

Bio-Fuel Source from Combination Feed of Sewage Sludge and Rice Waste

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Abstract— Fast pyrolysis of rice waste and treated sewage sludge was carried out by using fluidized-bed pyrolytic reactor. The aim of the study was to produce bio-oil from combination of sewage sludge and rice waste. The study focus on process optimization based on optimum bio-oil yield produced. The experiment was carried out at varying temperature ranging from 500 to 650 °C. Nitrogen gas was supplied as purge flow with a 50 ml/min flow rate. Co-cracking of feedstocks was conducted to ascertain the appropriate combination or proportion of two or more waste sources which could be combined to optimize the bio-oil yield and balanced each other's weaknesses. The characterization of the feedstocks was also carried out. The optimum bio-oil obtained were 35.46 ± 0.38 wt%, 25.74 ± 0.83 wt% and 21.53 ± 0.58 wt% obtained from RH, RS and TSS respectively at an optimum operating temperature of 600 °C. The bio-oil produced from optimum temperature was analyzed by GC-MS. The study indicated that the majority chemical compounds of bio-oil from fast pyrolysis were phenol, aromatic, nitrogenated compound, alkenes and alkanes.

Keywords—component; pyrolysis; rice waste; treated sewage sludge; bio-oil

I. INTRODUCTION

Economic development and rising of living in Malaysia have led to increase in the quantity of waste generation. It is estimated that over 9 million tonnes of rice waste are generated annually from rice milling industry. Normally rice waste is used as animal feed, composting, burned as thermal energy for during purposes and others are burned on the field. Whereas, the total production of domestic sewage sludge in Malaysia is 3.2 million cubic meter per year [1]. Most of the sewage sludge waste was disposed by sanitary landfills, agriculture decomposition, incineration and dumping into the sea [2].

Utilization of the two sources of waste via energy recovery has the potential to solve waste management problem and also generate useful energy. There are several technologies for converting biomass into energy and higher value products, these are mainly classified as: biochemical process, physical methods, agro-chemical and thermo-chemical process. Amongst other thermo-chemical processes (direct combustion, gasification and pyrolysis), pyrolysis has attracted the most attention [2].

Pyrolysis is a technology which could convert biomass into energy in absence of oxygen. This thermal degradation produces three main products: char (solid), bio-oil (liquid) and gas [3]. Generally, there are two types of pyrolysis

process. The process may be conventional or flash pyrolysis. There are various types of reactors that could be used in the pyrolysis process.

Reference [4] investigated the pyrolysis of a single feed, sewage sludge from wastewater treatment plant of petrochemical industry using fixed-bed reactor. The process produced 39.3 - 43.9 wt% bio-oil, char 39.9 - 41.2 wt% and 14.9 - 20.9 wt% of gas at temperature 500 °C. Reference [5] investigated three types of sludge from different types of food processing factories using the same reactor type. The process was conducted from room temperature to 500 °C. The bio-oil produced was 22.0 % to 53.6 %. Reference [6] pyrolyzed sewage sludge in quartz reactor at 350, 450, 550 and 950 °C. The bio-oil yield reached a maximum value at 450 °C with 13 wt%. The compounds indentified in bio-oil were grouped as follows: n-alkanes and 1-alkenes, monoaromatics hydrocarbons, nitrogenated compounds, and polyaromatic hydrocarbons (PAHs).

Reference [7] pyrolyzed rice husk at temperatures between 420 °C to 540 °C in a fluidized bed, with a capacity of 7 kg/h. The experiment showed the highest bio-oil yield of 56 wt% which was obtained at 465 °C. Pyrolysis of rice husk using fluidized-bed has also been done by [8]. The study showed that the optimum bio-oil produced was 50 wt% at temperature of 475 °C running at a capacity of 120 kg/h.

Many researchers have investigated the effect of operating parameters such as temperature and residence time on product distribution of individual sample. Nevertheless, there are limited studies on effect of blending two types of biomass feedstock. There are researches conducted on combination feed such as coal with sewage sludge, sugarcane baggasse with petroleum residue [9], biomass with plastic and tyre [10], sawdust with waste tyre [10], willow with biopolymers [11], and wood with synthetic polymer [12].

