International Journal of Engineering and Technology Research
Published by Cambridge Research and Publications
Vol. 17 No.5
September, 2019.

RESPONSE OPTIMIZATION APPROACH OF BIO-OIL PRODUCTION PARAMETERS USING SHEA BUTTER SHELL.

MOHAMMED B. I.[*1] AND GARBA M. U.[2]
[1,2]Department of Chemical Engineering Federal University of Technology, Minna

Abstract.

This paper focus on the response optimization approach of Bio-oil production operating parameters from shea butter shell. The optimization of the pyrolysis thermal conversion of biomass was carried out using 2^3 Response Surface Methodology (RSM) experimental design of experiment studying the effect of Temperature (265-685 °C), Residence Time (7min-77 min), and Heating Rate (3-36 °C/min) at constant feed mass of 100g per run. The results of operating variable effects shows that bio-oil yield depends on significant variables of the process. Temperature and Heating Rate were found to be significant to obtain optimum bio-oil yield experimentally. Optimum yield off the study was 51.50 ml against 71.00 ml of the predicted model. The results of effect of process variables revealed that an optimum condition for the bio-oil synthesis was at a temperature of 600 °C, heating Rate of 30 °C/min and residence time of 20min of the parameters are values which optimum was obtained. The statistical analyses of the data lead to development of the second order quadratic polynomial regression model which establishes the relationship between bio-oil yield and the process variables. The model was able adequately to predict the bio yield with a co efficient of determination (R) of 0.7992.

Keywords: *Optimization, Approach, Bio-Oil, Parameters, Shea Butter Shell..*

INTRODUCTION

World consumption on particular energy source depends on availability and accessibility of technology, quantity of energy obtainable and fuel source. Fossil fuels is the primary source of energy supply worldwide. However, the use of fossil fuel energy supply is associated with alternatives use of environmental friendly and economical viable renewable sources of energy and chemicals (Yaman, 2004 and Smets *et al*., 2013).

Biomass is a renewable resource with great potential as an alternative to fossil fuels for supplying energy (Bridgwater, 2012 and Kumar *et al*., 2009). The potential for biomass to supply much larger amounts of useful energy with reduced environmental impacts compared to fossil fuels has stimulated substantial research and development of systems for handling, processing, and converting biomass to heat, electricity, solid, liquid and gaseous fuels, and other chemicals and products. The use of biomass to substitute of fossil resources results in low sulphur dioxide emissions and almost no net atmospheric carbon emissions, and hence serves to mitigate greenhouse gas and global climate change impact (Kumar *et al*., 2009).

Biomass has the potential to offer sources of energy and chemicals, with agricultural wastes gives the better alternative than used of biomass from consumable food products. Agricultural waste could be converted into chemicals by thermochemical conversion processes such as combustion, gasification and pyrolysis (Bulushev and Ross, 2011).

Shea butter shells are a major source of agricultural waste in West Africa and were used as raw material. It is non consumable for both animal and man after the shell is removed from karnel (Noumi *et al.*, 2013; Ouédraogo *et al.*, 2017). Therefore, use of shea butter shell as biomass for alternative source of energy will help in the environmental waste management.

However, the pyrolysis process is regarded as a promising process for the biomass optimization. The process offers an important opportunity for the utilization of the biomass from agricultural and forestry residues. (Bridgwater and Peacocke, 2000).

Pyrolysis is a thermal conversion process in the absence of oxygen, at atmospheric pressure and temperature range of (300-600 °C). It have been practiced for thousands of years to produce charcoal by slowly heating at temperature ranging between 300 °C and 400 °C, which is known as slow pyrolysis. High temperature and longer residence time favors the formation of gas than liquid fuels. This technology is known as gasification (Bridgwater, 2012 and Venderbosch, *et al.*, 2011). Fast pyrolysis is the volatilization of biomass at high temperature (400-700 °C) and heating rate (50 – 1000 °C/min) under inert atmosphere (Demirbas *et al.*, 2008).

In this present study, the optimization of bio-oil process parameters were studied using central composite design approach and the obtained char was characterized to determine the ultimate and proximate composition.

