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Pyrolytic conversion of spent palm fruit bunches into bio-fuels

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ABSTRACT

The threat which the disposal of spent palm fruit bunches constitutes to communities in oil palm processing communities in Nigeria coupled with the current global interest in alternative energy are the motivation for this work. An existing design of pyrolytic reactor consisting of a reactor unit, condensate receiver, copper pipe connectors and gas receiver was modified and adapted for converting spent palm fruit bunches into bio-fuels. The average char yield was 44.9 %, and the percentage of feedstock converted into pyro-gas and tar oil was 55.1 %. The char yield decreased gradually as temperature was increased from 300-700°C. Char yield was highest (39.78 %) when the temperature was 300°C and the lowest char yield was 25.05 % at 700 °C and the calorific values of char ranged between 21.12 and 23.76 MJkg^{-1}. This work presents the potential of generating energy from pyrolysed Spent Palm Fruit Bunches (SPFB), it abates the disposal problem that SPFB constitutes in the oil palm industry.

Keywords

Spent Palm Fruit Bunches, Thermo-Chemical conversion, Alternative Fuel, Char, Pyro-gas, Tar Oil

INTRODUCTION

Renewable energy is fast gaining global relevance in satisfying environmental concerns over fossil fuel usage and its contribution to the greenhouse gasses [1]. With the continual depletion of fossil fuel reserves and changing global climate, Nigeria like other countries of the world will have to contend the need for alternative energy sources in the near future. Wood and other forms of biomass are some of the resources available for producing renewable energy in the form of liquid, gaseous and solid fuels [2]. One of the known approaches is the conversion of biomass and organic wastes into a black carbonaceous solid, a mixture of gases and tar oil; the proportion of which depends on the biomass composition, temperature and duration of the pyrolytic process. This thermo-chemical process provides a liquid fuel that may be used instead of fuel oil for static heating or electricity generation.

The liquid can also be used to produce a range of chemicals which can be readily stored or transported [1, 3]. Apart from generating bio-fuels, pyrolysis is a very efficient process that eliminates odour from the degradation of solid organic wastes. Soltes [4] documented that tar oil may be fractionated into gasoline and diesel fuels to run engines; and may also be processed as disinfectant, germicides and wood preservatives while the gasses may be used for powering internal combustion engines or processed into liquid fuels. Pyrolysis has received considerable attention as a method for waste disposal in an environmentally acceptable manner with remarkable resource recovery at the same time [5]. Several works have been documented on pyrolytic conversion of bulky agricultural wastes into alternative energy sources [6-10]. Sukiran *et. al.* [11] documented a pyrolytic process for pulverizing spent palm fruit bunches (SPFB) under varied conditions in a fluidized fixed-bed reactor. Bamgboye and Oniya [9] reported the pyrolytic conversion of corncobs to medium grade fuels and chemical preservatives; yielding pyro-gas, tar oil, pyroligenous acid and tar with about 91.49% conversion efficiency. The studies of Ojolo and Bamgboye [10] on the thermo-chemical conversion of municipal solid wastes to produce fuel and reduce waste showed that municipal solid wastes when pyrolysed can be converted into useful fuel products such as tar oil, pyro-gas and char. The process is being used in Netherlands and USA to recycle plastic waste and shred rubbish [12]. Ogunsina *et. al.* [13] investigated the thermochemical conversion of cashew nut shells into alternative fuel sources; the disposal of which has hitherto been a serious menace in the cashew nut processing industry.

In Africa and Asia, widespread cultivation of oil palm (*Elaeis guineensis*) is driven by the vegetable and industrial oils (palm oil and palm kernel oil respectively) that its fruits provide. Presently, Nigeria ranks third among the largest producers of palm oil in the world after Malaysia and Indonesia; although the industry is largely concentrated in rural communities where processing is by manual or semi-manual methods [14]. The major unit operations include reception of the palm fruit bunches, sterilization, threshing, digestion, pulp pressing, oil clarification, nut recovery, oil and nut drying. Considerable amount of biomass such as the mesocarp fibre, shell, SPFB, frond, trunk and mill effluent are generated in each unit at different stages but SPFB is usually the bulkiest. In Nigeria up till now, SPFB is still being incinerated due to the dearth of information regarding its potentials as a source of alternative fuels.

