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A Review on Co-Pyrolysis of Biomass and Plastic: Insight into Synergistic Effect and Operating Condition

Nazriyatul Nazihah Roslan[1], Hamizura Hassan[1]
1Faculty of Chemical Engineering with Environment, UiTM Permatang Pauh, 13500 Pulau Pinang

Corresponding author: hamizura179@isiswa.uitm.edu.my

Abstract:
Biomass is considered to have a better potential to be used as a renewable energy source to substitute fossil fuels. The production of oil from biomass and plastics can be achieved by pyrolysis process. However, the pyrolysis oil from pyrolysis contains high oxygenated compound which leads to low caloric value and corrosion problems. Many researchers have discussed an alternative technique to enhance the quality and quantity of oil by using co-pyrolysis process. Co-pyrolysis is a thermal conversion process involving two or more feedstock materials. A comparison between co-pyrolysis of biomass and plastics is established in the present work. This article also focused on several studies based on published articles and books. It was found that production of bio-oil yield depends on biomass feedstock and type of plastics use and compositions such as moisture content, volatile matter, carbon (C), oxygen (O), nitrogen (N), ash and the presence of lignocellulose. This study discussed a comprehensive review on the co-pyrolysis of biomass and plastics influences the bio-oil yield through several point of views, including operating variables such as temperature, heating rate, blending ratio and synergistic effect and characteristics of by products as well. To obtain high grade of bio-oil, the maximum temperature, heating rate and blending ratio are 500℃, 10℃/min, and 1:1 respectively. The hydrogen donation from plastics effect the synergistic effect of biomass and plastics. In conclusion, by utilizing biomass and plastics, the volume of wastes can be controlled in the landfill reduce the consumption of fossil fuels, save the environment and increasing energy security of the nation.

***Keywords*:**
Co-pyrolysis, Biomass, Pyrolysis, Plastics, Synergistic Effect

Objectives:

- To review co-pyrolysis of biomass and plastics for the production of high quality of bio-oil.

Methodology:

To collect data for study, the extensive search was conducted for peer-reviewed articles published in 2000-2020 period with an addition from government, news article and market-research source. The total number of articles considered database included: Science Direct (90), Scopus (4), Academia (10), SpringerLink (5) & ACS Publications (4). The keywords focus on “co-pyrolysis of biomass and plastics”, "bio-oil production", "biodiesel", "biofuel production" and "plastics". Other resources are from books. The uses of different resources allowed to find more information for review study.

Results:

Effect of feedstock properties on co-pyrolysis of biomass and plastics

Most of the studies have investigated biomass as a feedstock in co-pyrolysis process. Table 1 summarizes on studies on co-pyrolysis of biomass mixed with plastics to produce pyrolysis oil.

Table 1: Co-pyrolysis studies [2] [15] [53] [54] [55] [56]

Type of materials		**Temperature °C**	**Liquid Yield**		**Calorific Value (MJ/kg)**		
Biomass	**Plastics**		**Biomass**	**Mixture (1:1)**			Ref
Palm Shell	PS	500	46.14	61.63	HHV: 11.94	HHV: 38.01	[2]
Pinecone	LDPE PP PS	500	47.3	63.9 64.1 69.7	HHV:20.1	HHV: 46.33 HHV: 45.58 HHV: 46.43	[15]
Willow	PS	450	49.71	14.5	HHV: 16.13	HHV: 20.22	[53]
Potato skin	HDPE	500	23.0	39.0	HHV: 16	HHV: 18.49	[54]
Wood chip	BP	500	39.3	63.10	HHV: 19.90	HHV: 45.00	[55]
Pine residue	PE-56% PS-17% PP-27%	400	32.0	53.00	HHV: 20.00	HHV: 45.00	[55]
Pinewood saw dust	PS	450	46.00	67.00	Not reported	Not reported	[56]
Willow	BP S PO S	450	50.1	52.79 59.24 51.52	HHV: 16.10	HHV: 19.10 HHV: 15.70 HHV: 19.20	[55]

Synergistic effect

A synergetic effect plays a key role in improving the quality and quantity of oil. Numerous researches have studied the synergetic effect between co-pyrolysis of biomass and plastics [2, 14, 11]. It can be achieved through radical interaction during the co-pyrolysis process. Johannes et al. [57] stated positive or negative energy depend on the type and contact of components, duration of pyrolysis process, temperature, heating rate, removal of equilibrium of volatiles formed, or catalyst. All of these factors give major influences the synergetic effect which can be varied on co-pyrolysis process. Biomass and plastics have different decomposition in thermal pyrolysis process. Biomass involves exothermic and endothermic reaction, whereas plastic occurs by a radical mechanism. Plastic known as hydrogen donors with biomass because it is rich in hydrogen content compared to biomass alone. The mechanism of hydrogen donation in the synergestic effect between biomass and plastics.

