Co-pyrolysis of lemongrass waste and residual cooking oil in a fixed bed reactor

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Abstract. Co-pyrolysis of lemongrass waste and residual cooking oil was examined in a fixed bed reactor. The goal was to study the effect of pyrolysis parameters on bio-oil yield. Bio-oil product characteristics between lemongrass pyrolysis and residual cooking oil co-pyrolysis were analysed. The variable parameters were temperature (350, 400, 450 and 500 °C), particle size lemongrass (< 150, 150, 212, 300 and 425μm) and holding time (3, 5 and 7 minutes). The mixing ratios of lemongrass waste to waste cooking oil were respectively 100:0, 90:10, 80:20, 60:40 and 50:50. The optimal temperature was 400 °C with the highest yield of 30.5 percent bio-oil at the particle size of 300 μm, holding time of 5 minutes and the mixing ratio of 80:20. The addition of residual cooking oil increased the quality of the bio-oil obtained in term of phenol compounds.

1. Introduction
With the rapid outgrowth, demand for energy is rising along with population and economic development. The quest for renewable energy has intensified due to the detrimental effects of the use of fossil fuels on the atmosphere, such as global warming and acid rain [1]. The use of biomass as an abundant energy source and renewable energy is a promising alternative and has drawn more interest [2]. Biomass is one of the best green options for replacing fossil resources in many applications, such as heat production, power generation, fuels for transportation and chemicals processing [3]. Biomass sources include biomass and biomass waste, crops and their by-products, urban solid waste, food production waste, aquatic plants and algae [4]. Thermochemical conversion is a great promise to turn biomass into energy effectively and economically, which can be used in various applications [5]. The key thermal processes available for conversion of biomass are combustion, pyrolysis and gasification [6], [7]. In specific, for biomass conversion into bio-char, bio-oil, and gases, pyrolysis has gained dominance [8]. In the pyrolysis process, biomass in an inert atmosphere is decomposed at elevated temperatures [9]. Bio-oil has been known as the most valuable pyrolysis product [10]. Many factors, such as reaction temperature, holding time, heating rate, gas flow rate, and particle size, drive the pyrolysis process [11], [12].
In the tropics of Africa, Indonesia, India and Malaysia, lemongrass is one of the important oil plants widely grown [13]. Additionally, lemongrass is a high-biomass crop that may have biofuel production applications. The cost of producing biofuel could be low because of the quality of its high-value essential oil since biomass will be a by-product of the processing of essential oil [14]. Thus, lemongrass suitable to be a new high-value specialty crop and a worthy biofuel source.

It is interesting that residual cooking oil also shows a high potential for bio-oil upgrading to be a hydrogen supply. The addition of waste cooking oil during raw bio-oil cracking would significantly improve the quality of bio-oils by increasing the olefin and aromatic content [15]. Therefore, waste cooking oil was discussed in this study as the catalyst to improve the bio-oil quality.

The goal of this study is to study the effect of pyrolysis parameters on bio-oil yield and to compare the characteristics of bio-oil products between individual lemongrass pyrolysis and lemongrass co-pyrolysis with residual cooking oil.

2. Methodology

The main materials in this analysis were lemongrass waste and the residual cooking oil. The lemongrass was collected at Arau, Perlis, while the residual cooking oil was collected from the Jejawi, Perlis food stall. The lemongrass waste was dried under the sun for several days. After that, it was dried using oven at temperature of 105°C for 24 hours to remove moisture content [16]. It was then grinded and sieved to particle sizes of <150, 150, 212, 300 and 425 μm. The residual cooking oil was filtered to removed dirt and solid.

Lemongrass samples were analysed using a Mettler Teledo TGA/DSC Thermogravimetric Analyzer (TGA) to obtain the content of moisture, volatile matter, fixed carbon, and ash. To classify the functional groups, the residual cooking oil was analysed using the Perkin Elmer Fourier Transform Infra-Red (FTIR) Spectrometer.

The pyrolysis experiments were conducted using a Catabest Reactor System fixed-bed reactor tube with a 20 mm diameter and a 30 cm height. In all runs 5 g of samples were used at a constant heating rate of 80 °C/min and 50 ml/min of nitrogen gas flow rate. The experiment was conducted to determine the optimum bio-oil yield of each investigated four parameters: heating temperature, particle size, heating time, and mixing ratio. The temperature effect on the bio-oil yield was determined by the temperature manipulation at 350 °C, 400 °C, 450 °C, 500 °C and 550 °C. Then, the particle sizes were varied by < 150, 150, 212, 300 and 425 μm using the optimum temperature previously obtained. The effect of heating time was investigated with variation of 3, 5 and 7 minutes. Finally, after the previous optimum parameters were obtained, the co-pyrolysis process was carried out by mixing the lemongrass with the residual cooking oil in ratios of 10:0, 9:1, 8:2, 6:4 and 5:5, respectively. The products yield (bio-oil and char) were weighed and the gas yield was calculated by difference. The functional group of bio-oil was analysed using FTIR.

