

Optimization and modeling of process parameters on the yield of enhanced pyrolysis oil during co-pyrolysis of cassava peel with polystyrene

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A B S T R A C T

The co-pyrolysis of cassava peel (CP) and a synthetic waste, that is polystyrene (PS) has been investigated to optimize the yield of biofuel with improved properties. The main and interaction effects of process variables (temperature, feedstock ratio, and pyrolysis time) on the yield of pyrolysis oil were modeled and the optimal condition for enhanced pyrolysis oil yield was determined using response surface methodology by employing the central composite design matrix. A model equation was generated using the data obtained and the significance of the model was investigated using analysis of variance to determine if the fit of multiple regressions was significant. Some physical properties of the pyrolysis oil at the optimum condition were determined to investigate the suitability of the pyrolysis oil as a fuel source. From the statistical analysis, the study concluded that the feedstock ratio has the most significant effect on the yield of pyrolysis oil.

1. Introduction

The rapid increase in the rate of growth of human population, industrialization, and economic prosperities of nations has placed a huge demand on the use of fossil fuels such as coal, crude oil, and natural gas which has resulted in the depletion of these resources and severe environmental challenges resulting to ecological and economic imbalance as a result of the utilization and exploitation of these conventional fuels (Cepeliogullar and Putun, 2013; ; Uzoejinwa et al., 2019; Mishra and Mohanty, 2020). This has encouraged research efforts into new frontiers to seek alternative fuels. According to Shafiee and Topal (Shafiee and Topal, 2009), the world's coal reserve is estimated to be available till at least the year 2112 and will be the only fossil fuel available in the world after 2042. Research efforts are geared toward finding alternative fuels and developing technologies that are highly efficient, sustainable, and environmentally friendly (Abnisa and Daud, 2014). Countries of the world can deal with the problems resulting from rapid population and economic growth resulting in the emission of a high percentage of carbon dioxide into the atmosphere by switching to a sustainable low carbon energy system (Zhang et al., 2017).

Nigeria like other developing nations is facing myriads of energy-related problems including environmental challenges due to exploration and exploitation of fossil fuel, depletion of fossil fuel reserves, inadequate electricity supply due to rapid population growth, and lack of proper planning by the government. These highlighted challenges in Nigeria and other nations of the world can be resolved by utilizing the abundantly available renewable energy resources such as biomass, solar, wind, hydropower energy. Biomass represents an important renewable

energy resource and has the advantage of being converted into several forms of fuel called biofuels. Biofuel can exist in solid (char), liquid (bio-oil), and gas with flexibility in its production and marketing (Zhao and Yan, 2012). According to Uzoejinwa et al. (2019) by the middle of the twenty-first century biomass which is currently the fourth largest source of renewable energy is expected to contribute between 15 and 50% of the energy supply worldwide. Biomass refers to all forms of organic energy resources derived from both plant and animal together with the by-product obtained from utilizing these materials which have accumulated over some time apart from fossil fuel. They are substances where energy from the sun is trapped and stored (Goyal et al., 2008) including those derived from food crops (wheat, soybean sugarcane, corn starch), and those from energy crops (willow, poplar, elephant grass, and so on). The availability of biomass materials varies from one country to another and is dependent on factors such as climatic and geographical conditions, population growth and demand for food products, industrialization, advancement in agriculture production and processing techniques, lifestyle, and energy production, and processing technology (Uzoejinwa et al., 2019; Mishra and Mohanty, 2020).

