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Original Research Article

EVALUATION OF THE ENERGY POTENTIAL OF PYROLYSED SCRAP TYRE

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ABSTRACT

This study is focused on the evaluation of energy potentials of scrap tire through the process of pyrolysis. The ultimate analysis of the char resulting from pyrolysis gave an average value of 38.83kJ/g for the heating value and 470.00kg/m^3 for specific gravity. The average fixed carbon content was 33.38% while the volatile matters gave an average of 58.40%. The ultimate analysis of the raw tire samples gave values of 36.10kJ/g for the heating value and 343.00kg/m^3 for specific gravity. Moisture content of 1.09%, volatile matter of 58.40% and ash content of 7.14%, whereas, carbon content of 554.66 g, Hydrogen of content 37.73 g, Nitrogen content 3.38 g and sulphur content of 7.99 g. It was observed that the heating value for char was higher than the heating value of raw tyre. The heating value obtained in this study was small compared to the the energy requirement for operating the furnace. This is because the pyrolysis experimentation was carried out using only 1kg of scrap tyre at different temperatures. The heating value is an indication that pyrolysis of scrap tyre in a large scale would serve as a viable source of energy resource.

1. INTRODUCTION

Pyrolysis is a thermochemical decomposition of organic material at temperatures between 400 °C and 900 °C without the presence of oxygen or other reagents (Goyal et al., 2008; Mohammad et al., 2012) In response to the environmental problems and health hazards caused by countless scrap tyre piles around the globe, most industrialized countries have instigated legal guidelines to address this issue (Mpanyana et al., 2009). In order to counter greenhouse gas emissions, the European Union ratified the Kyoto Protocol and emphasized the potential for scientific innovation in 2002, but unfortunately there has been a failure to meet the desired targets (Mohammad et al., 2012). Kurt (2008) categorized the hazards associated with the indiscriminate disposal and accumulation of large quantities of scrap tire outdoors as high-level, and such activity as high-risk, as this may result in an uncontrolled fire explosion that is detrimental to public health and environment.

In a bid to reduce the hazardous effects of scrap tires on our environment, the amount of solid waste littering our environment and to pursue alternative energy sources, recycling solid waste to useful products becomes a sustainable approach for launching into a cleaner future (Eddie, 2014). There is therefore growing need to bridge the gap in technology between the developed and the developing countries by researching into recycling scrap tire wastes into useful products and implementing the use of both the technique and the products in the Nigerian energy sector.

The production of bio-liquids and other products (char and gas) through pyrolysis of different biomass species has been investigated in the past. Some variety of these biomass include pyrolysis of beech wood in a horizontal cylindrical stainless steel reactor (Demirbas, 2005). Asadullah et al. (2007) investigated the potentials of bio-oil production from fixed bed pyrolysis of bagasse using different temperatures ranging from 300-600ºC. Pyrolysis of olive and hazelnut bagasse biomass samples with two selected catalyst such as activated alumina and sodium feldspar was carried out in a fixed bed reactor (Demiral and Sensoz, 2008). Mohan et al. (2007) investigated the use of bio-char by-products from fast wood/bark pyrolysis as adsorbents for the removal of the toxic metals from water. Aho et al. (2008) carried out a catalytic pyrolysis of biomass from pine wood was carried out in a fluidized bed reactor at a temperature of 450ºC. Pyrolysis of the straw-stalk of rape plant within a tubular reactor under static atmosphere at 650ºC pyrolysis temperature and at 30ºC min^{-1} heating rate was investigated by Karaosmanoglu and Tetik (1999). Catalytic pyrolysis of cotton-seed cake was studied by Putun et al. (2006) under different experimental condition. The three primary products obtained from pyrolysis of biomass are char, permanent gases, and vapors which at ambient temperature condenses to a dark brown viscous liquid. Maximum liquid production occurs at temperatures between 350°C and 500°C (Fahmi et al., 2008).

This study is thus directed towards meeting the energy needs by researching into the energy potential of waste car tires through pyrolysis and analysis to evaluate its usability as an alternative energy resource.

2. MATERIALS AND METHODS

2.1. Materials

The scrap tyres were sourced from different automobile and tyre vulcanizing workshops in Benin City. Other materials used in the study include BOSCH RS325 reciprocating saw, weighing balance, furnace, pyrolysis condensing unit, thermocouple, cylindrical drum, delivery tube and GallenKamp ballistic bomb calorimeter.