In this study, a mixture of sewage sludge and rice waste was chosen as the feed. Rice wastes include a mixture of rice husk and rice straw. Co-pyrolysis of rice waste with treated sewage sludge was investigated based on an optimum bio-oil yield. To the understanding of the author, no previous work on combinational feed of sewage sludge and rice waste was published in Malaysia.

II. MATERIALS AND METHODS

A. Materials

Treated sewage sludge (TSS) was obtained from Indah Water Consortium Sdn. Bhd. Wastewater treatment plants,

whereas rice husk (RH) and rice straw (RS) were obtained from Bernas Sdn. Bhd. The samples were subjected to air drying for 1-2 days, and then dried in the oven at 105 °C for 24 h to remove the moisture. The sample was then ground in a grinder and sieved into fractions of particle with diameter < 1 mm. The sample were then stored in an air tight container.

B. Characterization of Raw Materials

The chemical analyses of the samples were carried out according to the American Standard (ASTM) test methods. The standard test methods for biomass fuel analyses were: moisture content ASTM E 871-82, ash content ASTM E 830-87 and volatile matter ASTM E 897-88. Calorific value of the sample was determined by using bomb calorimeter Model: IKA C 5000 (Cole Parmer, USA).

C. Pyrolysis Experiment

Pyrolysis was performed in a fluidized-bed pyrolysis reactor as shown in Fig. 1. The unit comprised of a high temperature ALLOY 90 4L reactor column constructed of stainless steel with an internal diameter of 21 cm and heights of 54 cm. K-type thermocouples were attached in the reactor. The sample was fed into the column by means of a motorized extruder.

The reactor was heated externally and nitrogen gas was supplied to maintain the inert atmosphere in the reactor and also to drive the pyrolyzed vapor product to the condensers that was set at -10 °C. The experimental conditions for pyrolysis process were: temperature of 500 °C to 650 °C; particle size < 1 mm; nitrogen flow rate of 50 ml/min⁻¹ (at room temperature and atmospheric pressure) and heating rate of 30 °C min⁻¹. The residence time was 2 seconds to convert sample into vapor form. The condensable product (liquid) collected in the oil containers was weighed. The yields of the resulting products were thus calculated based on the mass of feedstock.

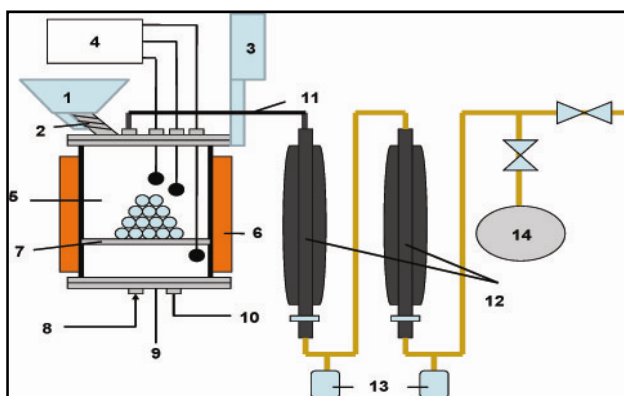


Figure 1. Schematic diagram of fluidized-bed reactor

1) Sample feed hopper, 2) Extruder, 3) Control panel, 4) Temperature heater, 5) Reactor vessel 90 4L with quick lamp, 6) Heater, 7) Sample mesh support, 8) Nitrogen inlet, 9) Char collector Condensers, 10) Bottom thermocouple, 11) Product line, 12) Condensers, 13) Bio-oil collector, 14) Gas Collector and 15) Gas ventilation.

D. Characterization of the Liquid Products

Pyrolysis process produced 3 types of product; liquid; char and gas. In this study only liquid products were characterized, gas was vented to the atmosphere. The moisture, pH, density, viscosity and ultimate analysis of the bio-oil products were determined. The chemical composition of the liquid was identified by using Gas Chromatography Mass Spectrometer (GC-MS).