Biomass is converted into fuel by employing either thermochemical or biochemical methods. However, thermochemical methods such as combustion, gasification, pyrolysis, and liquefaction are preferred since they are relatively faster than those from biochemical methods. Also, thermochemical methods can be deployed in producing energy from some waste materials such as plastics which are not amenable to decomposition via the activities of microorganisms as found in biochemical methods (Kositkanawuth et al., 2014). Pyrolysis is considered to be the most efficient and promising method of conversion with a high

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fuel-to-feed ratio when compared with other thermochemical methods (Demirbas, 2002). Pyrolysis involves the thermal decomposition of a solid in the absence of oxygen to produce a wide array of solid, liquid, and gaseous products. Pyrolysis technology has been at the forefront of research endeavors for the conversion of biomass into biofuel because it is very efficient in the extraction of energy from biomass especially liquid fuel known as pyrolysis oil. Several investigations have been done on the potentials of converting different biomass types into biofuel via pyrolysis and utilizing these biofuels as energy sources (Gavrilescu, 2008). However, the use of biomass as energy sources is hampered by competing interests as sources of food for human consumption and the availability of land for crop production (Uzoejinwa et al., 2018).

In recent times, the utilization of agricultural production and processing wastes as energy sources has taken center stage (Ke et al., 2019; Moustakas et al., 2019; Bilandzija et al., 2018). Agricultural production and processing wastes refer to all such biomass materials resulting as a byproduct from the production and processing including crop field residues such as crop straw, crop process residues such as rice husk and corn cob, livestock breeding wastes like farm manure, and slaughterhouse wastes such as carcasses (Wei et al., 2020). Advances in technology have made the conversion of these wastes into diverse forms for energy utilization through processes such as gasification, pyrolysis, and so on. The utilization of agricultural production and processing waste for energy cannot be overemphasized since large-scale farming generates a huge amount of waste which contributes significantly to environmental pollution challenges if not properly managed (Tsapekos et al., 2018; Paudel et al., 2017).

Pyrolysis oil from different biomass sources has the potential to be deployed as fuel for diverse applications. However, a major drawback to its utilization is the high oxygen content of the pyrolysis oil resulting in low calorific value and instability when compared with fossil fuels (Bridgwater et al., 1999; Oasmaa and Czernik, 1999; Isahak et al., 2012; Li et al., 2014). The overall properties of the pyrolysis oil can be enhanced leading to improvement in the quantity and quality of pyrolysis oil when biomass is blended with synthetic polymers such as plastics because synthetic polymers contain lesser oxygen and have calorific values comparable to that of conventional fossil fuels (Abnisa et al., 2013; Mei-Yu and Bao-Xia, 2016). The inherent properties of biomass and synthetic polymers differ leading to a change in the thermal behavior and reactivity of the resulting material and the product formed from the co-pyrolysis. Several studies have been conducted on the co-pyrolysis of biomass with synthetic polymers with the overall aim of improving the quality and quantity of pyrolysis oil produced from the process. Mishra and Mohanty (2020) investigated the co-pyrolysis of different plastic wastes with Mahua seed; they submitted that blending plastic waste at 20 wt% with the biomass yielded the maximum amount of pyrolysis oil and resulting in the minimization of oxygen-rich compound in the product of pyrolysis. Hossain et al. (2019) blended polyethylene and rice straw using a feedstock ratio of 1:1 in a fixed bed reactor and obtained a maximum yield of 61 wt% at 430 °C, they also submitted that there was a significant improvement in the quality of pyrolysis oil obtained compared with when each was individually pyrolysed. Kositkanawuth et al. (2017) also carried out a study on the co-pyrolysis of Sargassum brown algae with polystyrene and submitted that the co-feeding macroalgae with polystyrene having low oxygen content improved the quantity and quality of pyrolysis oil produced Xue et al. (2015) co-pyrolysed high-density polyethylene (HDPE) and red oak from 525 °C to 675 °C in a continuous fluidized bed reactor and reported 57.6 wt% yield of liquid oil at 625 °C with enhanced properties. Feedstock ratio was identified by Sharypov et al. (2003) as the most vital parameter in the production of pyrolysis oil with their study corroborated by Abnisa and Daud (2014) who also studied the co-pyrolysis of palm shell and polystyrene waste mixed in the production of pyrolysis oil.