2.2. Methods

Using BOSCH RS325 reciprocating saw, the collected scrap tyres were cut into sample sizes of 20 mm x 30 mm and weighed in various portions of 1 kg each. A portion of the samples were taken for proximate and elemental analysis to ascertain the chemical content of the sample. A mass of 1kg of the sample was introduced into the furnace heating chamber and was covered. The cover was tightened and the surfaces secures with asbestos gaskets to prevent leakage of gas from the heating chamber. The heating chamber was well positioned into the furnace and all necessary checks are made on the line. All the other components were well positioned and arranged to allow easy movement and access to the various units of the furnace. The condensate receiver was positioned in an ice bath and the gas receiver was also positioned in the ice bath to provide cooling. The water level in the water reservoir was checked and the temperature in the reservoir was lowered by the aid of ice cubes. The batch reactor used for the pyrolysis of scrap tyre experimentation in this study is schematically shown in Figure 1.

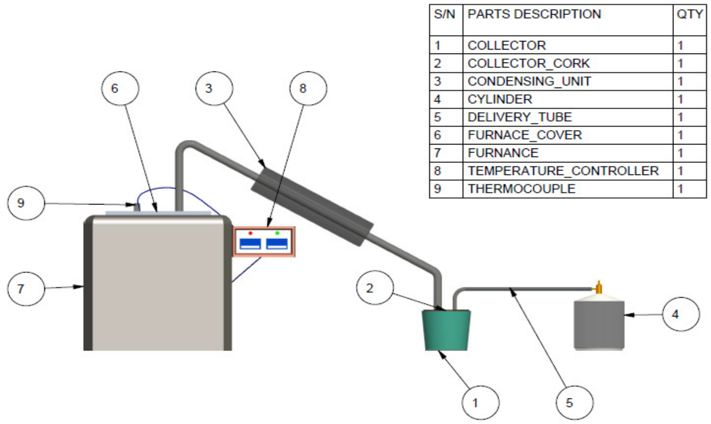

Figure 1: Batch reactor for scrap tyre pyrolysis

The heating chamber placed in the electric furnace was connected to the condensate receiver using copper pipe. After ensuring that all the connections are tightly fitted and all electrical connections were in place, the thermocouple measuring the temperature in the heating chamber was pre-set to 250ºC. The furnace was then heated via electrical means. The system was monitored at interval and the temperature of the heating chamber and the furnace materials were recorded off the digital displays of the thermocouples. As soon as the pre-set temperature was reached, the system was allowed to stay for a retention time of 30 minutes. The system was allowed to cool by itself and the weight of the resulting solid product is taken. The procedure was repeated for temperatures of 350ºC, 450ºC, and 600˚C. At each pyrolysing temperature, the solid residue resulting from the pyrolysis process was recovered from the heating chamber into a weighing pan where it was measured. All the solid product samples collected for each temperature was tested for: volatile matter, ash content, fixed carbon content, heating value, and specific gravity. The ultimate analysis of each sample was also carried out and the heating values determined with the help of a bomb calorimeter.

2.3. Weight Determination

The weight of the sample W_{st} is given by Equation 1.

$$W_{st} = W_{Pst} - W_{pan} \quad (1)$$

Where, the weight of measuring pan is denoted as W_{pan} and the weight of measuring pan together with the scrap tyre sample is denoted as W_{Pst}.

Weight of char W_{char} produced was determined using Equation 2.

$$W_{char} = W_{Pchar} - W_{pan} \quad (2)$$

Where, W_{Pchar} denotes the weight of the char and measured weight of the pan.

The weight of the tar was determined by subtracting the weight of the condensate receiver from the weight obtained as expressed in Equation 3.

$$W_{tar} = W_{ctar} - W_{cr} \quad (3)$$

Where, W_{cr} is the weight of the condensate receiver, W_{ctar} denotes the weight of tar together with the condensate receiver and W_{tar} is the weight of tar produced.

