Pyrolysis of Waste Plastic Laminates and Coconut Husk: Optimization of Fuel Oil Yield, Higher Heating Value and Energy Value

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Abstract
Alongside increasing use of single-use plastics, especially in developing countries is increasing mismanaged solid wastes. There is great need for economically viable processes such as pyrolysis that can convert waste to energy resource. Coconut husk, which is also an abundant waste in tropical countries is a good material for co-pyrolysis with single-use plastic, as both have high energy content. Thus, this study determines the potential of plastic laminates and coconut husk pyrolysis as feedstock for production of pyrolystic oil. It aimed to determine the effects of feedstock mixture composition (percent coconut husk: (32%, 42%, 51% coconut husk), process temperature (500^{o}C, 600^{o}C, 700^{o}C) and particle sizes (1cm, 3cm, 5cm) on the percentage yield, gross calorific value and energy value of the output pyrolytic oil. Using RSM response optimizer, optimum oil yield is 32.5%, which is at feedstock of 50.42% coconut husk, 5-cm partcle size and 700^{o}C. Feedstock of 32% coconit husk, 5-cm particle size and 700^{o}C will give the highest HHV of 34.1142 MJ/Kg. Maximum energy of 6.0032 MJ will be obtained at feedstock of 51% coconut husk, 5-cm particle size and 700^{o}C. ANOVA analysis showed that all the three parameters tested are significant factors affecting oil yield and energy yields. Temperature and percentage coconut husk have greater influences on yield, HHV and energy value than particle size.
Keywords: coconut husk, plastic laminates, co-pyrolysis

1. Introduction

The global production of plastics has increased 183 times, from 1.7 Mt in 1950 to 311 Mt in 2015 (UNEP, 2016). Recent estimates show that ca. 8 million MT/year of plastics are brought to the oceans (Jambeck et al., 2015) and Philippines is among the top 10 countries as sources of mismanaged plastic wastes reaching the ocean. Plastics is about 10% of the wastes in dumpsites and sanitary landfills. On top of this ca. 1.88 million MT of mismanaged plastics were from the Philippines (Jambeck et al., 2015). Meanwhile , agricultural waste biomass is considered as one of the renewable energy sources with the highest potential to contribute to the energy needs of modern society (Balasundram et al., 2017). The thermal process of converting waste plastics and biomass into fuels are promising techniques to eliminating refuse which otherwise is harmful to the environment, and decrease the dependence on fossil fuels (Kunwar et al., 2016) (Hassan et al., 2016). Feedstock mixture, i.e., the ratio of coconut husk to plastics is expected to affect the yield and properties of the pyrolytic oil because the two feedstock are of different composition and properties. The effect of particle size is yet to be determined. Heat transfer and therefore rate of pyrolysis is possibly affected by particle size. This study aimed to determine the optimum conditions, i.e., feedstock composition, particle size and operating temperature, for batchwise co-pyrolysis of coconut husk and plastic laminates. Separate optimization criteria were oil yield, HHV and energy value.

2. Methods

Through Box-Behnken design, a response surface method (RSM), batchwise co-pyrolysis process was optimized considering three parameters: feedstock composition (32%, 42% and 51% coconut husk), particle size (1, 3 and 5 cm) and operating temperature (500, 600 and 700^{o}C). The response parameters were oil yield, HHV and energy value. Waste plastic laminates and coconut husk were collected from dumpsite and agricultural area. Before pyrolysis the materials were cleaned, dried and cut using scissors to have 1, 3 and 5 cm particle size. Total weight of feedstock per batch were 170g, 164g and 176g. Co-pyrolysis of coconut husk and waste plastic laminates were done in a batch reactor of 6-in inside diameter and 0.28-in thick shell. The product gaseous stream was collected through a condenser, from which the condensed portion was collected as the pyrolytic oil product. Pyrolytic oil HHV was determined using a bomb calorimeter.