Different factors such as feedstock blending ratio, pyrolysis temperature, resident time, heating rate, particle size, feed to catalyst ratio,

etc. contribute towards improving the yield and quality parameters of pyrolysis oil during co-pyrolysis. The optimization of these process parameters is a very important and interesting area currently gaining momentum. The co-pyrolysis of blends of waste plastics and Mahua oilseed was carried out by Mishra and Mohanty (2020) and they submitted that the blend having 20 wt% of plastic has the highest yield with substantial improvement in hydrocarbon content and minimization in oxygen-rich products in the pyrolysis oil. Uzoejinwa et al. (2018) carried out a study on the optimum condition required to maximize the yield of pyrolysis oil during the co-pyrolysis of seaweeds and waste plastics and submitted that an obvious synergistic effect enhanced the yield of pyrolysis oil with all three parameters considered, that is, feedstock blending ratio, temperature, and heating rate significantly affecting the yield. Similarly, Hu et al. (2017) also carried out a study on the co-pyrolysis of lingo-cellulosic biomass (wood sawdust) and petroleum sludge by employing response surface methodology.

Co-pyrolysis technology is a very promising technique, the modeling, and optimization of which will contribute towards the production of high-quality pyrolysis oil and help to reduce the problem of waste disposal significantly. Although some research efforts have been carried out on the co-pyrolysis of different biomass with polystyrene; the co-pyrolysis of cassava peel waste with polystyrene and the optimization of the process parameters remain undocumented to the best of the authors' knowledge. Recently, the world cassava production stands at 291 million tonnes (Otekinrin and Sawicka, 2019). Nigeria, with annual production above 59 million metric tonnes (MT) per in 2017 is the highest cassava producer in the world representing about 20% of global production (Food and Agriculture Organization of the United Nations (FAO) 2019). The processing of cassava generates a huge volume of cassava peel wastes which are carelessly dumped on dumpsites and allowed to deteriorate or burnt; utilizing cassava peel wastes as a feedstock for energy production will significantly enhance the management of cassava peel wastes thereby mitigating the challenge of environmental pollution associated with the mismanagement of the waste. PS is a major component used in food packaging industries in Nigeria and constitutes a large fraction of the 2.5 million tonnes plastic wastes generated annually in Nigeria (voanews). PS can also be deployed for energy generation instead of constituting environmental and health risks associated with the improper management of solid wastes in developing countries like Nigeria. This research endeavor carried out a study on the optimization of some of the process parameters in the co-pyrolysis of cassava peel wastes with polystyrene in a fixed bed reactor towards producing high-quality pyrolysis oil and reduction of these waste fractions. The study will help to develop an effective strategy most especially in the area of operations planning, recycling, and management of waste fractions.

2. Materials and methods

2.1. Materials

Cassava peel waste and polystyrene were used as feedstock for this experimental study. Cassava peel wastes obtained from a local cassava processing factory in Ile-Ife, Osun State, Nigeria were sundried and then pulverized particle sizes ranging between 0.18–0.45 mm and oven-dried for 24 h at 80 °C (Uzoejinwa et al., 2018). Polystyrene waste samples obtained from food packs discarded on a dumpsite in Ile-Ife Osun State, Nigeria were thoroughly cleaned and then shredded to an approximate uniform size of 10 × 10 mm and air-dried (Yuliansyah et al., 2015). The prepared feedstock materials were then thoroughly mixed at different mass ratios.

2.2. Experimental analysis

The proximate analyses of the feedstock materials were obtained on a dry basis using ASTM standards to determine the fixed carbon content, the volatile matter content, moisture content, and ash content. Ultimate

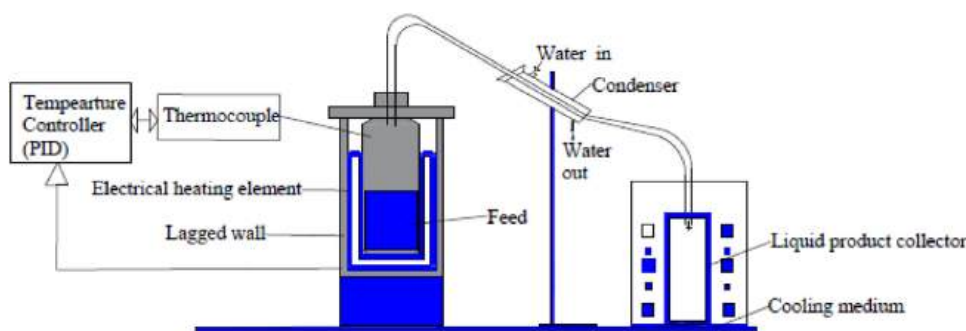


Fig. 1. Schematic diagram of experimental arrangement.