MATERIAL AND METHODOLOGY

Materials

Shea butter shell was used as biomass sample. The shea butter shell waste from the local shea butter production factory was obtained from production site Kuso-Tachin village via Bida Local Government of Niger State, Nigeria

Method

Proximate and Ultimate Analysis

The residual moisture was determined based on ASTM 1762/1964. It was first determined the moisture pre-drying (U) of shea butter shell waste. After pre-drying, it was determined the residual moisture content (u) of ground shea butter shell waste with an approximate particle size of 60 mesh. After removing moisture from the biomass, the following procedures were carried out. The standard ash, volatile matter and fixed carbon were determined based on ASTM E 1755 and ASTM D 1762, respectively. CHNS Analysis Elemental Analyser Vario El Cube was used to determine the contents of C,H,N,O based on ASTM D 5291. The sulfur content was determined by LECO S-144 DR based on ASTM D 4239.

Calorific Value

The 6400 Automatic Isoperibol Calorimeter Paar was used to determine the High Heating Valueand Low Heating Value based on ASTM D 5865.

Pyrolysis Reactor

A tubular reactor (TR), placed in a furnace (Entech, ETF3050/15S) was used for fixed-bed pyrolysis with a heating rate of < 10 K min^{-1} and a temperature up to 1400 °C. The furnace consisted of a stainless steel tube with an alumina tube fitted with electrical heating elements and gas supply. 100g of the pure shea butter shell sample was loaded into the alumina boat placed in the furnace middle. The tubular reactor was purged with N_2 as the inert gas carrier. Once the preset temperature was reached at the desired residence time, the sample was kept for about 10 min or 4 h in the furnace to ensure complete conversion. In the current studies, the bio-oil and char was collected. (Trubetskaya, 2016).

Design of Experiment for Response Surface Methodology (RSM)

A three factorial Central Composite Design (CCD) version 7.0.0 was applied for the fast pyrolysis of shea butter shell to produce Bio-oil in terms of effect of three operating parameters (Temperature (A), Residence Time (B), and Heating Rate (C). the experiment was conducted including 2^3 factorial design and Response Surface Methodology (RSM) design equation is ($2^n + 2n + 6$). Where the first, second and third term of the expression represents factorial, axial and center components respectively of the central composite design.

Table 1: Ranges and Levels of Independent Variables in RSM Design

Table1 shows the ranges and code of independent variables in the design of experiment.

Parameter	**-α**	**-**	**0**	**+**	**+α**
A: Temperature (ºC)	265	350	475	600	685
B: Residence Time (min)	7	10	35	60	77
C: Heating Rate (ºC/min)	3	10	20	30	36

Design Equation.

A quadratic regression model in equation (based on the coded factors) was generated based on the central composite design and of the experimental data:

Final Equation in Terms of coded Factors:

$$\text{Bio-oil Yield} = +23.25 + 14.27A + 7.94B + 15.93C + 2.63AB - 4.87AC + 4.25BC + 5.70A^2 + 2.52B^2 + 5.70C^2$$

Final Equation in Terms of Significant Factors:

$$\text{Bio-oil Yield} = +24.85211 - 0.18366A + 0.57156C$$

Where A, is the temperature in (°C), B is the Residence Time in (min) and Heating Rate in (°C/min)

RESULTS AND DISCUSSIONS

Proximate and Utimate Analysis

Table 2: Proximate and Utimate Analysis of Shea Butter Shell

		Proximate Analysis (wt. %)				**Utimate Analysis (wt. %)**			
	Moisture Content	**Ash Content**	**Volatile Matter Content**	**Fixed Carbon**	**Carbon**	**Hydrogen**	**Sulphur**	**Nitrogen**	**Oxygen**
Shell	10.34	1.72	80.80	16.14	84.66	10.19	0.30	0.59	4.86
Bio-Char @475^{o}C	6.20	0.80	14.00	19.00	47.10	7.00	0.20	2.30	43.40

Low Heating Value (LHV) = 139.0kJ/kg
High Heating Value (HHV) = 20400kJ/kg
Heat Capacity = 11800HJ/kg

Proximate Analysis Discussion

In order to determine the differences in the quality of biomass waste and the biochar produced by the pyrolysis, analysis was performed. As with raw sample material, the composition was determined by the value of the water content (moisture in air dried sample), ash (ash content), easy fly material (volatile matter), solid carbon (fixed carbon), and calorific value. Table 1.0 shows the characteristics of shea butter shell waster and biochar. The moisture content of the dried shell and biochar was determine to be 10.34 % and 6.20 % respectively. Result of the dried sample was close to was observed by (Yin, 2011) to be 10.07 % for wood waste and bio-solid mixture. The ash content was observed for both sample to be 1.72 % and 0.80 % respectively. According to Jaya *et al.*, 2012, ash content influence the deposition rate of the biomass and incase of wood fuel has low ash compare to herbaceous straw grasses and bark content in the fuel. Therefor the low ash content and high volatile matter of the biomass with recorded to be 80.40 % for the dried shea butter shell enhance the bio-oil yield of the pyrolysis. After thermal process the volatile matter reduced to 14.00 % which make it suitable for further adsorbent processing. The Carbon, Hydrogen, sulphur, Nitrogen and Oxygen were recorded in the table above, high carbon content shows that the biomass contains high level of cellulose, hemicellulose, lignin which later decompose thermally to yield bio-oil.

