rapid change. The change in value between these temperatures may signify the onset of cracking of carbon particles. The effect of Temperature on char yield from the pyrolysed Scrap tyres is presented in Figure 1.

As shown in Figure 2-5, it was observed that the present of char in the pyrolysed product is due to the present of carbon black content in the original tyre samples. This is evidence in the char composition which predominantly consist of carbon and other inorganics with exact compositions depending on the pyrolysis conditions (Martinez *et al.,* 2013; Alsaleh and Sattler, 2014).

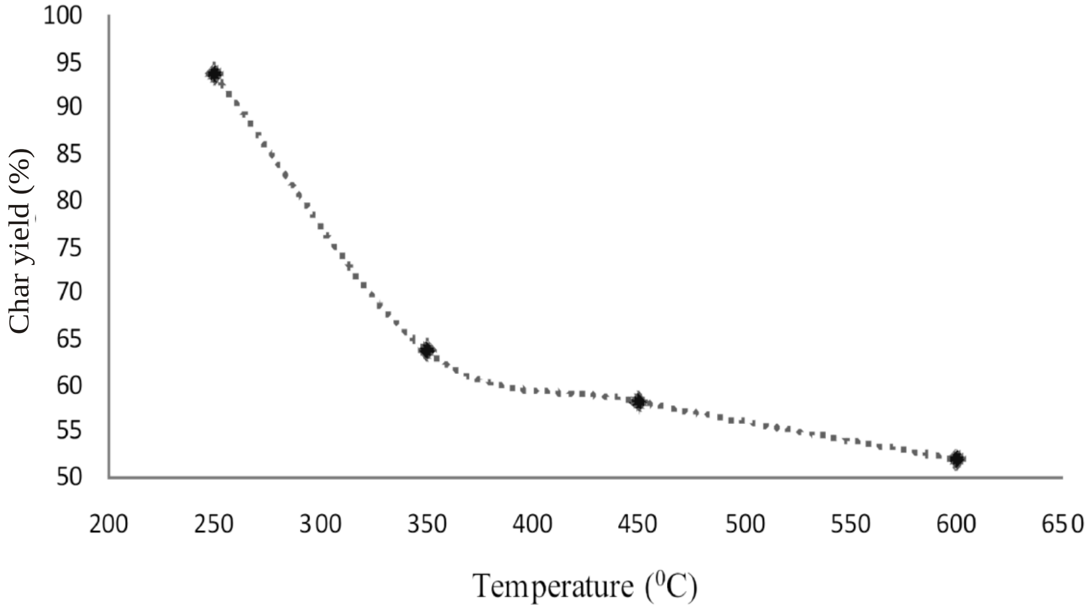


Figure 1: Effect of Temperature on char yield from the pyrolysis of scrap tyres

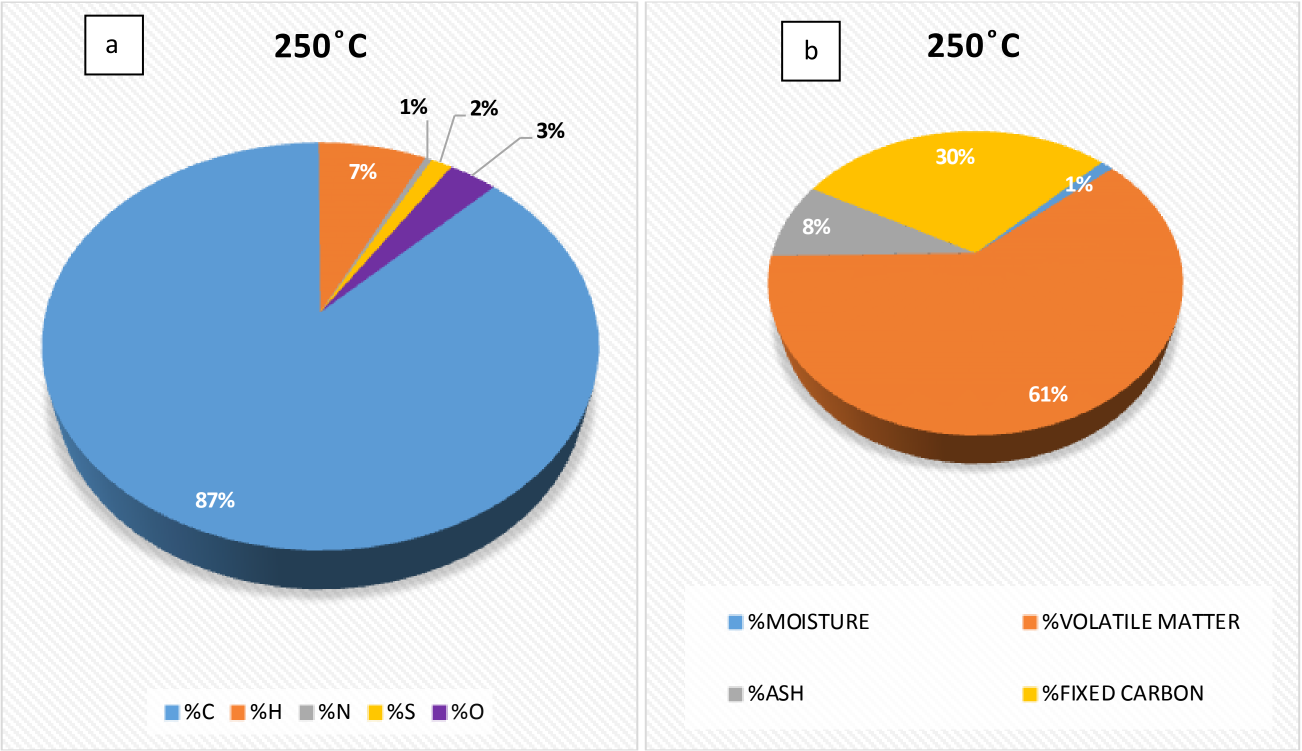


Figure 2: (a) Proximate analysis (b) Proximate analysis of pyrolysed product at 250°C

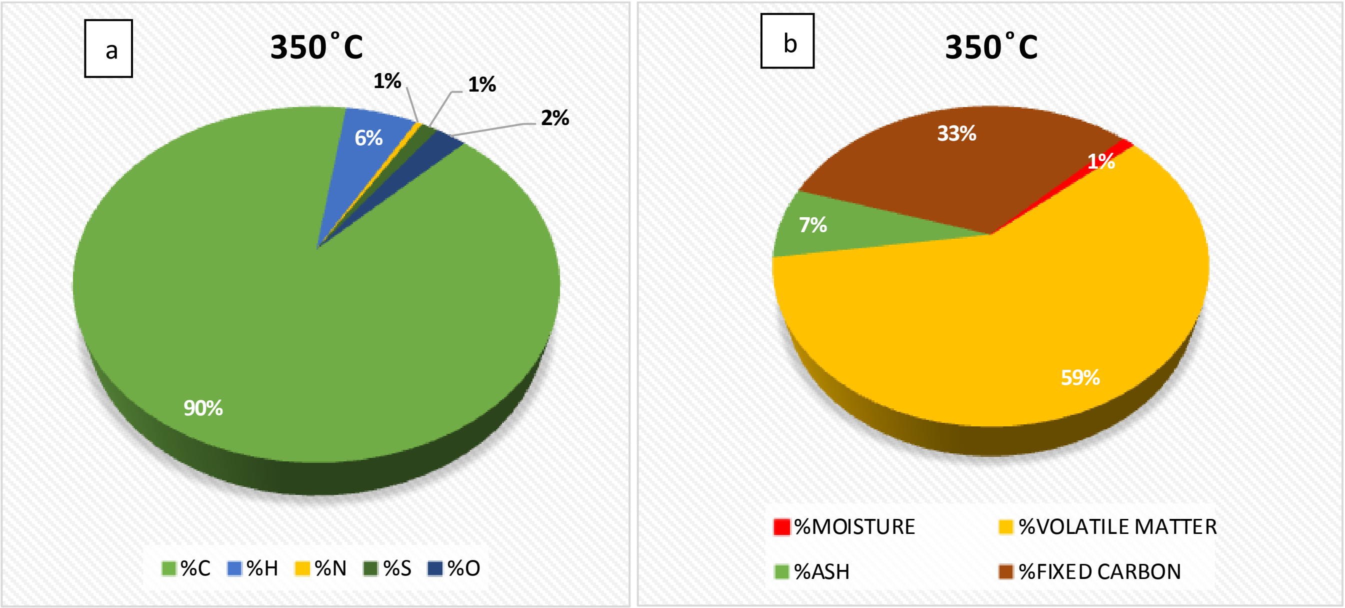


Figure 3: (a) Ultimate analysis (b) Proximate analysis of pyrolysed product at 350°C