Table 1
Physicochemical properties of cassava peel and Polystyrene (PS).

Parameters	Cassava peel (CP)	Polystyrene (PS)
<i>Proximate analysis (wt%)</i>		
Fixed carbon	13.57	0.8
Volatile matter	78.73	98.31
Ash content	2.01	0.1
Moisture content	5.69	0.79
<i>Ultimate analysis (wt%)</i>		
Hydrogen	6.28	5.74
Nitrogen	0.72	–
carbon	53.66	93.76
sulfur	0.29	–
Oxygen	37.61	0.50
Calorific value (MJ/kg)	15.92	41.1

analysis was also done to determine the elemental compositions of each sample. The proximate and ultimate analyses of the feedstocks (CP and PS) are shown in Table 1. As presented in the table, polystyrene had a relatively higher volatile matter and negligible moisture content compared with cassava peel. The percentage volatile matter of cassava peel and PS were 78.73 and 98.31 wt% respectively. The two samples also have low ash content with cassava peel having 2.01% while polystyrene had an ash content of 0.1 wt%, this suggests that both samples are good candidates for fuel because high ash content leads to an increment in combustion remnant resulting in a reduction in the heating effect of the fuel (Bajracharya et al., 2016). PS consists mainly of carbon and hydrogen with a little amount of oxygen and trace quantities of nitrogen and sulfur. The high percentage of carbon and hydrogen in the plastic samples shows that they are good sources of liquid hydrocarbon which can be deplored as biofuel (Uzoejinwa et al., 2019). The nitrogen (N) and sulfur (S) content determine the rate of emission of their oxides (NOx and SOx) which are by-products from the combustion of a fuel feedstock.

2.3. Experimental set-up

The co-pyrolysis experiments were carried out in a laboratory-scale fixed-bed pyrolyser as shown in Fig. 1. A programmable temperature controller was attached to the reactor which was fabricated from stainless steel having an internal diameter of 10 cm and a height of 33.5 cm and heated with an electric resistance wire. Temperature changes within the reactor were taken using a type K thermocouple inserted into the reactor. The organic phase was recovered in a product collection vessel immersed in a freezing mixture consisting of a blend of ice and calcium chloride in ratio 1:4

2.4. Experimental design and optimization

Design Expert Software Version 8.0.0 was used to design the experiments and the design matrix employed in the study was the central composite design (face-centered) model. The independent variables are the feedstock ratio (% wt), reaction temperature (°C), and reaction time

Table 2
Specification of variables and the experimental domain.

Independent Variable	Code	Experimental Domain		
		–1	0	+1
A: Temperature (°C)	X ₁	400	500	600
B: Ratio of Cassava Peels/Plastic Wastes (%)	X ₂	70/30	50/50	30/70
C: Reaction Time (min)	X ₃	30	40	50

(minutes) to achieve a high value of bio-oil yield (%) set as the measurable response factor. Each batch of the experiment was carried out with 150 g of feedstock and the variables are varied over three levels as shown in Table 2 below. In this study, the liquid product was considered as the main product while the bio-char and non-condensable gas were considered as the byproduct.