Relationship between Operating Variables on Bio-oil Yield

The 3 dimensional (3D) surface plot of the second order model helps to understand better the interactive effect between the variables on the yield of bio-oil.

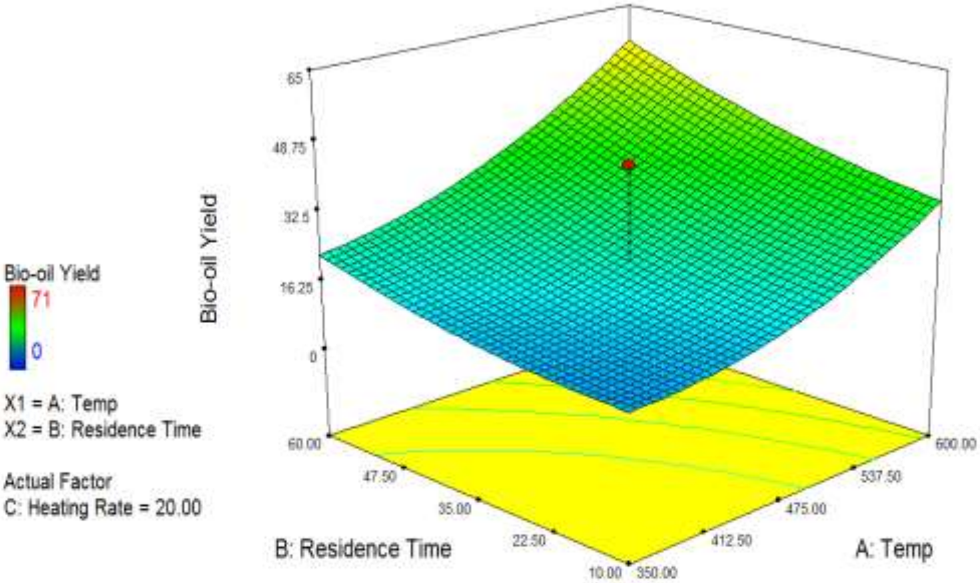

Figure 1: The Response surface contour for interaction between Temperature and Residence Time on Bio-oil Yield.

Figure 1 shows the interactive effect of temperature and Residence Time on bio-oil yield. It can be seen that the bio-oil yield increases as temperature increases which might be due to increase in the thermal decomposition of the cellulose and Hemicellulose in the biomass and this results to higher conversion of the Bio-oil yield. The increasing effect of temperature shows that 47.20 ml yield was recorded at temperature of 600 °C.