E. Statistical Analysis

The characteristic of feedstock and influence of the types of feedstock on the product distribution and on some liquid characteristics were made by means of the one-way analysis of variance (abbreviated one-way ANOVA). This technique was used to compare the mean of two or more sample (using Duncan test). Data were expressed as means \pm standard deviation (SD). A p-value of less than 0.05 was considered as statistically significant. ANOVA was performed using the statistical software SPSS (SPSS Inc., Chicago, USA).

III. RESULTS AND DISCUSSION

A. Characterization of Raw Materials

The proximate and ultimate analyses were performed on all samples. The proximate analysis was to determine the percentage of moisture content, volatile matter, ash content and fixed carbon. While ultimate analysis was used to determine the percentage of carbon, hydrogen, nitrogen, oxygen and sulphur. The results were listed in Table I.

Volatile matter and fixed carbon contents provided a measure of the ease with which the biomass could be ignited, gasified and oxidized depending on the biomass utilization [11]. These characterizations were important to establish the suitability of the feedstock for thermo-chemical conversion. High volatile matter content with low ash and sulfur content were the main criteria for pyrolytic conversion. Volatile matter of RH, RS and TSS were 79.70 ± 1.79 wt%, 67.55 ± 2.40 wt% and 50.33 ± 0.85 wt% respectively.

TABLE I. CHARACTERIZATION OF RAW MATERIALS

Test Parameter	Raw Materials		
	RH	RS	TSS
<i>Proximate analysis (wt %)</i>			
Moisture	8.27 \pm 0.01 ^a	7.99 \pm 0.16 ^a	6.33 \pm 0.29 ^b
Ash	12.31 \pm 0.02 ^a	15.43 \pm 0.11 ^b	42.38 \pm 0.94 ^c
Volatile Matter	79.70 \pm 1.79 ^a	67.55 \pm 2.40 ^b	50.33 \pm 0.85 ^c
Fixed Carbon	3.38 \pm 3.37 ^a	9.04 \pm 2.66 ^b	0.97 \pm 0.20 ^a
<i>Ultimate analysis^a (wt %)</i>			
Carbon	38.42 \pm 0.18 ^a	35.11 \pm 0.47 ^b	27.03 \pm 0.19 ^c
Hydrogen	5.09 \pm 0.01 ^a	4.49 \pm 0.13 ^b	3.61 \pm 0.13 ^c
Nitrogen	1.01 \pm 0.01 ^a	1.95 \pm 0.01 ^b	4.06 \pm 0.03 ^b
Oxygen ^b	55.48 \pm 0.16 ^a	59.43 \pm 1.71 ^b	65.31 \pm 0.35 ^c
<i>Calorific Value (MJ/kg)</i>	14.38 \pm 0.09 ^a	12.40 \pm 0.16 ^b	11.30 \pm 0.05 ^c

^a Data are the means of triplicate replications \pm standard deviation. Values within lines followed by the same letter are not significantly different at P < 0.05 (Duncan's Multiple Range test).

n.d. : Not detected

^a : Dry base

^b : Calculated by difference

While the ash content were 12.31 ± 0.02 wt%, 15.43 ± 0.11 and 42.38 ± 0.94 wt% respectively. The influence of volatile matter and ash content on production of liquid yield was also reported [9] and [10]. According to the authors, liquid yield obtained from the pyrolysis process increased with an increase of their volatile matter and with a decrease in ash content.

Ultimate analysis showed that RH gave higher carbon content with 38.42 ± 0.18 wt% while RS and TSS were 35.11 ± 0.47 wt% and 27.03 ± 0.19 wt% respectively. Moreover the calorific value can be sequence as $RH > RS > TSS$ which were 14.38 ± 0.09 MJ/kg, 12.40 ± 0.16 MJ/kg and 11.30 ± 0.05 MJ/kg.

B. Influence of Temperature in Production of Pyrolysis Products

Pyrolysis process converted the rice husk, rice straw and treated sewage sludge into several products; liquid, char and gas. In this study, after 2 seconds the first condensate collected was in the form of white vapor followed immediately by the liquid product, usually termed as crude bio-oil. The crude bio-oil was generally red brown colored products with an irritable odor [13].