The total number of treatment combinations was calculated to be 20 experimental runs by employing the equation below (Abnisa et al., 2013)

$$N = 2^k + 2k + N_o \quad (1)$$

Where k represents the number of independent variables and N_o is the amount of repetition of experiments at the central point. Each blend was heated to the reaction temperature as specified in Table 2, and a condenser was used to transform the volatile into liquid form and collected in an oil collector. After each pyrolysis process, the weight pyrolysis oil contained in the oil collector was determined and the weight of the biochar left in the reactor also taken. The percentage yield of pyrolysis oil and biochar was then determined using the equation by Ross et al. (2008) while the yield of bio gas was determined from the overall mass balance.

$$\text{Desired yield (wt\%)} = \frac{\text{Desired product}}{\text{Total product}} \times 100\% \quad (2)$$

The result from the experimental runs was then incorporated to the polynomial model to estimate the response of the system using the equation below (Abnisa et al., 2011)

$$Y = \beta_o + \sum_{i=1}^n \beta_i \times X_i + \sum_{i=1}^n \beta_{ii} \times X_i^2 + \sum_{i=1}^n \sum_{j>1}^n 6 \beta_{ij} \times X_i X_j \quad (3)$$

where Y represents the response predicted; n represents the number of experiment performed; β_o , β_i , β_{ii} and β_{ij} are regression coefficients for the constant, linear, quadratic and interaction coefficients, respectively; and X_i and X_j are the coded independent factors.

2.5. Characterization of pyrolysis oil

The elemental analysis of the pyrolysis oil at optimum condition was done using ASTM standards. Before the characterization, the pyrolysis oil was separated into two fractions using a centrifugation process by employing the method developed by Bertero et al. (2012). The method involved the centrifugation of the pyrolysis oil for 8 min at 3200 rpm.

Table 3
Central composite design (CCD) matrix of experimental and yield response.

Run	Reaction temperature (°C)	Feedstock ratio (cassava peel: polystyrene)	Time (minutes)	Bio-char yield (wt%)	Gas yield (wt%)	Liquid yield (wt%)
20	400	30	30	19.6	47.8	32.6
18	400	30	50	18.2	47.7	34.1
1	400	50	40	24.1	39.1	35.8
10	400	70	30	34.7	28.8	36.5
4	400	70	50	29.1	34.2	36.7
13	500	30	40	13.8	49.3	36.9
8	500	50	30	19.4	41.5	39.1
17	500	50	40	17.6	43.3	39.1
14	500	50	40	16.2	44.6	39.2
12	500	50	40	16.7	44.0	39.3
11	500	50	40	16.3	44.4	39.3
6	500	50	40	16.2	44.5	39.3
16	500	50	40	16.4	44.3	39.3
5	500	50	50	16.3	44.3	39.4
7	500	70	40	17.9	42.6	39.5
19	600	30	30	12.8	47.3	39.9
9	600	30	50	12.1	46.8	40.4
15	600	50	40	14.7	44.2	41.1
2	600	70	30	14.1	44.7	41.2
3	600	70	50	13.4	45.3	41.3

The calorific value of the pyrolysis oil was determined using an oxygen bomb calorimeter (XRY-1C) available at the department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. Other properties such as density, pH, pour point and flash point were also carried out.

3. Results and discussion

3.1. Optimization study of processing conditions

The quantity of pyrolysis oil produced during co-pyrolysis of cassava peel and polystyrene at different operating conditions is presented in Table 3. The result in Table 3 showed a variation in the yield of pyrolysis oil from 32.6 wt% to 41.3 wt% and it can be generally seen that the yield of pyrolysis oil increased with increases in the proportion of PS in the blend, which has been attributed to the higher volatile matter content and a higher percentage of hydrogen and carbon in polystyrene compared with cassava peel (Uzoejinwa et al., 2018). A model was developed by fitting by a second-order polynomial function for the yield of pyrolysis oil as shown by Eq. (4). Response surface methodology was employed in modeling the main and interaction effects of the three experimental factors that is, temperature (A), feedstock ratio (B), reaction time (C) and the result revealed that these main and interaction effects were significant in determining the yield of pyrolysis oil.

$$\text{Yield} = 39.32 + 0.98A + 2.72B + 0.68C - 0.37AB - 0.20AC - 0.15BC + 0.15A^2 - 0.55B^2 - 1.25C^2 \quad (4)$$