The objective of this work is to adapt an existing design of pyrolytic reactor for the thermo-chemical conversion of SPFB into bio-fuels. It is with the view to construct and test the reactor for use as a means of converting SPFB into bio-fuels.

MATERIALS AND METHODS

Materials

The following materials and equipment were used for this investigation: weighing machine, oven, pyrolytic reactor, stop watch, SPFB, cutlass (for cutting the SPFB bunches into smaller chunks) and hammer mill. About 20 kg of dried (18.8 % moisture content) SPFB were collected from Seldot palm oil mill, Gbongan, Osun State, Nigeria. The SPFB were kept in polythene bags until when needed to prevent moisture loss.

Description and limitations of the existing pyrolytic reactor and modifications made

The reactor developed by Ojolo and Bamgboye [8] is composed of a furnace which encloses a retort, a gas holder and condensate receiver (Fig. 1). The retort was connected to the condensing unit with copper pipes. The reactor was made of 1.6 mm thick mild steel into a cylinder of 5 dm^3 volume with a sealed bottom. A 3000 W capacity heating element connected to a 220 V single phase power source was placed at the bottom of the reactor. The reactor was lagged with fibre glass to prevent heat loss by radiation. A 1200 ^oC thermostat was installed inside the heating chamber for temperature control using a bimetallic material incorporated inside the heating chamber to monitor the resident time and heating rate of the feedstock. The condensate receiver was a mild steel container placed on a bed of ice. It condenses the tar oil from the mixture of gases conveyed from the reactor while the gaseous fraction is further conveyed to the gas receiver through the lagged copper pipe. The gas receiver is made of glass with a cork to prevent heat loss.

The reactor had been tested with corn cobs and cashew nut shells. However, with SPFB, the major limitation was the inability of the system to withstand the pressure generated at temperatures above 650 ^oC and there was backflow of pyrogas into the condensate receiver.

Design Modifications

A clip and a high heat resistance gasket were introduced to constitute an improved air tight cover that prevents leakage in and out of the container. A non-return flow valve controlled by gas pressure was in between the gas receiver and the condensate receiver. The valve poppet opens to allow gas passage to the receiver when the gas pressure rises above 35 kPa and does not allow a backward flow.

