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PRODUCTION OF LIQUID FUEL FROM CO–PYROLYSIS OF JATROPHA CAKE WITH TYRE WASTE

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Abstract: The oil produced via pyrolysis of biomass has potential for use as a substitute for fossil fuels. However, the oil needs to be upgraded since it contains high levels of oxygen, which causes low calorific value and corrosion problems. In this regard, the co–pyrolysis technique offers simplicity and effectiveness in order to produce a high–grade pyrolysis oil. Co–pyrolysis is a process which involves two or more materials as feedstock. .Apparently no study on the co–pyrolysis of Jatropha seed cake with tyre waste. The feedstock materials were Jatropha cake and tyre waste. The characterization of the feedstock materials were carried out based on proximate and ultimate analysis. The Jatropha cake with tyre waste were in particle form and were pyrolyzed in an externally heated fixed bed reactor with nitrogen as an inert gas. The reactor was heated by means of electrical furnace. The products of the experiment were: liquid fuel, char and gas. The parameters that were found to influence the product yields significantly includes: feed ratio, temperature and reaction time. The optimum liquid yield obtained from the co–pyrolysis of Jatropha cake with tyre waste was 68.0 wt% (that is at the optimum parameters of feed ratio 1:1, temperature 500 °C and reaction time of 45 minutes).

Keywords: co–pyrolysis, fixed bed reactor, feedstock materials, Jatropha cake and tyre waste

1. INTRODUCTION

Fossil fuels such as petroleum and natural gas are predicted to phased out after 2042, and only the coal reserves that will be available until at least 2112 (Shafee, 2018). This condition has made researchers try to put more attention to find solutions by utilizing alternative energy. One of the interesting options is the use of biomass as energy. Biomass is very abundant worldwide and can be easily found in diverse forms such as agricultural residues, wood residues, dedicated energy crops, and municipal solid waste (Easterly and Burham, 1996 and Babajo, 2020). Biomass based on its availability and its status as a waste product is one of the prime sources of renewable energy worldwide.

Biomass is the major energy source in Nigeria, contributing about 78% of Nigeria's primary energy supply (Sulaiman and Abdullahi, 2011; Bbajo et al., 2021). Biomass originates from plants or their by–products that are produced completely or partly by photosynthesis such as forestry residues, agricultural bi products or animal wastes that can be used as a source of energy (Hasan, 2002). The use of biomass as an energy source also benefits the environment because it has been recognized as a carbon neutral energy source. The conversion of biomass into energy can be achieved in several ways, such as thermal, biological, and physical methods. In thermal conversion, pyrolysis is one of the most promising processes that can be used to convert biomass to various types of products such as liquid, char and gas. This technique has been recognized as an environmentally friendly method because no wastes are produced during the process. The process has also received more attention because it can produce liquid yield of up to 75 wt% with conditions of moderate temperature (500 °C) and short hot vapor residence time (Bridgewater, 2006). The liquid from the pyrolysis process has the potential to be applied as fuels or feedstock for many commodity chemicals. The research to produce liquid fuel via the pyrolysis of biomass has been conducted since the last four decades. In 1972, the energy crisis has pushed researchers to put more attention to maximize the production of pyrolysis oil by minimizing the byproducts of char and gases (Antal and Gronli , 2003). One of the best use of pyrolysis was achieved in the 1980s (Vamvuka, 2011). This technique has successfully led to several improvements, such as the high yield of oil production. Although the issue of oil quantity has been addressed, the improvement in oil quality still requires further research. Currently, several research efforts are focused in finding the suitable technique to produce high–grade pyrolysis oil and to explore more new variations of biomass that can be used as feedstock in the pyrolysis process. The oil produced from the pyrolysis of biomass has a high level of oxygen content and can cause many problems, such as low calorific value, high viscosity, corrosion problems, and instability. The current research finding showed that the technologies to eliminate the oxygen content are still expensive and can cost more than the oil itself (Zheng, 2011). Therefore, the sustainability of this research seems necessary to overcome this cost and to improve the quality of pyrolysis oil that is expected to compete with fossil–based liquid fuel.