From the model equation, it can be seen that the feedstock ratio (B) has the greatest influence on the pyrolysis oil yield due to its large coefficient. The result for the analysis of variance (ANOVA) is as shown in Table 4. The p-value serves as a tool for determining the significance of each coefficient. Smaller p-values indicate a higher level of significance for the corresponding coefficient. From the Table, A, B, C and C² are significant model terms at a p-value of 0.05. The most significant factor on the yield of pyrolysis oil is the feedstock ratio B due to the fact that B has the smallest p-value when compared with other parameters. The same trend was reported by other researchers who concluded that there was a significant enhancement of the pyrolysis oil yield when the plastic component was at a higher ratio than biomass in co-pyrolysis (Cornelissen et al., 2008). The fit of the model is expressed by the coefficient of determination, R², (0.9743) which indicates that 97.43% of the variability in the response could be explained by the model. The

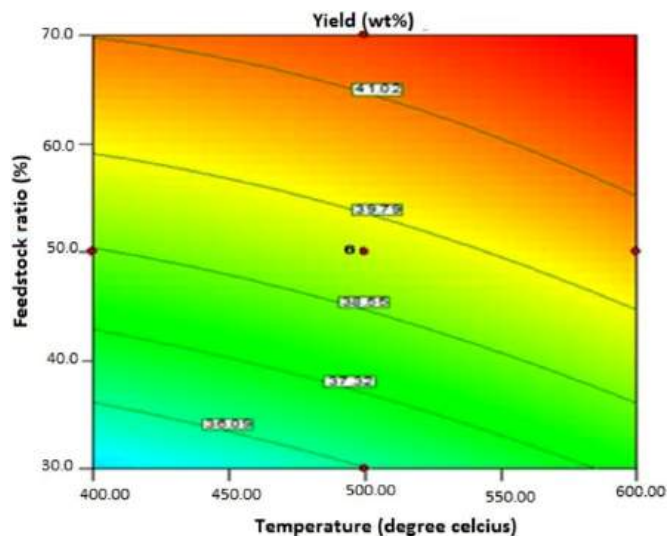


Fig. 2. Contour plot of pyrolysis-oil yield with the combined effect of feedstock ratio and reaction temperature.

adequacy of precision ratio which measures the signal to noise ratio is calculated to be 24.335. This indicates an adequate signal since the adequacy of precision ratio is above 4.

All the three parameters considered (feedstock ratio, reaction time, and reaction temperature) were found to have significant effects on the yield of the pyrolysis oil, based on ANOVA, contour plots were developed. Contours plots are employed to provide a visual interpretation of the interaction between two variables. The shape of the contour plots provides a measure of the significance of the mutual interaction between the variables. When a plot is circular in shape, it suggests that the interactions between variables are negligible while an elliptical contour plot signifies that the interaction between variables is significant. The contour plot for the yield of pyrolysis oil from the variation of CP and PS feedstock ratio and reaction temperature is as shown in Fig. 2 which shows that increasing the ratio of PS in the blend and reaction temperature leads to a corresponding increase in the yield of the pyrolysis-oil.

This indicates a direct relationship between these variables during pyrolysis. Maximum pyrolysis oil yield of 41.02 wt% was obtained at the optimal condition of a reaction time of 40 min and temperature

Table 4
ANOVA for response surface quadratic model.

Source	Sum of Squares	Df	Mean Square	F-Value	p-value Prob > F	Remarks
Model	101.620	9	11.291	42.05	< 0.0001	Significant
A-Temperature	9.604	1	9.604	35.77	0.0001	
B-Feedstock ratio	73.984	1	73.984	275.56	< 0.0001	
C-Time	4.624	1	4.624	17.22	0.0020	
AB	1.125	1	1.125	4.19	0.0678	
AC	0.320	1	0.320	1.19	0.3006	
BC	0.180	1	0.180	0.67	0.4320	
A ²	0.066	1	0.066	0.24	0.6316	
B ²	0.818	1	0.818	3.05	0.1115	
C ²	4.266	1	4.266	15.89	0.0026	
Residual	2.685	10	0.268			
Lack of Fit	2.665	5	0.533	133.24	< 0.0001	Significant
Pure Error	0.020	5	0.004			
Cor Total	104.300	19				

Std. Dev = 0.52.
 Mean = 38.5.
 R-squared = 0.9743.
 Adj R-squared = 0.9511.
 Pred R-squared = 0.7897.
 PRESS = 21.94.
 Adeq. Precision = 24.335.