Effect of Temperature

Temperature plays an important role for final production in co-pyrolysis process. The effect of parameters on optimum yield of oil has been studied by Akhtar and Amin [61]. In co-pyrolysis of biomass and plastics, the maximum temperature to produce oil is within the range of 400-550℃. Within this temperature range, the production of oil achieved was more than 45wt%. Cepeliogullar and Putun [62] conducted a study on PET pyrolysis using a fixed-bed reactor at 500℃. A heating rate was set at 10$℃/min$ and nitrogen was used as sweeping gas in the experiment. It was observed that the production of oil yield was 23.1 wt% while the production of gaseous was 76.9wt%. PET has low volatile matter of 86.73% compared to other plastics such as PS, PP, LDPE, and HDPE. Thus, when co-pyrolysis was conducted using PET at high temperature, the volatile matter decreased which reduce the pyrolysis oil yield.

Effect of Heating Rate

Heating rate plays an important role in pyrolysis of biomass as the rate of heat rate affect the composition of biomass and plastics to produce the final product. Low heating rate ensures that no thermal cracking of biomass takes place. Meanwhile, high heating rate, increases the gaseous and liquid yield [66] . An average heating rate at 10-20$℃/min$ to enhance the bio-oil yield. Prasad et. al [51] studied co-pyrolysis of Juliflora with LDPE for bio-oil production at five different heating rate from 10$℃/min$ until 50$℃/min$. The result showed the optimum of heating rate was found to be 10$℃/min$ with the production of bio-oil yield at 26%. A higher heating rate leads to increase in liquid production in the pyrolysis process. Uzun et al. [54] also stated that the reduction of the water content in the bio-oil with the increase of the heating rate, obtaining a better quality bio-oil. Fast heating rate inhibits secondary dehydration. High heating rate not only reduce the water content, but also reduce the oxygen content in pyrolysis liquid and improve the quality and quantity of oil-yield.

Effect of blending ratio

The blending ratio of biomass and plastics influence on the production of solid, liquid and gas [68]. Some of the researchers have studied the effect of blending ratio of biomass and plastics. A study conducted by Wu et al. [69] on co-pyrolysis of corn stover (CS) and polypropylene (PP) at 500℃ with different CC/PP ratios; 1:0, 3:1, 1:1, 1:3, and 0:1. It observed that the oil yield of PP alone was 57.1% compared to CS alone which was 19.1%. When CS/PP ratio was 1:3, the yield of oil increased from 30.8% to 52.1%. When CS/P ratio was 1:1, the oils produced contained a significant amount of C and H, while the O content was only 6.3 wt percent, and the pyrolysis oil deoxidation rate was up to 74.9%. Furthermore, HHV of oil from CS alone was 22.44 MJ/kg. When PP added with CS, the HHV of pyrolysis oil was 41.78 KJ/kg. Due to H/C of PP is higher than CS, PP acts as a hydrogen donor and combines with unstable free radicals during pyrolysis process. It explained that adding plastics with biomass produce good amount of oil yield. Biomass is decomposed much faster than plastics. For co-pyrolysis of biomass and plastics, plastics not fully decomposed. Moreover, these bonds are difficult to separate than constituents of cellulose, hemicellulose and lignin in biomass which are linked together with weak ether bonds (R-O-R) with bond energy of 380-420kj/mol [70].

Conclusion:

In conclusion, the use of co-pyrolysis technique in biomass wastes and plastics highly recommended. Many researchers have suggested this technique due to many advantages. The benefits of co-pyrolysis are considered to be cheap, simple and effective method to obtain high-quality of oil. The production of bio-oil depending on type of feedstock and type of polymer use. By utilizing biomass and plastics, the volume of wastes can be controlled in the landfill. Co-pyrolysis could reduce the consumption of fossil fuels, save the environment and increasing energy security of the nation. Moreover, numerous researches have studied the synergetic effect between co-pyrolysis of biomass and plastic. It explained that a synergetic effect plays a key role in improving the quality and quantity of oil.