Then weight of gas produced (W_{gp}) can be determined using equation 4 while the actual weight of gas produced (W_{agas}) was determined using Equation 5.

$$W_{gp} = W_{char} + W_{tar} + W_{agas} \quad (4)$$
$$W_{agas} = W_{st} - W_{char} - W_{tar} \quad (5)$$

However, the weight of gas collected (W_{cgas}) is given by Equation 6.

$$W_{cgas} = W_{ggas} - W_{gr} \quad (6)$$

Where W_{gr} is the gas receiver weight and W_{ggas} is the weight of the gas receiver plus collected gas.

2.4. Product Yield

Product yield is the ratio of the weight of product to the sample in percentage and was determined using Equation 7.

$$\bar{Y}_{char} = \frac{W_{char}}{W_{st}} \times 100 \quad (7)$$

2.5. 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).

2.6. 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).

2.7. Percentage Ash Content

A mass of 2 g of sample was introduced into a previously weighed crucible and placed in a muffle furnace set at 900˚C for 6 hours till a white greyish matter was obtained. The percentage of ash was calculated using Equation 8.

$$\%Ash = \frac{M_a - M_o}{M_s} \quad (8)$$

Where, M_a is the mass of the crucible with ash, M_o is the mass of the crucible and M_s is the mass of the sample.

2.8. Moisture Content

A mass of 2 g of sample was introduced into a previously weighed crucible and placed in a Gallen Kamp drying oven at 105˚C. The change in weight was taken at every 6 hours till a constant mass was obtained. The percentage moisture was calculated using Equation 9.

$$\%\ Moisture\ Content = \frac{W_i - W_f}{W_i} \times 100 \quad (9)$$

Where W_i the initial is mass of the sample and W_f is the final constant mass of the sample.

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2.9. Volatile Matter

An amount (2 g) of sample was weighed and introduced into a closed crucible and heated in a GallenKamp muffle furnace set at 600˚C for six minutes and then heated for another six minutes at a temperature of 900˚C. The amount of volatile matter is equal to the loss in weight which is calculated using Equation 10.

$$\%\, Volatile\ Matter = \frac{W_i - W_f}{W_i} \times 100 \tag{10}$$

Where, W_i is the initial mass of the sample and W_f is the final constant mass of the sample.

2.10. Fixed Carbon

Fixed carbon is the solid combustible residue that remained after pyrolysis of the scrap tyre. The amount of fixed carbon was calculated using Equation 11.

$$\%Fixed\ Carbon = 100 - (\%Moisture + \%\ Ash + \%\ Volatile\ Matter) \tag{11}$$

2.11. Heating Value

The gross energy determination was done using GallenKamp Ballistic Bomb Calorimeter as shown in Figure 2.

Figure 2: GallenKamp ballistic bomb calorimeter

The method used is the Energy Determination (AOAC Official Method 2003.09) modified by Wallace et al. (2011)

3. RESULTS AND DISCUSSION

The results of the elemental composition of the pyrolysed product are shown in Table 1. Considering the results detailed by Table 1, there is a reduction in weight of carbon present in the solid product of the pyrolysis experiment as pyrolysing temperature was increased. The rapid change in the weight of carbon between temperatures 250˚C and 350˚C can further corroborate the assertion that devolatisation of the tyre starts at temperatures between these pyrolysing temperatures (Haydary et al 2006). Comparing the results of the raw tyre samples with those of the average obtained after pyrolysis, it can be deduced that hydrogen, oxygen and sulphur were being spent as the process progresses. However, carbon and nitrogen did not react to an appreciable extent throughout the process. This may be due to the absence of excess oxygen which will readily combine with carbon or nitrogen to form oxides. The various weights of the tire samples against the chemical compositions for carbon, hydrogen and oxygen composition for the pyrolysed products are shown in Figures 3, 4 and 5 respectively.