Around 1.5 billion tires are produced worldwide every year, which will eventually be categorized or interpreted as waste tires (Williams, 2013 and Hita et al., 2016). Waste tires are known to have a significant impact on increasing the urban waste stream and it will become a major threat to the environment. Approximately 64% of waste tires are sent to landfill or illegally dumped or stockpiled, with only 13% of them being recycled (Wang, 2016). In landfills, waste tires are not easily degraded, but tend to float to the top over time due to trapped gases, thus breaking landfill covers. The incineration of waste tires requires the expensive control system of air emissions because this process produces toxic gases, which contain carcinogenic and mutagenic chemicals. Special treatment and attention are needed to tackle waste tires, and pyrolysis has been found to be a technically feasible way to treat tires and recover valuable products.

Wastes of tires are considered to be potential sources to use as a co–feed in co–pyrolysis to produce liquid fuel (Babajo et. al., 2019). As well as those materials having high energy content, the sources are particularly easy to find and available in huge amounts in all countries around the world. Pyrolysis of tire waste with other biomass (Jatropha cake) wastes will encourage the creation of innovative new concepts in waste management, energy security enhancement, and environmental concerns. Therefore, it is important to note that development of the co–pyrolysis process to produce liquid fuel may be applicable in most countries.

2. MATERIALS AND METHODS

— Materials

The materials used in this study includes:

- Jatropha Curcas Seed Cake: Jatropha curcas seed cake was selected for this study. It was obtained at Technology Business Incubation Center (TBIC), Kano, in Kano state. It was used as one of the feed stock in this research.
- Shredded rubber tire was selected as tire waste in this study. It was used as one of the feed stocks in the co–pyrolysis process because of its availability, and are not easily degraded, which may become a major threat to the environment. It was obtained at Kofar Wambai, Kano market, Kano state. The waste tire was cut into small sizes using an iron saw and the iron reinforcement in the tire was removed. The sample was washed and allowed to dry.
- Thermocouple: A thermocouple is a sensor used to measure temperature. The thermocouple is a sensing device which detects the temperature produced by the electric heater. The thermocouple that was used for this research was for measuring the temperature in the reactor. The thermocouple consists of a wire which was placed in the reactor in order to detect the temperature inside the reactor. The model of the thermocouple used was PSI–TTM 1 model.
- Temperature Controller: A temperature controller is a device that controls the temperature of the electric heater. It was used for controlling the temperature inside the reactor. The model of the temperature controller used in this research was TEC201 Model.
- Test Sieves: The test sieve that was used for this study was a standard sieve that will sieve the particle of the material or feed stock of not more than 2 mm. It was used for sieving the feed stocks to a desired particle size.
- Weight Balance: This is a device to measure weight. The type of weight balance that was used for this study was Digital of (TCS–100–ZE11) model. It was used for determining the weight of the material or feedstock.
- Stop Watch: The type of stop watch that was used for this research was Digital Stop watch of N1280 model. The stop watch was used for measuring the time that will take a material or a feed stock to pyrolyze.

— Methods

Jatropha seed cake and tyre waste were sorted, sun dried and shredded into smaller size. Proximate and ultimate analysis of a sample of the prepared feedstock was undertaken based on American Society for Testing and Methods (ASTM).

Proximate Analysis of the Feedstock Materials

The proximate analysis is defined as the loss in weight of the feedstock materials (Jatropha curcas seed cake and tyre waste) in terms of moisture content, ash content, volatile matter and fixed carbon. The proximate analysis was carried out in accordance with ASTM D3172–73.

Determination of Ash Content (ASTM D 2939–07)

The samples (Jatropha curcas seed cake and tyre waste) were weighed and burnt in a furnace at 350 °C and was left for some time in the furnace and the ash was later weighed. The ash content was determined on dried basis as follows:

$$\text{Ash content (wt \%)} = \left(\frac{W_3-W_1}{W_2-W_1}\right)\times 100 \tag{2.1}$$

where W_1= weight of empty crucible, W_2 = weight of crucible and sample and W_3 = weight of crucible and sample after heating.

≡ Determination of Moisture Content (ASTM D 4643 –18)

Percentage of moisture content (MC) of the samples was determined by calculating the loss in weight of sample using oven drying at temperature of 105 °C –115 °C until the weight of the sample was constant, after 60 minutes oven dried weight was obtained. Moisture content was then calculated as thus;

$$\text{Moisture content (wt \%)} = \left(\frac{W_5 - W_6}{W_5 - W_4}\right) \times 100 \tag{2.2}$$

where W_4= weight of empty crucible, W_5 = weight of crucible and sample, and W_6 = weight of crucible and sample after heating.