3. Results and Discussion

3.1. Effect of pyrolysis temperature

The pyrolysis process temperature was varied at 350 °C, 400 °C, 450 °C, and 500 °C to get the optimum temperature with maximum yield of the bio-oil product. The heating rate was maintained at 80 °C/min with a holding time of 5 minutes and particle size of 300 μm without adding the residual cooking oil. For all experiments the nitrogen flow was set at 50 ml / min. Figure 1 shows the effect of pyrolysis temperature on products yield. The optimum pyrolysis temperature was 400°C with the highest bio-oil yield of 30.1 %. Bio-oil yield increased as the temperature increased to the optimum point. Pyrolysis at lower temperatures tended to produce more char [17]. The lemongrass waste sample has undergone a phase of decomposition as the thermal energy in the fixed bed reactor breaks the strong sample bond into gases. The volatile matter was then condensed into bio-oil formation. Beyond optimum temperature, the yield of bio-oil decreased since the heat burned the sample too quickly as the solid sample was transformed into gases in a short time [18].
3.2. Effect of holding time
The holding time was the time held for reaction of the pyrolysis process and ranged at 3, 5 and 7 minutes. From earlier experiments the temperature of 400 °C was chosen as a fixed temperature. Figure 2 illustrates the effects of holding time on products yield. Bio-oil output was obviously the highest with 30.1% at 5 minutes holding time. It suggested the best holding time to carry out the process as no longer or shorter duration than 5 minutes would result in a decrease in the percentage of bio-oil product. The yield of bio-oil was lower at holding time of less than 5 minutes as the decomposition process to form bio-oil could not complete as the time was too short. With a holding time of more than 5 minutes, the bio-oil yield decreased as a result of the char production and produced more char with higher stability decomposition and the so-called continuous char devolatilization process [19]

3.3. Effect of particle size
The particle size of lemongrass was varied at <150, 150, 212, 300 and 425 μm. The temperature and holding time were selected based previous effect of temperature and holding time on the optimum bio-
oil yield. Figure 3 shows the effects of particle size on products yield. The best particle size for obtaining the highest percentage of bio-oil yield was at 300 μm. There was no yield of bio-oil at the smallest particle size (< 150μm), and then, as particle sizes increased, the yield increased proportionally. Bio-oil yield decreased beyond 300μm. The smaller the particle size, the greater the surface area that is required for the pyrolysis process. However, too small size may end up with zero bio-oil yield as the sample was burned too quickly without reducing volatile matter quality [19].

![Figure 3. Effect of particle size](image1)

3.4. Effect of mixing ratio

The co-pyrolysis process was introduced as the process involved two samples (lemongrass waste and residual cooking oil). The mixing ratio was varied at 100:0, 90:10, 80:20, 60:40, and 50:50 with proportion of lemongrass waste to residual cooking oil, respectively. Figure 4 shows the effect of mixing ratio on co-pyrolysis process. From the figure, mixing ratio of 80:20 showed the highest bio-oil yield. It demonstrated that by adding a correct amount of catalyst into the sample, it can produce the highest bio-oil product. The bio-oil yield decreased as the waste cooking amount addition over than 20 % in the mixing.

![Figure 4. Effect of mixing ratio](image2)
3.5. Characterization of bio-oil

Figure 5 shows the functional group of bio-oil using FTIR. FTIR analysis was done on the bio-oil products of pyrolysis of residual cooking oil, pyrolysis of lemongrass waste and co-pyrolysis of lemongrass waste and residual cooking oil. Carboxylic acid, alkane, aldehyde, alcohol, and some double bond functional group such as ketone and ester were found in the samples.

The FTIR analysis of bio-oil product from lemongrass waste pyrolysis showed peaks at 3320, 2924, 2890, 1632, 1387, 1274 and 723 cm\(^{-1}\) and when residual cooking oil was introduced in the pyrolysis process, the peaks shifted slightly at peaks of 2916, 1635, 1366, 1276, 1014 and 695 cm\(^{-1}\). Generally, bio-oil sample from co-pyrolysis process with addition of residual cooking oil contained more functional groups. Spectra analysis showed O-H stretching vibrations at range 3200 to 3500 cm\(^{-1}\) with broad peak indicated the existence of strong alcohols and phenols. The peak intensity of bio-oil from co-pyrolysis was increased than the bio-oil from pyrolysis of lemongrass. It indicated that the concentrations of alcohol and phenol were greater. C=N bond was detected at range 1850 to 2700 cm\(^{-1}\) on co-pyrolysis product. However, this peak was not detected in the individual pyrolysis of lemongrass. Therefore, more functional group were found in the bio-oil from co-pyrolysis of lemongrass waste and residual cooking oil.

![FTIR analysis of bio-oil](image)

**Figure 5.** FTIR analysis of bio-oil

4. Conclusion

Pyrolysis process of lemongrass waste and residual cooking oil was conducted in a fixed-bed reactor to obtain optimum bio-oil product yield and evaluating the characteristics of bio-oil. The optimum bio-oil yield was found at temperature of 400°C, holding time of 5 minutes, particle size 300μm and mixing ratio of 80:20. The functional group of bio-oil increased in samples mixing during co-pyrolysis. The bio-oil with the addition of residual cooking oil which act as catalyst had better quality than individual pyrolysis of lemongrass waste in term of phenol group.
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