Operating temperature was the crucial parameter which had a significant effect on yield production [14]. The optimum temperature was discovered based on the optimum pyrolysis bio-oil yield produced. Individual RH, RS and TSS were pyrolyzed under similar parameter, which was at varying temperature from 500 to 650 °C.

Relationships between pyrolysis yields and temperature were shown in Fig. 2, Fig. 3 and Fig. 4 for sample RH, RS and TSS respectively. From the graph, the bio-oil yield first increased and then decreased with varying temperature, and the optimum yield were 35.46 ± 0.38 wt%, 25.74 ± 0.83 wt% and 21.53 ± 0.58 wt% respectively. The char yield decreased with increasing of temperature. On the other hand, the gas yield was increasing with increasing temperature.

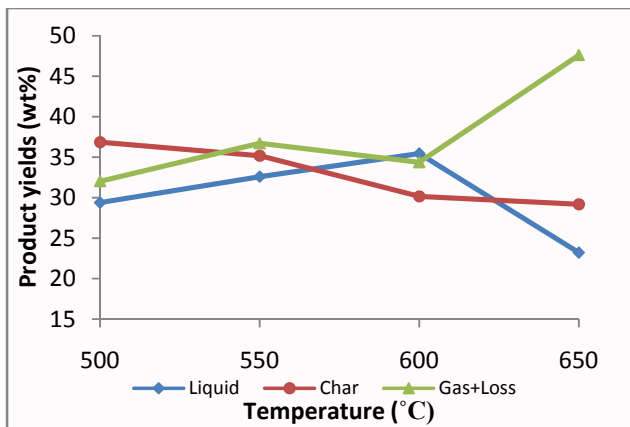


Figure 2. Product distribution of pyrolysis of RH

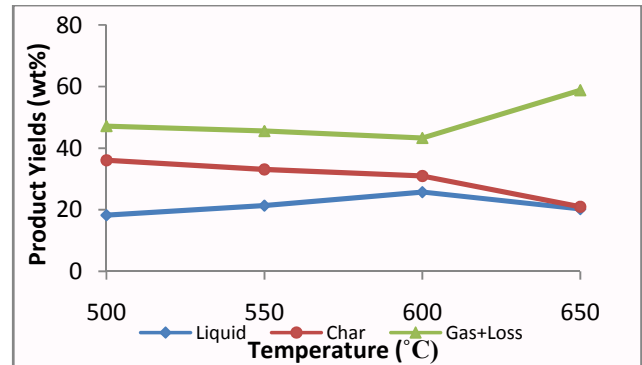


Figure 3. Product distribution of pyrolysis of RS

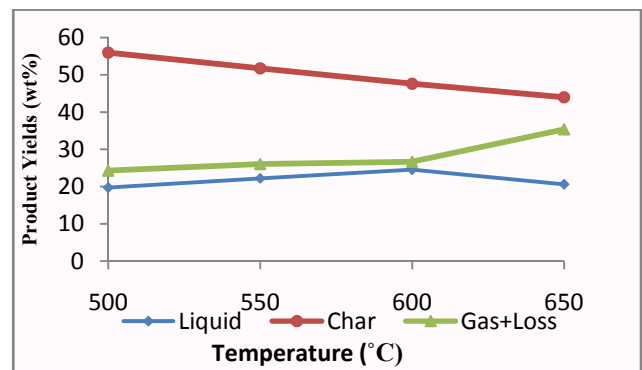


Figure 4. Product distribution of pyrolysis of TSS

C. Combination Feed

Co-cracking of feedstocks was study to discover the appropriated proportion of two or more material which could solve problem and balance each other weaknesses. The feedstocks were pyrolyzed at temperature 600°C which was based on the optimal temperature obtained in the individual pyrolysis process. The process underwent similar condition as individual pyrolysis process.