3. Results and Discussion

The yield, HHV and energy values obtained in pyrolysis batch runs are shown in table 1

Table 1. Pyrolysis performance (Yield, HHV and Energy Values) at different sets of process parameters: feedstock composition as percent coconut husk (CH), particle size (PZ) and temperature (T)

Run #	T°C	PZ cm	CH %	Yield %	HHV MJ/kg	Energy MJ
1	500	1	42	19.72	25.4	4.32
2	700	1	42	25	25.5	4.34
3	500	5	42	20	25.5	4.33
4	700	5	42	30.5	26	4.41
5	500	3	51	10.2	21	3.46
6	700	3	51	25.5	21.4	3.51
7	500	3	32	20.17	33.9	5.96
8	700	3	32	25.17	33.9	5.963
9	600	1	51	18.33	21	3.44
10	600	5	51	13.98	21.4	3.5
11	600	1	32	27.5	33.9	5.95
12	600	5	32	31.17	33.9	5.962
13	600	3	42	24.1	25	4.25
14	600	3	42	23.4	25.5	4.34
15	600	3	42	22.2	25.8	4.39

The RSM analysis yields equations of response parameter Y as functions of process parameters (A,B, C): (Jung, KA. et. al, 2016)

$$Y = \propto_0 + \sum_{i=1}^{4} \propto_i X_i + \sum_{i=1}^{4} \propto_{ii} X_i X_i + \sum_{i=1}^{4} \sum_{i<j=2}^{4} \left(\propto_{ij} X_i X_j \right)$$

where Xi are the input variables, which influence the response variable Y, $\mathbf{a_0}$ the offset term, a_i the ith linear coefficient, a_{ii} the quadratic coefficient and a_{ij} is the ijth interaction coefficient. The input values of A, B, C and D corresponding to the maximum value of Y were solved by setting the partial derivatives of the functions to zero.

$$\boldsymbol{Pyrolytic\ Oil\ Yield}\ (\%) = \mathbf{6.84107 + 0.028622 * A - 1.58238 * B + 0.30868 * C + 6.52500E-003 * AB + 2.67552E-003 * AC - 0.10315 * BC - 9.56667E-005 * A^2 + 0.38208 * B^2 - 0.025039 * C^2}$$

$$\boldsymbol{Pyrolytic\ Oil\ HHV} \left(\frac{MJ}{Kg}\right) = \mathbf{+92.311 - 0.016791 * A - 0.53992 * B - 2.27809 * C + 5.4875E-004 * AB + 7.09336E-004 * AC - 4.4232E-003 * BC + 1.10083E-005 * A^2 + 0.013708 * B^2 + 0.018752 * C^2}$$

$$\boldsymbol{Pyrolytic\ Oil\ Energy}\ (MJ) = \mathbf{+3.48274 - 1.21013E-003 * A - 0.041068 * B - 0.056791 * C + 3.875E-005 * AB + 5.87137E-006 * AC + 3.93845E-004 * BC + 7.70833E-007 * A^2 + 9.27083E-004 * B^2 + 5.54946E-004 * C^2}$$

where A is the pyrolysis temperature(°C), B is the particle size (cm) and C is the loading mass of coconut husk (percentage).. A, B, C, are the linear factors; AB, AC, and BC represent interaction terms of factors; A^2, B^2, and C^2 stand for quadratic terms of factors.

3.1 ANOVA and optimum values

The ANOVA values for yield, HHV and energy value were (F = 4.90, P = 0.0475), (F = 556.62, P = <0.0001) and (F = 12.93, P = 0.0058), respectively indicating model significance. According to the F-values, the linear term of coconut husk (C) and temperature (A), had a more significant influence on the pyrolytic oil yield, HHV and energy values than did particle size (B). Using response optimizer, the optimum yield of 32.5% occurs at a temperature of 700°C, 5cm particle size and 50.42% coconut husk. For HHV and energy value, for temperature of 700°C, 5.0 cm particle size and 32% coconut husk will have a maximum value of 34.1142 MJ/Kg and 6.0032 MJ respectively.

The total energy values and oil yields ranges from 21-34 MJ per kg and 10-31% of mixed coconut husk and plastic laminates, respectively.

The obtained HHV values were higher than the coconut husk alone was used, with calorific value around 18.62 MJ/kg (Zafar et al., 2015).

4. Conclusions

This study has shown great potential for converting single-use plastic laminates and coconut husk through co-pyrolysis to into an alternative fuel oil, thus addressing both solid waste problems and declining fossil fuel resources. Co-pyrolysis of coconut husk and waste plastic laminates produced fuel oil of good HHV, which is much higher than that of coconut husk alone. Feedstock composition (i.e., percent coconut husk) and pyrolysis temperature have greater, more significant effect than particle size on oil yield, HHV and energy value content of the feedstock. For best oil yield (g oil/g feedstock), temperature should be as high as 700°C and feedstock is of higher percent coconut husk. For best HHV and energy yield (J/kg feedstock), temperature should be at most 700°C and coconut husk is ca. 32% in the feedstock.

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