≡ Determination of Volatile Matter (ASTM E897 – 88)

Percentage of volatile matter (VM) of the samples was determined by calculating the loss in weight of sample using electrical furnace at temperature of 500°C – 550°C, until the weight of the sample was constant, after 10 minutes to obtain dry weight, by weighing the dried sample after been cooled. Volatile matter was then calculated as thus;

$$\%\,VM = \left(\frac{W_8 - W_9}{W_5 - W_7}\right) \times 100 \tag{2.3}$$

where W_7= weight of empty crucible, W_8 = weight of crucible and sample and W_9 = weight of crucible and sample after heating.

≡ Determination of Fixed Carbon (ASTM E– 870)

This was calculated by subtracting the sum of % of moisture content, volatile matter (VM) and % of ash content (AC) of the samples from 100.

$$\%FC = 100 - (\%\,MC + \%\,AC + \%\,VM) \tag{2.4}$$

≡ Ultimate Analysis of the Feedstock Materials

The purpose of the test was to determine element percent of carbon, hydrogen, nitrogen, oxygen and sulphur content in the feedstock materials. The ultimate analysis was conducted according to ASTM standards E777 – 17a, E – 778–15 and E – 711–15. This is the estimation of the important chemical elements present in the feed stock materials of this study. The composition of the elements are percentage of carbon (C), hydrogen (H), Nitrogen (N_2), Sulphur (S) and Oxygen (O_2).

≡ The Co–pyrolysis System

Pyrolysis is the thermal decomposition of materials at elevated temperatures in an inert atmosphere. There are three byproducts of pyrolysis process which includes; liquid, gas and char. The main objective of this co–pyrolysis system is to produce liquid fuel. The main components of the system are the reactor and the condenser.

The figure 1 below shows the conceptual representation of the pyrolysis system.

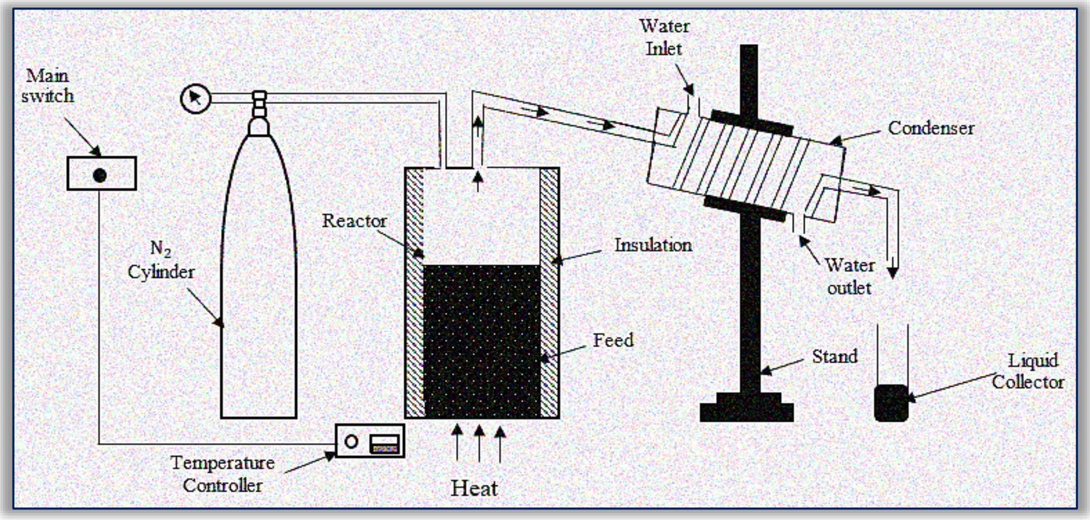

Figure 1: Conceptual Representation of Co–Pyrolysis System

≡ Experimental procedure

Dried and weighted Jatropha curcas seed cake with tyre waste of (1:1) of particle size of 1.5mm was fed into the fixed bed reactor for pyrolysis. The sample was taken in the stainless steel reactor for each run and placed in an electrically heated furnace. Pyrolysis experiments were carried out at different temperatures of 450 °C, 500 °C and 550 °C with a heating rate of 20°C $min^{-1}$and maintained till the reaction completes which is 30 minutes. A nitrogen flow rate of 2 L/ min was employed in other to purge air out of the system which prevent it from secondary cracking. The volatiles from the reactor were condensed in a water cooled condenser and the non–condensable gases were flared into the atmosphere. The condensed oil was collected in a liquid collector, and weighted. The remaining residue (char) was also collected and weighted after cooling the reactor. The weight of non–condensable gases was measured by applying mass difference. All experiments were performed thrice and the average values were reported.