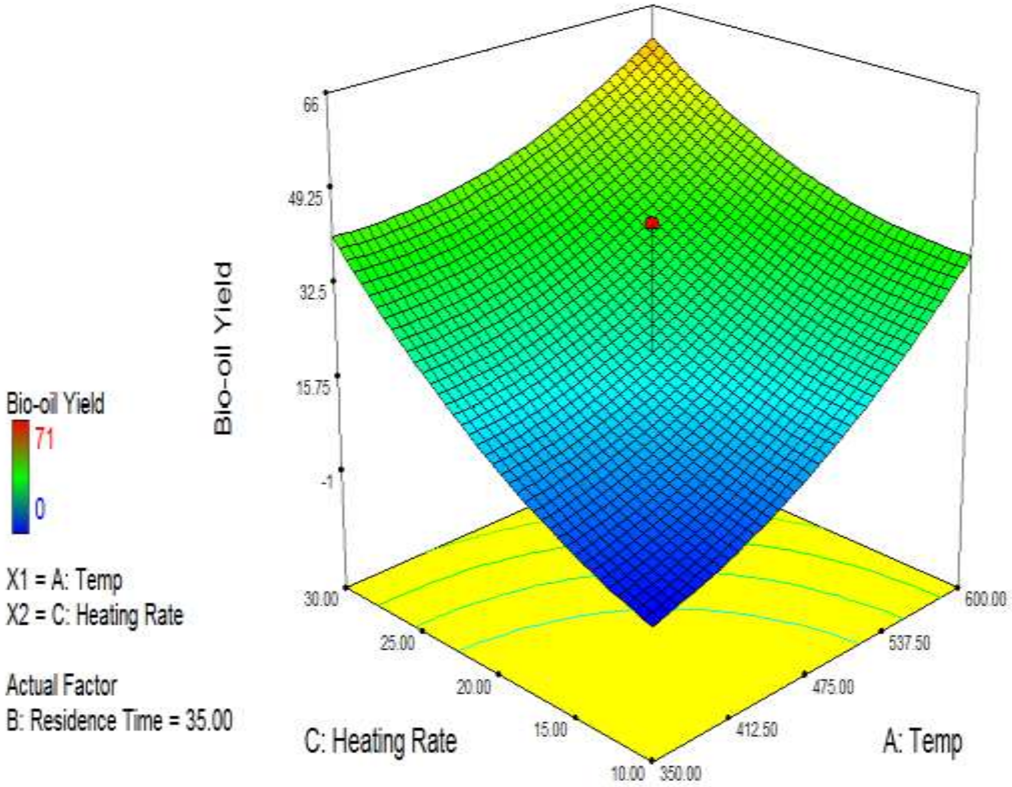

Figure 2: The Response surface contour for interaction between Temperature and Residence Time on Bio-oil Yield.

Figure 2 shows the interactive effect of Temperature and Heating Rate on the yield of bio-oil yield. The bio-oil yield increase with increase in both heating rate and temperature; this is due to availability of heat required to break the bonds in the cellulose and lignin therefore result into high conversion of the bio-oil yield. The increase in Heating Rate effect shows that yield of 51.20 ml was recorded at the operating condition; Temperature of 600 °C, Heating Rate of 30 °C/min and reaction time of 10 min. Therefore the bio-oil yield has a linear relationship with the Temperature and Heating Rate, the yield increases from 23.25 ml at temperature of 475 °C and Heating Rate of 20 °C/min to 51.20 ml at temperature of 600 °C and heating rate of 30 °C/min.

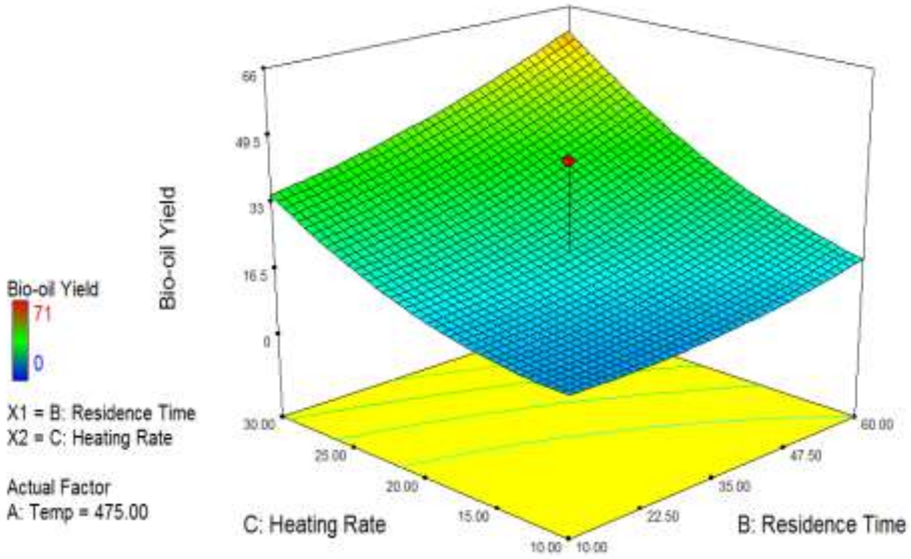

Figure 3: The Response surface contour for interaction between Residence Time and Heating Rate on Bio-oil Yield.

Figure 3 presents the interactive effect of heating rate and resident time on the yield of bio-oil. There was no significant effect of the increase in resident time on the yield, this is due to the biomass composition degradation and conversion which depends on temperature and heating rate. It was observed that at low and high residence time, the yield of the bio-oil shows no significant effect.

CONCLUSION

This research was carried out to study the effects of key process parameters on the yield of shea butter shell bio-oil. The optimization of pyrolysis process of was made possible by three-factorial central composite design using response surface methodology in 20 experimental runs. A second-order quadratic model capable of predicting the shea butter shell bio-oil yield based on the process variables was developed. 71.20 ml optimum yield was predicted with desirability of 0.7992 at optimum conditions of temperature and heating rate 600 °C and 30 °C/ml. Statistical analysis of variance (ANOVA) of results show that both temperature and heating rate has a positive effect on the bio-oil yield, residence time effect is less significant, however temperature and heating rate has higher effect than the residence time.