The blending of 70:30 ratios of rice husk and rice straw (RHS) were blended with treated sewage sludge according to several blending ratios; 30:70, 50:50, and 70:30 (weight percent basis). Fig. 5 showed the product distribution of combination feed. The graph showed that the blended of rice waste and treated sewage sludge produced lower bio-oil yield compared to the individual of RHS and higher bio-oil yield when compared to the individual TSS. This result indicated that the use of treated sewage sludge in a combination with rice waste (CF) did not significantly reduce the bio-oil yield from the individual rice waste samples.

Moreover, it could be seen that the increasing to the blending ratio (percent basis) of TSS was accompanied by a sharp increased in the char or solid residue formation from 39.06 ± 0.26 wt% to 63.73 ± 1.08 wt%. This possibility was discussed earlier in the previous section where the increased of char agreed with the low ash content.

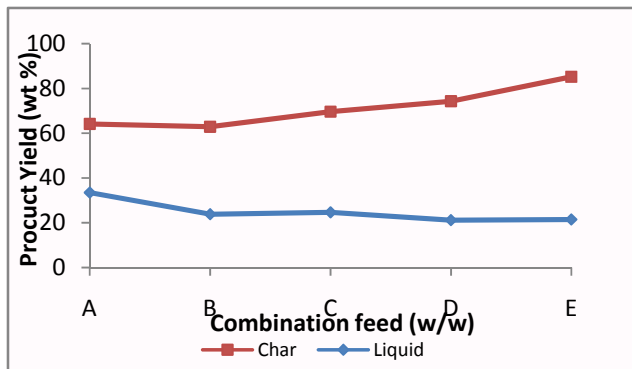


Figure 5. Product distribution of pyrolysis of blended of RHS with TSS

A: Original RHS
 B: 70:30 ratios of RHS with TSS
 C: 50:50 ratios of RHS with TSS
 D: 30:70 ratios of RHS with TSS
 E: Original TSS

D. Characterization of Bio-oil

Bio-oil produced from the optimum experimental conditions were characterized by several instrumental techniques. The physicochemical properties of the bio-oil products; moisture content, pH, density, viscosity and ultimate analysis were presented in Table II.

The water content of the liquid sludge was 94.57 ± 1.87 , 95.22 ± 1.43 and 95.56 ± 0.18 wt% for RH, RS and TSS respectively. The results were comparable to the previous study by [15] which was in the range of 72 - 90 wt %. The possible presence of volatile matter dissolve in the liquid sludge should also be considered. Moreover the water probably formed during pyrolysis when the breaking up of functional groups from the volatile compounds during homogeneous secondary reactions [16]. The pH of the RH and RS were 2.78 ± 0.01 and 4.30 ± 0.05 respectively, which was acidic while. TSS was 95.56 ± 0.05 which was basic probably due to the majority of chemical compound present which was amine groups. The viscosity of the bio-oil was determined by using dynamic viscometer (Sofraser, USA).

TABLE II. CHEMICAL CHARACTERIZATION OF BIO-OIL

Chemical characteristics	Bio-oil		
	RH	RS	TSS
Moisture ^a (wt%)	94.57±1.87	95.22±1.43	95.56±0.18
pH	2.78±0.01	4.30±0.05	9.45±0.05
Density ^b (mg/ml)	955.99±15.01	950.89±5.96	963.10±8.82
Viscosity ^c (mPa s)	0.61±0.02	0.58±0.07	2.99±0.17
Ultimate analysis ^b (wt%)			
Carbon	80.90	50.73	69.09
Hydrogen	16.44	42.89	16.50
Nitrogen	2.66	6.38	14.41
Sulphur	n.d	n.d	n.d

^a : Moisture content included volatile matter

^b : As received

^c : Measured at 40 °C

n.d : Not detected

The viscosity of RH, RS and TSS were 0.61 ± 0.02 mPa s, 0.58 ± 0.07 mPa s and respectively 2.99 ± 0.17 mPa s respectively.

The values of carbon, oxygen, nitrogen and sulphur of the liquid bio-oil product were listed in Table 2. From the data, the carbon, hydrogen and nitrogen were 50.73 - 80.90 wt%, 16.44 – 42.89 wt% and 2.66-14.41 wt% respectively.