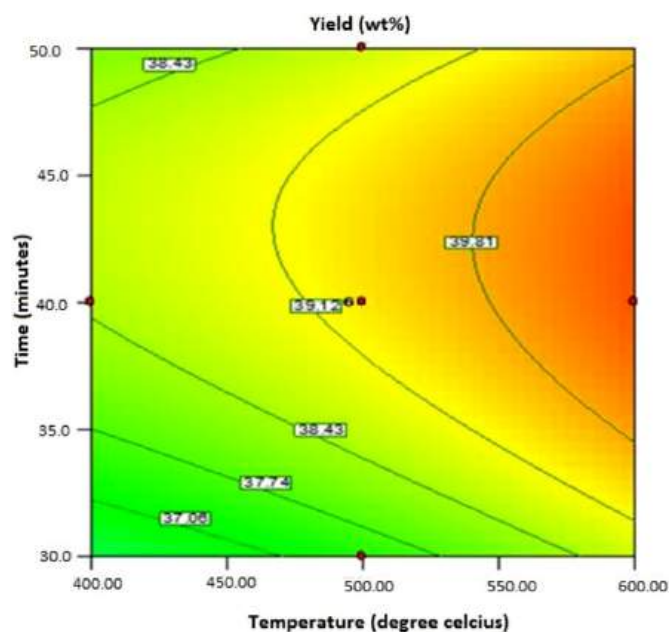


Fig. 3. Contour plot of pyrolysis-oil yield with the combined effect of reaction time and temperature.

of 600 °C when the proportion of PS in the blend was 70 wt%. Fig. 3 showed the contour plot for the pyrolysis oil yield from the variation of reaction temperature and reaction time. The contour plot for the yield of pyrolysis oil from the variation in feedstock ratio and reaction time is shown in Fig. 4. The quadratic model presented in Eq. (4) was used in the optimization of the yield of pyrolysis oil by differentiating the equation and solving for the values of A, B and C, at the stationary points. The prediction of the model suggests that at a reaction temperature of 446.4 °C, feedstock ratio of 40:60 (CP: PS) and reaction time of 45.2 min, the yield of pyrolysis-oil was maximized at 42.71 wt.%. Validation of the model's prediction was done by carrying out three confirmatory tests in the fixed bed reactor at the optimal conditions specified as shown in Table 5. The mean yield of pyrolysis oil during actual experimentation from Table 5 is 42.72 wt.% which is close to the model's prediction of pyrolysis oil yield, indicating that the model's prediction is accurate.

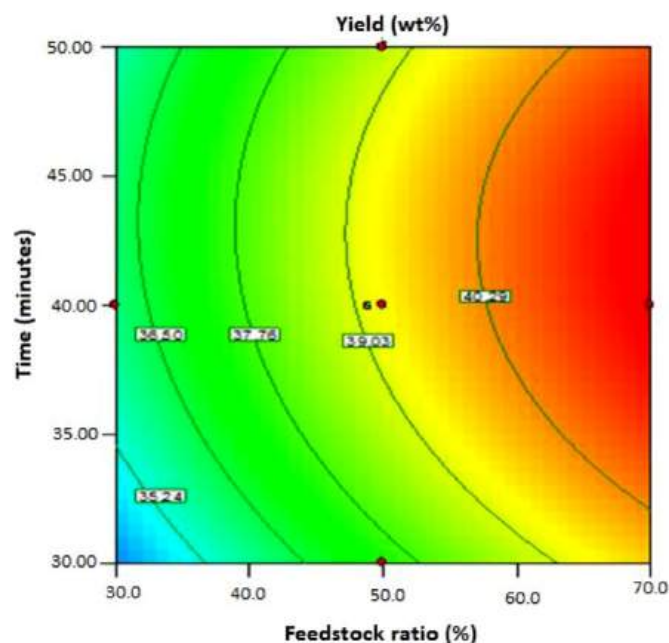


Fig. 4. Contour plot of pyrolysis-oil yield with the combined effect of reaction time and feed ratio.