The liquid fuel yield was collected after it was condensed and was recorded carefully kept (separately) in well–sealed containers under room temperature. This procedure was repeated for the following feed ratios of 1:2 and 1:3 (i.e Jatropha cake with tyre waste) and the temperatures of 500 °C and 550 °C, with the reaction time of 45 and 60 minutes. The plate 1 below shows the co–pyrolysis set up used for the production of liquid fuel from jatropha cake with tyre waste.

Plate 1: Co–pyrolysis Set–up

3. RESULTS AND DISCUSSION

— Results and Discussions

The Table 1 shows the results of proximate and ultimate analysis of Jatropha seed cake.

Proximate analysis (Table 1) shows that the sample (Jatropha cake) had high concentration of volatile matter (78.30%). The inherent moisture content of the sample was 0.76%. The ash and fixed carbon content contains 1.8% and 19.14% respectively.

Ultimate analysis data (Table 1) indicates that the sample contains high proportion of carbon of 57.20%, with relatively low concentrations of sulphur (0.5%), nitrogen (6.10%), and hydrogen (8.30%). The oxygen content of the sample was found by calculation (27.90%). The calorific value or energy content of the sample was determined to be 25.47 MJ/kg.

The Table 2 depicts the results of proximate and ultimate analysis of tyre waste.

Proximate analysis (Table 2) shows that the sample (tyre waste) has high content of volatile matter (55.95 %). The inherent moisture content of the sample was 0.57 %, however, the sample contains 15.30 % of ash content. The fixed carbon obtained from the sample by calculation was 28.18 %

Ultimate analysis data (Table 2) indicates that the tyre waste contains high proportion of carbon of 83.0 %, with low sulphur contents of (0.2 %), nitrogen (1.50 %), and hydrogen (5.52%). The oxygen content of the sample was found by calculation (9.78 %). The calorific value or energy content of the sample determined was 30.47 MJ/kg.

The Table 3 depicts the results of liquid fuel produced via co–pyrolysis of Jatropha cake with tyre waste operating under various conditions using Taguchi's design of experiment

Table 1: Proximate and Ultimate Analysis of Jatropha Cake.

Proximate Analysis (% wt)	
Moisture content	0.76
Volatile matter	78.30
Ash content	1.80
Fixed Carbon	19.14
Ultimate Analysis (% wt)	
Carbon	57.20
Hydrogen	8.30
Nitrogen	6.10
Sulphur	0.50
Oxygen	27.90
Calorific value (MJ/Kg)	25.47

Table 2: Proximate and Ultimate Analysis of Tyre Waste

Proximate Analysis (% wt)	
Moisture content	0.57
Volatile matter	55.95
Ash content	15.30
Fixed Carbon	28.18
Ultimate Analysis (% wt)	
Carbon	83.00
Hydrogen	5.52
Nitrogen	1.50
Sulphur	0.20
Oxygen	9.78
Calorific value (MJ/Kg)	30.47

Table 3: Co–pyrolysis of Jatropha Cake with Tyre Waste

Experiment Number	Parameters			Liquid Fuel (wt%)
	Feed Ratio	Temperature (°C)	Reaction Time (Min)	
1	1:1	450	30	63.0
2	1:1	500	45	68.0
3	1:1	550	60	60.0
4	1:2	450	45	57.3
5	1:2	500	60	58.2
6	1:2	550	30	53.0
7	1:3	450	60	52.0
8	1:3	500	30	53.0
9	1:3	550	45	50.3

It can be observed that from Table 3, at constant feed ratio of 1:1, as the temperature and the reaction time increases, the liquid yield produced decreases with the exception of the reaction temperature of 500 °C and reaction time of 45 minutes, which had liquid yield of 68.0 wt%. It can also be observed that, at constant feed ratio of 1:2, as the temperature increases and the reaction time decreases, the liquid yield produced also decreases with the exception of the reaction temperature of 500 °C and reaction time of 60 minutes, which had liquid yield of 58.2 wt%. It can also note that, at constant feed ratio of 1:3, as the temperature increases and the reaction time decreases, the liquid yield produced also decreases with the exception of the reaction temperature of 500 °C and reaction time of 30 minutes, which had liquid yield of 53.0 wt%.