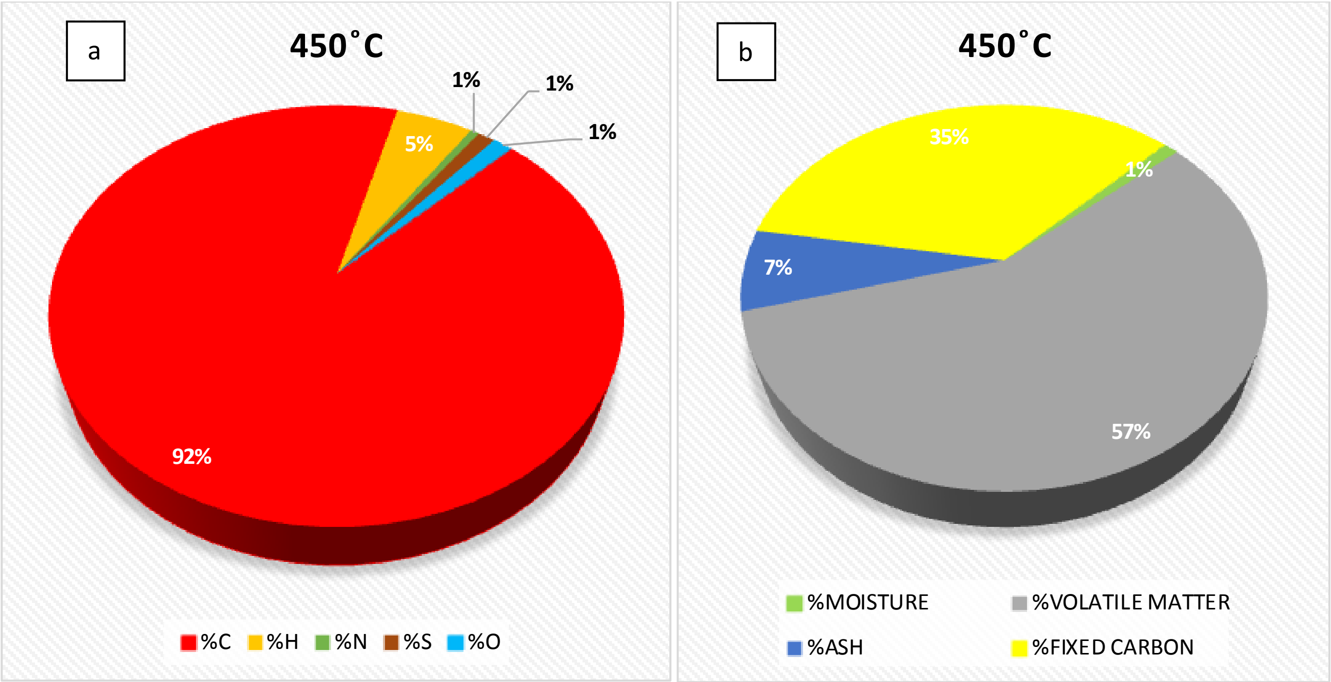


Figure 4: (a) Ultimate analysis (b) Proximate analysis of pyrolysed product at 450°C