3.3. Characterization of pyrolysis-oil

The pyrolysis oil obtained under optimum conditions, that is, reaction time of 45.2 min, reaction temperature of 446.4 °C, and feedstock ratio of 40:60 (CP: PS) was employed in the determination of physical and chemical characteristics. A summary of the characterization of pyrolysis oil and comparison with conventional diesel is given in Table 6. The dynamic viscosity of the pyrolysis-oil was 2.35 mPas which is within the range of 1.3 - 2.4 mPas for conventional diesel fuel (ASTM D975 2013). The pH value of the pyrolysis-oil for the co-pyrolysis of cassava peel and PS at optimized conditions was 3.1. The pH value in the range of 2 to 4 indicated the presence of organic acid. The density of pyrolysis-oil was found to be 0.94 g/cm³, which is slightly higher but in close comparison to the range of 0.815–0.870 g/cm³ for diesel (ASTM D975 2013).

Table 5
Confirmatory experimental run at optimal condition.

Runs	Experimental factors			Pyrolysis oil yield (wt.%)	
	Reaction Temperature (°C)	Feedstock Ratio (wt.%) CP:PS	Time (Minutes)	Actual	Predicted
1	446.4	40:60	45.2	42.75	42.71
2	446.4	40:60	45.2	42.74	42.71
3	446.4	40:60	45.2	42.67	42.71

Table 6
Comparison of characteristics of pyrolysis oil with conventional diesel.

Properties	Unit	This study	Conventional diesel (ASTM D975 2013)
Dynamic Viscosity	mPas	2.35	1.3–2.4 @ 25 °C
pH		3.1	5.6 @25 °C
Density	g/cm ³	0.94	0.815 - 0.870
F lash point	°C	52.1	52 Min
P our point	°C	−6	−9.5 °C
Calorific value (HHV)	MJ/kg	40.6	43.06

The flash point of the pyrolysis-oil was 52.1 °C, is lower than the range specified for conventional diesel (55–60 °C) according to (ASTM D975 2013). The pour point of the optimized pyrolysis oil in this study was found to be −6 °C which is better than that obtained from the pyrolysis of biomass materials. Calorific value is an important characteristic of any substance being considered for the generation of energy. A high calorific is indicative of a high energy content, therefore a large amount of energy can be generated with less quantity of fuel. The calorific value (HHV) of the pyrolytic liquid is determined to be 40.6 MJ/kg which is comparable to the HHV of 43.06 MJ/kg for conventional diesel (ASTM D975 2013).

4. Conclusion

The investigation of the co-pyrolysis behavior of cassava peel with polystyrene was done to determine the optimum processing condition to maximize the yield of enhanced pyrolysis oil. Main and interaction effect of the co-pyrolysis parameters, that is, reaction temperature, reaction time and feedstock ratio on the yield of pyrolysis oil were modeled and optimization studies was done to predict the optimum processing condition to maximize the yield of enhanced pyrolysis oil using central composite experimental design. Result from experimental investigations revealed that the feedstock ratio has the most significant effect on the yield of pyrolysis oil due to the large value of its coefficient in the model equation developed and its small p-value. The prediction of the model developed gives the optimum conditions for maximizing pyrolysis oil yield to 42.71 wt%. at reaction temperature of 446.4 °C, feedstock ratio of 40:60 (CP: PS) and reaction time of 45.2 min. Characterization of the pyrolysis oil obtained at optimized setpoints had similar viscosity and heating values as conventional diesel. Further studies can be carried out on the upgrading to pyrolysis oil to serve as a substitute for diesel fuel and to investigate the potential of pyrolysis in the management of these wastes to help mitigate the challenge of solid waste disposal.

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