REFERENCE

Bridgwater, A. V., Peacocke, G. V. C. (2000); Fast pyrolysis processes for biomass. *Renew Sustain Energy Rev*. 4:1-73.Bridgwater, A. V. (2012); *Biomass and Bioenergy, 38* (2–3), 68–94.

Bulushev, D.A., Ross, J.H.R. (2004): Catalysis for conversion of biomass to fuels via pyrolysis and gasification: a review. Catal. Today 171, 1–13 (2011) Czernik, S.; Bridgwater, A. V. *Energy & Fuels*, No. 12, 590–598.

Demirbas A. (2008); Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energ Conver Manage; 49:2106–16. http://dx.doi.org/ 10.1016/j. enconman.2008.02.020

Kumar Sadhukan, A., Gupta, P., Kumar Saha, R. (2009); Modelling of pyrolysis of largewoodparticles. *Bioresource Technology*. 100, 3134-3139.

Noumi ES, Dabat M, Blin J. (2013); Energy efficiency and waste reuse: a solution for sustainability in poor West African countries? Case study of the shea butter supply chain in Burkina Faso energy efficiency and waste reuse: a solution for sustainability in poor West African countries. J Renew Sustain Energy; 53134. http://dx.doi.org/10.1063/1.4824432.

Ouédraogo IWK, Mouras S, Changotadé OA, Blin J. (2017); Development of a new solid catalyst for biodiesel production using local vegetable resources, adapted to the contexts of the West African countries. Waste and biomass valorization; 0:0. http://dx.doi.org/10.1007/s12649-017-9964-3.

Smets, K., Roukaerts, A., Czech, J., Reggers, G., Schreurs, S., Carleer, R., Yperman, J. (2013): Slow catalytic pyrolysis of rapeseed cake: product yield and characterization of the pyrolysis liquid. Biomass Bioenerg. 57, 180–190.

Trubetskaya, A. (2016). Fast pyrolysis of biomass at high temperatures. Kgs. Lyngby: Technical University of Denmark (DTU).

Venderbosch, R. H.; Wolter, P (2011). In *Thermochemical Processing of Biomass:*
Conversion into Fuels, Chemicals and Power; Brown, R. C., Ed.; John Wiley & Sons: Chichester, U.K.; pp 124–156.

Yaman, S. (2004); Pyrolysis of biomass to produce fuels and chemical feedstocks. Energy Convers. Manag. 45, 651–671.

Yin, C.Y. (2011); Prediction of higher heating values of biomass from proximate and ultimate analyses. Fuel 90, 1128–1132.

APPENDIX

Table 3: Surface Response design matrix for the production of Bio-oil

Run	A: Temperature (°C)	B: Residence Time (min)	C: Heating Rate (°C/min)	Experimented: Bio-oil Yield (mL)	Predicted: Bio-oil Yield (mL)
1	-1	-1	-1	5.00	6.95
2	1	-1	-1	25.30	21.56
3	-1	1	-1	4.50	6.95
4	1	1	-1	22.55	21.56
5	-1	-1	1	24.00	24.91
6	1	-1	1	51.20	71.00
7	-1	1	1	25.55	24.91
8	1	1	1	51.50	53.45
9	-1.682	0.000	0.000	4.50	5.75
10	1.682	0.000	0.000	47.20	47.25
11	0.000	-1.682	0.000	23.00	23.25
12	0.000	1.682	0.000	23.00	23.25
13	0.000	0.000	-1.682	4.50	3.54
14	0.000	0.000	1.682	49.00	50.01
15	0.000	0.000	0.000	22.55	23.25
16	0.000	0.000	0.000	22.50	23.25
17	0.000	0.000	0.000	22.50	23.25
18	0.000	0.000	0.000	23.00	23.25
19	0.000	0.000	0.000	22.55	23.25
20	0.000	0.000	0.000	22.55	23.25

Table 4: R-Squared Estimates

Standard Deviation	14.51	R-Squared	0.7992
Mean	32.75	Adj R-Squared	0.6184
C.V. %	44.32	Pred R-Squared	0.1797
PRESS	8604.36	Adeq Precision	7.434

Figure 4: Plot of Predicted and Actual Bio-oil Yield

Figure 4 shows the linear relationship between the predicted and experimental bio-oil yield of shea butter shell using fast pyrolysis