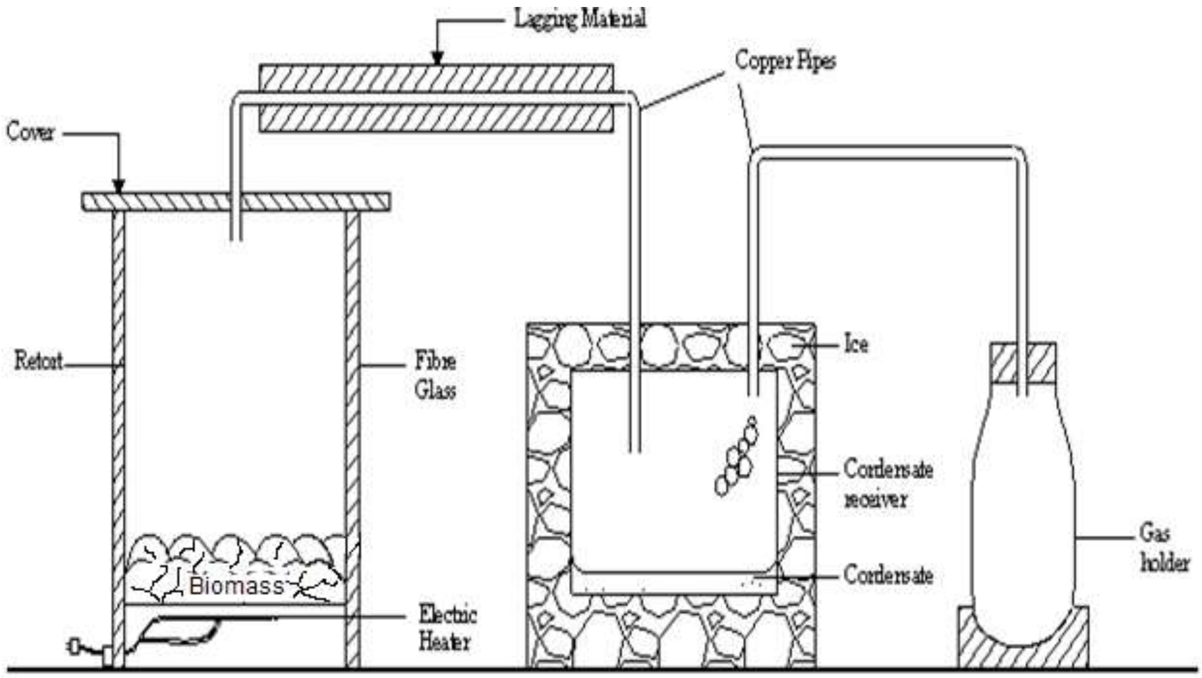


Fig. 1: Existing pyrolytic reactor by Ojolo and Bamgboye (2005)

Machine testing

The SPFB at an average moisture content of 18.8 % (wb) were chopped into smaller bits and milled into particle sizes in the range of 100 - 150 µm. To determine char yield and feedstock conversion efficiency, the reactor was loaded in batches with 300, 360, 350, 370, and 400 g of SPFB and heated continuously for 9 h at an average temperature 550 ˚C and allowed to cool [7, 8, 11]. Each run was repeated in triplicates. The weight of the char after the thermo-chemical process was measured and recorded. The char yield was calculated according to Equation (1). The distilled char oil was collected in the condensate receiver and pyrogas was collected in the pyrogas receiver.

$$Y_c = \frac{W_c}{W_w} \times 100\% \quad (1)$$

where, Y_c = Char yield

W_c = Weight of char after pyrolysis

W_w = Weight of feedstock.

Equation (2) gave the feedstock conversion efficiency (*i.e.* percentage of SPFB used up in the process).

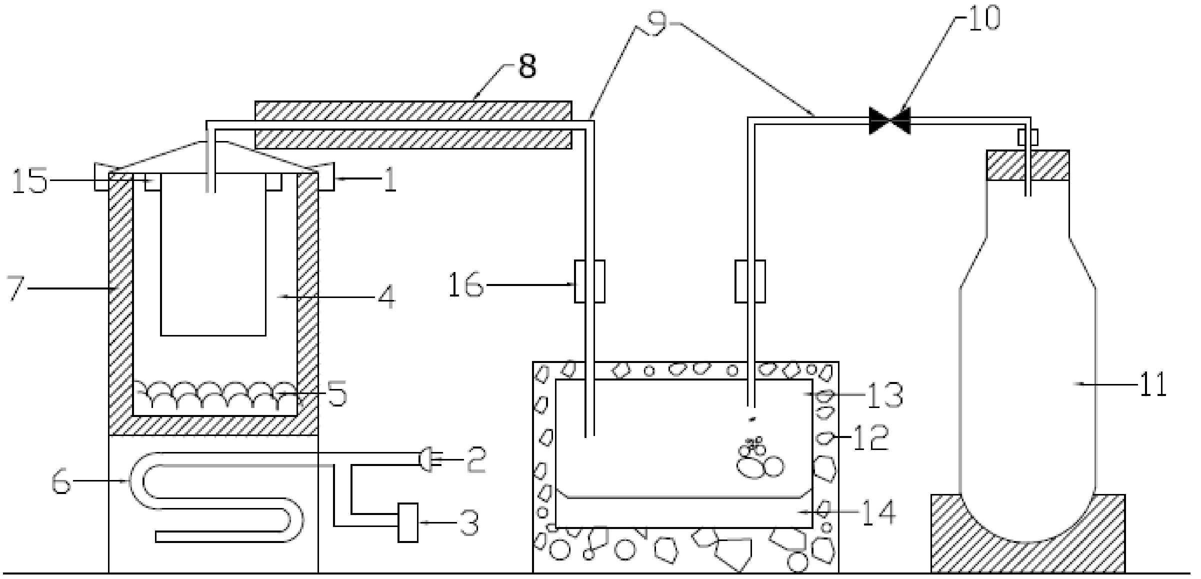
Feedstock conversion efficiency = % of EFB used $= \frac{W_w \times W_c}{W_w} \times 100\%$