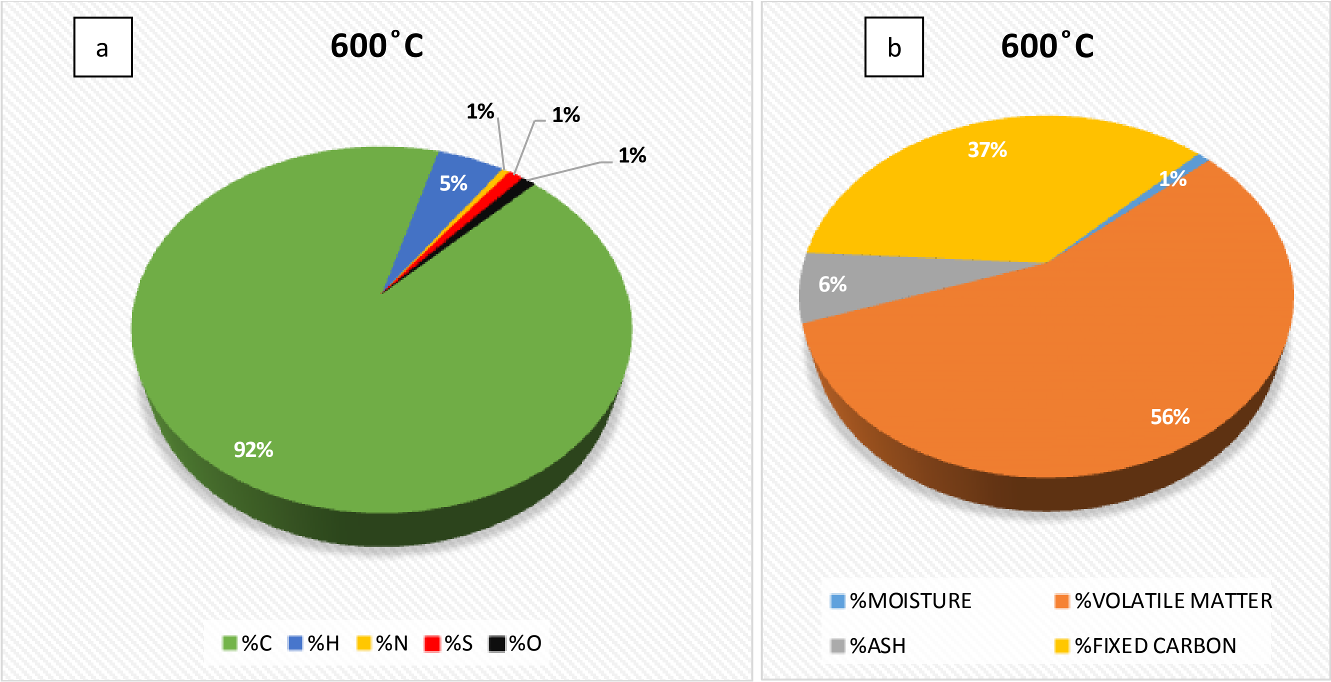


Figure 5: (a) Ultimate analysis (b) Proximate analysis of pyrolysed product at 600°C

Figures 2-5 show the proximate and ultimate analyses of each product at each pyrolysis temperature. The physical and chemical analysis of pyrolysed products helped to evaluate the changes in the composition of the pyrolysed product as temperature increased or decreased. The pyrolysis of scrap tyre samples shows that devolatization of the scrap tyres did not start at temperature of 250°C. This was first made obvious by the amount of weight change in the samples after the first experiment. There was however no characteristic change in the physical properties of the pyrolysed products at 250°C. The pyrolysis result at 250°C. produced solid products similar to the original tyre samples left in the heating/combustion chamber prior to pyrolysis taking place, that is, some parts of the samples had not been affected by the heat in the pyrolysis chamber at all. The weights of each element were presented as a percentage of the total weight of char produced. It was observed that the percentage of carbon in the char increased with increasing pyrolysis temperature.

CONCLUSIONS

A mass of 1 kg of scrap tyres was pyrolysed in each batch of pyrolysis experiment to obtain char at different pyrolysis temperatures. Proximate and ultimate analyses of the char resulting from the pyrolysis were carried out. The pyrolysis process produced char with average composition of 83.30% carbon, 5.45% hydrogen, 0.52% nitrogen, 1.17% sulphur and 1.90% oxygen composition which were obtained from the ultimate analysis. The analysis of percentage composition of the raw scrap tyre samples obtained from ultimate analysis gave 79.86% for carbon, 7.35% hydrogen, 0.39% nitrogen, 1.57% for sulphur and 6.50% for oxygen. There was an increase in carbon content as compared to that of the raw tyre samples. All the remaining compositions reduced with pyrolysis except nitrogen which also experienced an increased percentage composition. The major content of the solid product is however carbon as it has a very high percentage composition in the product after analysis.

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