Table 1: Elemental analysis of pyrolysed products by weight at different pyrolysing temperature

Temperature	Weight (g) of pyrolysed tire			
	C	H	N	S
250^{0}C	761.6232	64.0224	4.212	12.5424
350^{0}C	526.7353	33.6973	3.0576	7.7714
450^{0}C	489.0997	28.2609	3.2564	6.2802
600^{0}C	441.2019	24.9639	3.0102	5.3976
Average	554.665	37.7361	3.3841	7.9979
Raw Tyre Samples	798.6	73.5	4.5	15.7

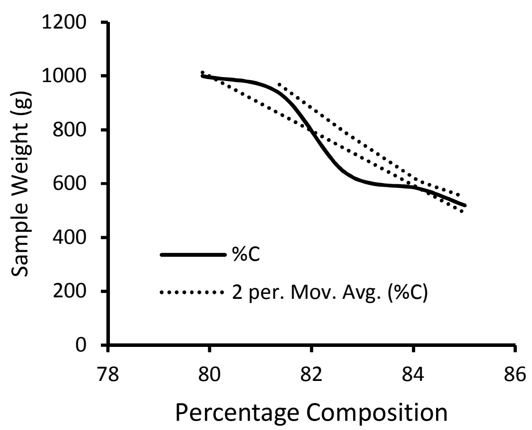

Figure 3: Plot of weight against Carbon composition for pyrolysed products

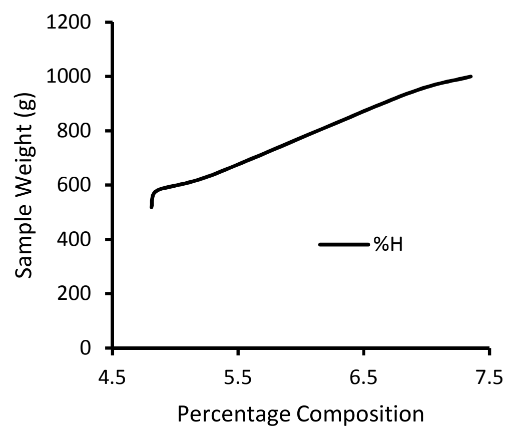

Figure 4: Plot of weight against Hydrogen composition for pyrolysed products

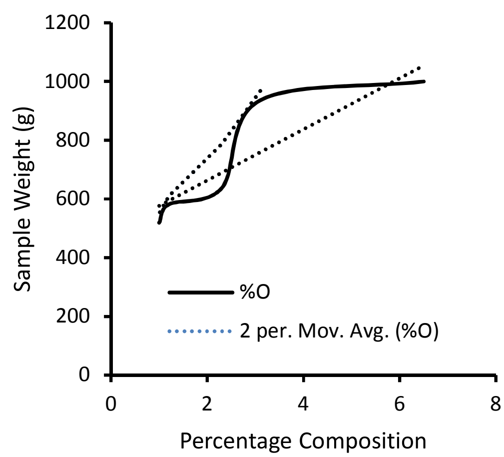

Figure 5: Plot of weight against Oxygen composition for pyrolysed products

The values obtained from the ultimate analysis of pyrolysed products by percentage at various pyrolysing temperatures were tabulated as shown in Table 2.

Table 2: Ultimate analysis of pyrolysed products by percentage at different pyrolysing temperature

Sample	%Moisture	%Volatile Matter	%Ash	%Fixed Carbon	Heating Value (kJ/g)	Specific gravity kg/m^3
Raw scrap tyre sample	1.25	62.10	8.67	27.98	36.10	243.00
250^{0}C	1.18	61.05	8.25	29.52	37.60	389.00
350^{0}C	1.11	59.11	7.18	32.60	38.40	437.00
450^{0}C	1.04	57.24	6.88	34.84	39.30	514.00
600^{0}C	1.01	56.21	6.24	36.54	40.00	540.00
average	1.09	58.40	7.14	33.38	38.83	470.00

The description of the heating values and specific gravity obtained from chemical analysis of the pyrolysed products were recorded in Table 3. Corresponding plots of the heating values and specific gravities of the pyrolysed products against the pyrolysing temperatures are shown in Figures 6 and Figure 7 respectively.

Table 3: Heating values and specific gravities from chemical analysis of pyrolysis products

Parameters	Heating Value (kJ/g)	Specific Gravity (kg/m^3)
Mean	39.2333	497
Standard Error	0.4631	30.9246
Median	39.3	514
Standard Deviation	0.8021	53.5631
Sample Variance	0.6433	2869
Skewness	-0.37144	-1.2844
Range	1.6	103
Minimum	38.4	437
Maximum	40	540
Sum	117.7	1491
Count	3	3
Confidence Level (95.0%)	1.9925	133.058