E. Chemical Compounds

The chemical compound of bio-oil product was analyzed by using GC-MS. In this study, the area % of the GC-MS chromatogram was used to indicate the amount of the various chemical compounds in the bio-oil. Table 3 listed the identified compound and their relative proportions (area %) in bio-oil at optimum temperature. As expected, the pyrolysis bio-oil was a very complex mixture of organic compounds that consisted of alkanes, alkenes, phenol, aromatic and nitrogenated compound which were the main compound of the bio-oil [17]. Alkanes and alkenes were also determined by [4, 18] pyrolytic oil from industrial sewage sludge.

TABLE III. MAIN COMPOUND IDENTIFIED IN BIO-OIL OBTAINED AT OPTIMUM CONDITION

Chemical Compound	Area %			
	RH	RS	TSS	CF
Pyrrrole	-	-	-	-
Pyridine	-	-	2.21	2.56
Pyrazine	-	-	-	-
Benzene and its derivatives	1.31	1.43	14.20	3.41
Indane	-	-	0.41	-
Indole	-	-	-	-
Phenol and its derivatives	-	-	1.05	10.82
Toluene	-	-	17.28	7.46
Xylene	1.40	1.62	4.46	1.83
Styrene	41.55	1.83	7.40	4.14
Alpha-Methystyrene	-	-	1.67	-
Naphthalene and its derivatives	-	-	6.00	3.90
2-Methylindene	-	-	1.16	1.56
1-Decene	-	-	5.92	-
1-Nonene	-	-	0.78	-
1-Dodecane	9.43	5.25	0.92	-
Indene	9.43	5.25	2.31	2.61
Cyclohexasiloxane, dodecamethyl-	27.72	16.11	5.54	20.43
Cycloheptasiloxane, tetradecamethyl-	17.87	14.38	8.23	18.47
Cyclotetrasiloxane, octamethyl-	1.41	1.57	6.04	-
Cyclopentasiloxane, decamethyl	-	-	1.48	-
Cyclononasiloxane, octadecamethyl-	-	-	0.87	-
6,8-Dichloro-2[-chlorophenyl]-4moacetylquinoline	3.98	2.20	-	-
1-Undecene	-	-	1.63	-
1-Tridecene	-	-	-	-
6-Tetradecene, (E)	-	-	2.75	-
Pentadecane	-	-	-	-
Benzofuran	-	-	-	3.18
1-Hexadecane	-	-	-	0.89

It was also seen that pyrolytic bio-oil produced from TSS contained high contents of nitrogenated aromatic, oxygenated hydrocarbons and heterocyclic compounds. These organic components could probably be derived from protein and amino acids that was found in microbial organism presence in the sewage sludge. Similar compounds have been identified in the pyrolytic oil of sewage sludge [5, 19, 20].

IV. CONCLUSION

Fast pyrolysis of different biomass which consisted of rice waste and treated sewage sludge were investigated using a fluidized-bed reactor at varying temperature. The optimum pyrolysis bio-oil were 35.46 ± 0.38 wt%, 25.74 ± 0.83 wt% and 21.53 ± 0.58 wt% obtained from RH, RS and TSS-respectively at an optimum operating temperature of 600 °C. Co-cracking of feedstocks indicated that the use of treated sewage sludge in a combination with rice waste did not significantly reduce the bio-oil yield from the individual rice waste samples. Therefore, it could be conducted that mixtures of rice husk, rice straw and treated sewage sludge in the appropriate proportion could be used as an alternatives source of feedstock for the production of bio-oil. Combination of feedstock helps in maximizing the volume of feedstock for energy conversion via pyrolysis. Moreover, this could be used as an alternative for the disposal of treated sewage sludge instead of the conventional method of handling such as incineration, possible dumping in the ocean and land filling. The major chemical compounds identified in the bio-oil yield were alkanes, alkenes, phenols, aromatics and nitrogenated compounds. The bio-oil potential as a replacement of a petroleum based fuel should be considered seriously especially in the current energy scenario of high petroleum fuel cost as well as the projected fuel shortage in the year 2020.

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