(2)

The reactor was used to pyrolyse SPFB considering five different temperature levels: 300, 400, 500, 600 and 700 ^oC. For each temperature level, there were three replicates of the experiment and the overall data was subjected to ANOVA using F-test. The ultimate analysis and the calorific values of the char produced during each temperature trial were determined using a Gallenkamp ballistic calorimeter (Cambridge Instrument Co. Ltd., England). The values are also presented as an average of three replicates.

RESULTS AND DISCUSSIONS

The schematic drawing of the modified reactor and the experimental pyrolytic reactor are shown in Figs. 2a and b. The functional elements of the modified unit are the reactor chamber, condensate receiver, copper pipes and pyrogas receiver. During testing, there was



1 -Clip;2 -Power source;3 -Temperature control unit;4 -pyrolitic reactor; 5 - Chopped Spent Palm Fruit Bunches; 6 -Heating element;7 -Fibre glass; 8-Lagging;9 -Copper pipes; 10 -Non-return valve;11 -Gas holder; 12 -Ice block;13 -Condensate reciever; 14 -Tar oil; 15-Gasket; 16-Connector.

Fig. 2a: The schematic drawing of the reactor showing the modifications made

Fig. 2b: The experimental pyrolytic reactor

noticeable gaseous emission after the first 2 h. After 4 h, some pyrogas was observed in the receiver and an insignificant amount of tar oil was observed in the tar oil receiver. At the end of each experimental run, considerable reduction was observed in the amount of feedstock residue (char) left in the reactor chamber.

During the five trials pyrolysis experiment with SPFB, the average percentage (by weight) of feedstock converted into pyrolytic products and char were 55.1 and 44.9 % respectively. The relative percentages of feedstock converted and char during each trial are shown in Fig. 3. With 55.1% conversion efficiency, apart from the bio-fuels that the pyrolysis of SPFB yields, it reduces the bulky waste that SPFB constitutes in the oil palm industry considerably. The char samples obtained after pyrolysis of SPFB at different temperatures 300 – 700 ^{o}C respectively are shown in Fig. 4 (i-v). The average percent yield of tar oil, char and pyrogas at different temperatures are shown in Fig. 5. It was observed that char yield decreased consistently as temperature increased from 300 to 700 °C. There was first an increase in pyrogas yield and later a decrease as temperature increased; whereas, tar oil yield shown no definite trend with increase in temperature [9, 10]. The highest and lowest yield of char was obtained as 39.78 and 25.05 % at 300 and 700 °C respectively. The relationship existing between temperature and the yield of pyrolytic products gave the best agreement by polynomial expressions (Fig. 5), except tar oil for which a power relationship gave the best fit. The equations of fit and the respective R^2 are as shown on Fig. 5. However, from the ANOVA, the effect of temperature on the yield of all pyrolytic products was found to be significant at 5 %.

The result of ultimate analysis and calorific value including the Hydrogen/Carbon (H/C) and Oxygen/Carbon (O/C) ratios of pyrolysed SPFB products at different temperatures are shown in Table 1. The values did not depict a definite trend but showed significant differences. The calorific values of char based on the different temperatures considered in this work ranged between 21.12 and 23.76 MJ/kg. Although the calorific values also did not show a definite trend, the highest was 23.76 MJ/kg at the pyrolytic temperature of 500 °C. The H/C ratios of char changed between 0.50 and 0.65. The highest H/C ratio of char was 0.65 when the pyrolysis temperature was 400 °C. The O/C ratios of the SPFB char ranged between 0.37 and 0.55. The highest O/C ratio of char obtained was 0.55 when pyrolysis temperature was 700 °C. The percentage range of hydrogen and nitrogen were 3.01 - 4.17 % and 1.98 - 2.68 % respectively. The highest hydrogen and nitrogen content obtained were 4.17 % and 2.68 %

at pyrolytic temperatures of 400°C in both cases.