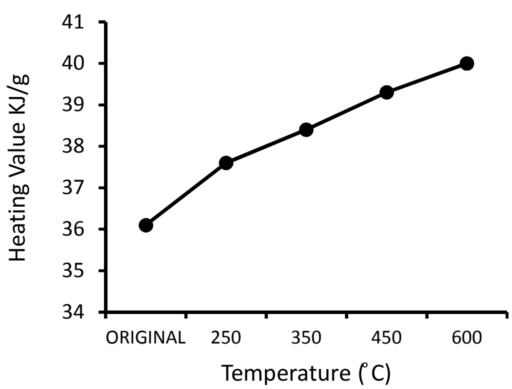

Figure 6: Plot of Heating Value (kJ/g) at different temperatures for pyrolysed products

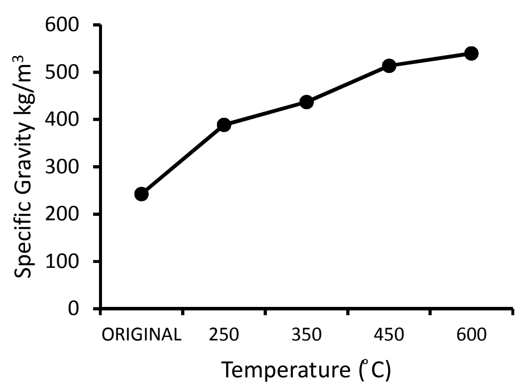

Figure 7: Plot of specific gravity kg/m^3 at different temperatures for pyrolysed products

As Pyrolysis temperature increases, most other elements present in the scrap tyres were converted into carbon, while simultaneously reducing the char yield. In other words, variation in temperature affected the solid, liquid and gas phase pyrolysis products and their physical/chemical yield as also observed by Martinez et al. (2013). This correlated with the investigation carried by Ali and Sattler, (2014), where the authors also found that extreme pyrolysis temperature (1000ºC and above) and long gas residence times in the furnace can volatilize the oil to gas. However, the interplay between the pyrolysis temperature and heating rate of the scrap tyre was highly essential in obtaining the products presented earlier in Table 1 and 2. Thermogravimetric studies of the pyrolysis of scrap tyres conducted by Senneca et al. (2009) indicated that higher heating rate would result in higher temperature which can lead to secondary reactions, and increasing the heating rate would increase the degradation rate and may as well affect the temperature at which maximum volatilization begins and ends. The results demonstrated an increase in the heating value (HV) concurrently with increasing pyrolysis process temperatures. It can therefore be inferred that pyrolysis at higher temperatures can yield a more energetic product. Figure 6 showed the measured values of the char HV resulting from the scrap tyre pyrolysis processes realised at different temperatures. The HV of the char increased from 37.6 kJ/g (at pyrolysis temperature of 250°C), to 40 kJ/g (at pyrolysis temperature of 600°C). Comparably, Ali and Sattler, (2014) reported that over 40MJ/kg heating value obtained from scrap tyres have been burned successfully in test furnaces and diesel engines. However, Nkosi and Muzenda (2014) obtained a fixed carbon content of 30% compared to 33.38% of fixed carbon obtained in this study, while a higher volatile matter of 62% was obtained compared to the average volatile matter of 58.40% obtained in this study. Furthermore, there was proximity as the same author obtained moisture content of 1% compared to 1.09% moisture content obtained in this study while ash content of 7% obtained by the author also correlated with the 7.14% moisture content obtained in this study. From Figure 7 which shows a plot of specific gravities against different temperatures of pyrolysed products, it is observed that the values obtained for specific gravity increased with the pyrolysis temperature.

4. CONCLUSION

The energy potential of pyrolysed scrap tyre was evaluated in this study. The ultimate analysis of the char resulting from pyrolysis gave an average value of 38.83kJ/g for the heating value and 470.00kg/m^3 for specific gravity. The average fixed carbon content was 33.38% while the volatile matters gave an average of 58.40%. The ultimate analysis of the raw tyre samples gave values of 36.10kJ/g for the heating value and 343.00kg/m^3 for specific gravity. Moisture content of 1.09%, volatile matter of 58.40% and ash content of 7.14%, whereas, carbon content of 554.66 g, Hydrogen of content 37.73 g, Nitrogen content 3.38 g and sulphur content of 7.99 g.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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