The confirmatory experiments were carried out with the optimal setting of the samples. The average liquid yield obtained for the co–pyrolysis of Jatropha cake with tyre waste was 68.4 wt%.

— Maximum Process for the Co–pyrolysis of Jatropha Cake with Tyre Waste

The figure 2 below shows the results of the optimization process for the co–pyrolysis of Jatropha cake with tyre waste.

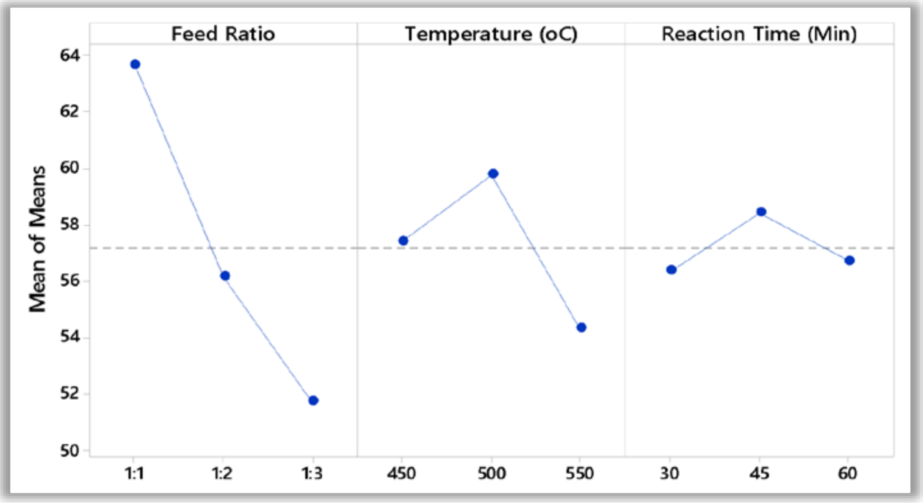

Figure 2: The graph of mean of means versus feed ratio, temperature and Reaction Time

It can be observed that from figure 2 above, as the feed ratio of the samples decreases the liquid yield increases, and the liquid fuel yield was optimum at the feed ratio of 1:1. More so, the reaction temperature and reaction time that produces high liquid fuel yield was at 500 °C and 45 minutes respectively. So the optimum parameters that can yield high liquid fuel was at a feed ratio of 1:1, reaction temperature of 500 °C and reaction time of 45 minutes. The result (liquid fuel) obtained at that conditions was 68.0wt%.

The Table 4 demonstrates the results of response table for means

Table 4. Response Table for Means

Level	Feed Ratio (A)	Temperature (°C) (B)	Reaction Time (min) (C)
1	63.67	57.43	56.40
2	56.17	59.80	58.43
3	51.73	54.33	56.73
Delta	11.93	5.47	2.03
Rank	1	2	3

The results from the Table 3.4 shows the effect of each parameter or factor in the liquid fuel production. It showed that the feed ratio has the greatest effect on the production of liquid fuel, followed by temperature, and then reaction time.

4. CONCLUSION AND RECOMMENDATION

— Conclusion

The findings of the characterization study using proximate and ultimate analysis indicate that, the Jatropha cake and tyre waste has a potential source of liquid fuel production. It was inferred from the Taguchi analysis that the combination of feed ratio of 1:1, reaction temperature of 500 °C and the reaction time of 45 minutes was the optimal setting for obtaining maximum liquid fuel for the co–pyrolysis of Jatropha cake with tyre waste. The confirmation experiments were carried out with the optimal setting on the sample. The average liquid yield obtained for the co–pyrolysis of Jatropha cake with tyre waste was 68.4 wt%. It can also concluded that, the ratio of feed stock material has greatest influence on the production of the liquid fuel compared to reaction temperature and reaction time.

— Recommendations

- ≡ Considering the results obtained from the study, the liquid fuel from Jatropha cake and tyre waste can be used as an alternative fuel.
- ≡ Other materials like HPDE (High density Polyethylene) and LDPE (Low density Polyethylene) and biomass mixtures should be researched upon to determine the synergy effect between them via co–pyrolysis technique.

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