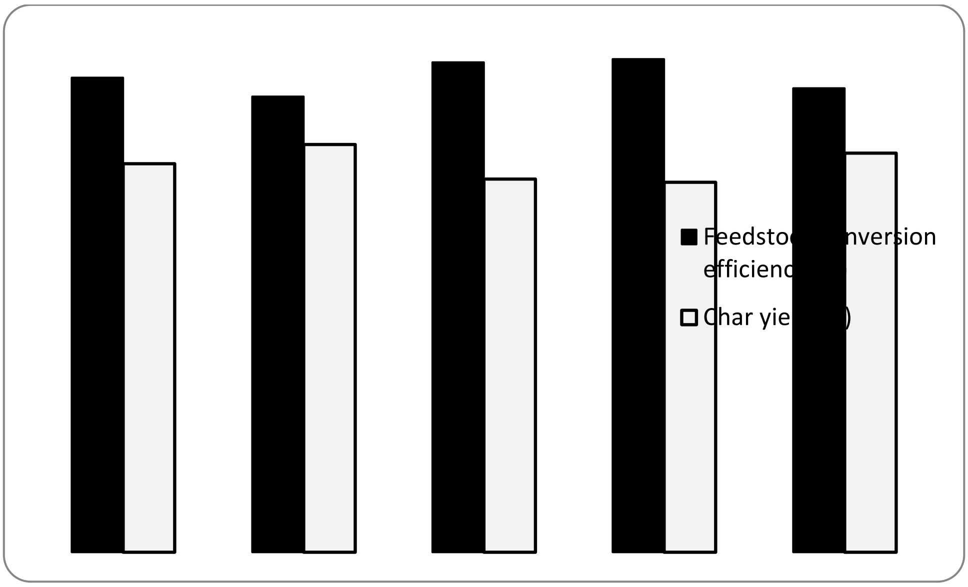


Fig. 3: Percent feedstock converted into fuel and char during a five trial pyrolysis experiment with SPFB

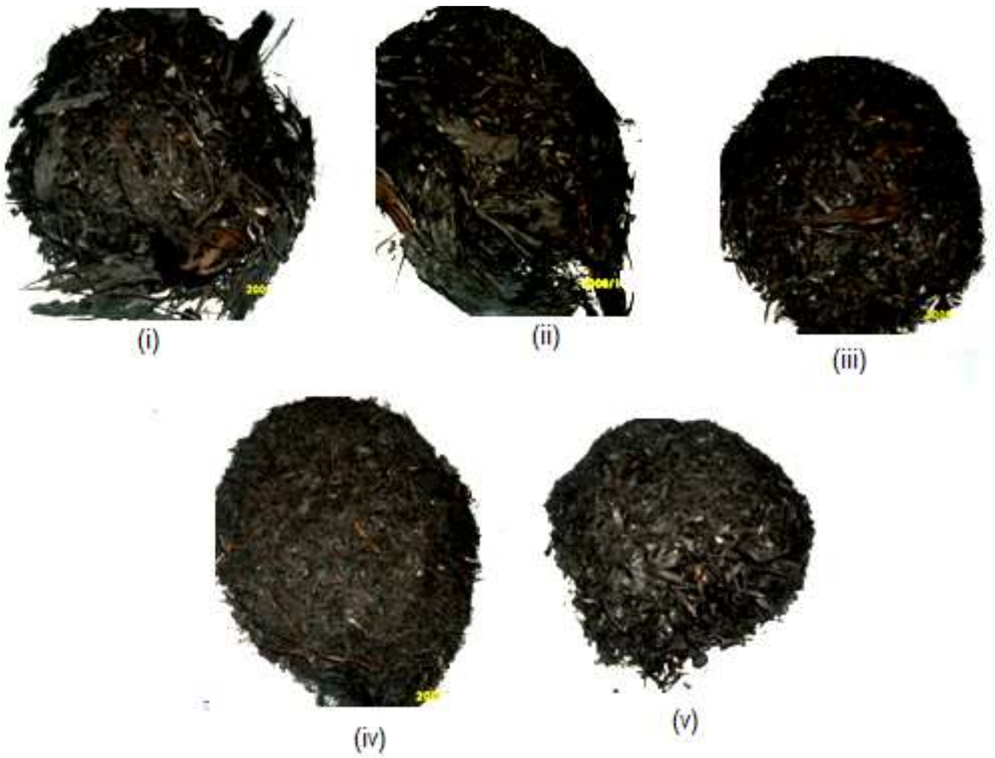


Fig. 4: Samples of char obtained after pyrolysis of SPFB at different temperatures of 300 – 700 °C respectively

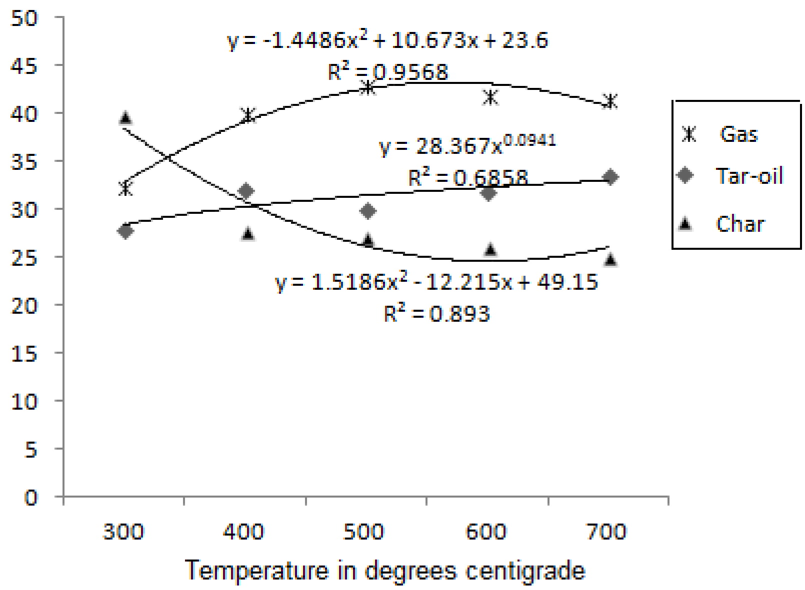


Fig. 5: Effect of heating temperature on the yield of pyrolytic products

Table 1: Properties of char obtained from pyrolysed spent palm fruit bunches

Temperature (°C)	Ultimate analysis						Calorific value (MJ/kg)
	C(%)	H(%)	N(%)	O(%) by diff.	O/C Molar ratio	H/C Molar ratio	
300	68.67	3.46	2.32	25.55	0.37	0.50	23.67
400	64.10	4.17	2.68	29.05	0.45	0.65	21.12
500	66.95	3.99	1.98	27.08	0.40	0.60	23.76
600	65.32	4.01	2.13	28.54	0.44	0.61	23.1
700	60.88	3.50	2.11	33.51	0.55	0.58	24.04

CONCLUSION

An existing pyrolytic reactor design was modified and adapted for converting spent palm fruit bunches into bio-fuels. The percentage of char produced was 44.9 %; about 55.1 % of the feedstock was converted to tar oil and pyrogas. Conversion of SPFB into bio-fuels offers means of abating the menace that the disposal of SPFB constitutes in oil palm mills and additional income for palm oil processors. Although pyrolytic conversion of different biomass feedstock has achieved wide recognition, there are still many empirical aspects of the process which require further study to improve reliability, performance, product consistency, product characteristics and scale-up.

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