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Bio-Oil Production Using Waste Biomass via Pyrolysis Process: Mini Review

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Abstract

Pyrolysis process using abundantly available biomass waste fabric is a promising, renewable, and sustainable energy supply for bio-oil production. In this study, the pyrolysis of waste biomass determines the highest yield of diverse parameters of material type, temperature, reactor, method, and analysis used. From the differences in the parameters stated above, there is an opportunity to select the proper parameters to get the desired nice and quantity of bio-oil and the very best bio-oil yield. The maximum yield of each bio-oil product for pyrolysis primarily based on the above parameters was 68.9%; 56.9%; 44.4%; 44.16%; 41.05%; 39.99%. The bio-oil made out of pyrolysis was changed into analyzed using GC-MS, ft-IR, NMR, TGA, SEM, Thermogravimetric analysis, HHV, FESEM evaluation methods and the substances used had been plastic, seaweeds, oat straw, rice straw , water hyacinth, timber sawdust, sawdust, microalgae.

INTRODUCTION

The swiftly growing demand for energy and the increasing use of biomass as a renewable energy supply is increasingly considered to be the main desire to update commercial fossil fuels and the growing environmental and sustainability challenges (Khan et al., 2009). Biomass waste increases each year and ample biomass reserves can be renewed. The software of biomass fuels for heat and energy generation can affect the reduction of greenhouse fuel (GHG) emissions (UNFCCC, 2015).

Biomass is a potential material as a raw material for renewable energy and can be converted into chemical compounds that have higher values (Antal, 1983; Bridgewater & Grassi, 1991; Chum and Overend, 2001;). Biomass is a renewable and hygienic supply that may be shaped as an outstanding pyrolysis product because this material is very volatile and smell coffee (Deng et al., 2017). Rice husk is one of the main types of biomass, Rice husk production in China is more than forty million per year (Pode, 2016). The amount of rice husk is so large that it need instant treatment, so as not to harm the environment (Khan et al., 2009). Therefore, rice husk pyrolysis may be a powerful technique for putting off such massive-scale effluents, growing power usage, and product best of pyrolysis. Studies have attempted to study the technique of rice husk and sludge co-pyrolysis. Lin et al. (2018) discovered that those materials accelerated product oil best and accelerated the formation of H_2, CO, and C1eC2 invites.

Sources of biomass include agricultural and forestry residues, wood sawdust, crops, organic waste, municipal and business wastes (McKendry, 2002; Duanguppama et al., 2016). Sawdust is obtained from the process of cutting wood in sawmills. every hundred kg of wood in the sawmill produces about 12-25 kg of sawdust (Varma & Mondal, 2016). The raw materials for biomass in renewable biofuels come from timber waste, energy vegetation, forest residues, urban

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solid waste, animal waste, and agricultural residues (Azargohar et al., 2013; Agarwal, 2007). Pyrolysis is one of the biofuel technologies that address biomass uncooked substances consisting of municipal solid waste, agricultural residues, energy crops, and wooded area residues that are very appealing options to grow the possibilities for using less suited biomass. The advantage of biomass over fossil fuels is that it contains low sulfur and nitrogen, does not cause pollution due to the presence of carbon dioxide when burning (Probstein & Hicks, 1982).

Diverse styles of biomass use different wastes from plastics. Biomass mix with polymer and known as co-pyrolysis to improve the properties of the pyrolytic oil produced from biomass (Gollakota et al., 2016). Park et al (2019) used polyethylene terephthalate, polypropylene and polyethylene. Muneer et al., (2019) prefer chose polystyrene and polyethylene terephthalate. The other researchers use different types of waste: occasional rank coal (Wu et al., 2017), polyvinyl chloride (€zsin & Pütün, 2018), sewage sludge (Wang et al., 2020) and tires (Idris et al., 2020). The usage of combined biomass and plastics in the co-pyrolysis lower the activation strength (Bura & Grupta, 2018) and increase value bioproducts (Uzoejinwa et al., 2018).

The pyrolysis process is a thermal decomposition process, which happens in the absence of oxygen, which converts lignocellulosic biomass into carbon-wealthy solids and liquids. the principal components of lignocellulosic biomass, namely cellulose, lignin, and hemicellulose, are all thermally degraded in the temperature range of 300-500 C. in addition, pyrolysis is one way to launch energy stored in biomass via transformation into different beneficial products (Magdziarz et al., 2020). Pyrolysis includes diverse and complicated chemical reactions that arise at once (Mishra and Mohanty, 2020), the temperature variety for the gradual pyrolysis system of biomass is 300-650 C (Basu, 2018). The preliminary products resulting from pyrolysis are condensed fuel and solid biochar. Pyrolysis is a new generation that produces products inside the form of bio-oil, biochar, syngas, and ash that may be used as renewable energy (Azargohar et al., 2013).

Some of the parameters that affect pyrolysis are the composition and output of the product, in particular, rely on the form of biomass and its particle size, pyrolysis temperature, reactor type, and heating rate (Lu et al., 2009). Many types of reactors that use to biomass/waste pyrolysis are batch, semi batch or continue (Salehi et al., 2009; Arami-Niya et al., 2011; Abnisa et al., 2013; Azargohar et al., 2013). It is generally known that continues reactor produce better liquid output than the use of batch or semi-batch reactors. Pyrolysis of biomass closer to attaining excessive power performance and adjusting the necessities to shape the favored product kind contemplating enjoy and understanding of the effect of pyrolysis parameters on system performance, which include response rate, product selectivity & yield, product properties, and power performance (Lu et al., 2009).

The production of renewable energy from biomass and waste has implications for research on organic, biochemical, and thermochemical routes (Demirbas, 2009; Maity, 2015). Recent evaluations consistent with organic routes consist of anaerobic digestion (Hagos et al., 2017), saccharification, and fermentation (Pothiraj et.al., 2015), while biochemical routes consist of biodiesel manufacturing (Gumba et al., 2016; Saxena et al., 2009). Recent evaluations of thermochemical routes consist of catalytic cracking (Mante et al., 2011; Huber et al., 2006), thermal pyrolysis (Roy & Dias, 2017; Jones et al., 2009; Butler et al., 2011), catalytic pyrolysis (Kabir & Hamid, 2017; Yildiz et al., 2016; Venderbosch, 2015; Bank & Bridgwater, 2016), hydro-pyrolysis (Balagurumurthy & Bhaskar, 2014; Linck et al, 2014), gasification (Farzad et al., 2016; Sansaniwal et al., 2017) and hydrothermal liquefaction (Guo et al., 2015; Arturi et al., 2016).

The purpose of this study is to study the bio-oil production using pyrolysis with waste biomass as raw material. The focuses of studies are the material of pyrolysis, the parameters that influencing pyrolysis, the products of pyrolysis, properties of bio-oil as main products of pyrolysis and benefits of bio-oil.

METHODS

This research was designed in a literature survey by collecting, identifying, and comparing related research journals. The object of research is the pyrolysis of waste biomass. The research subject is the material of pyrolysis, the parameters that influencing pyrolysis, the products of pyrolysis, properties of bio-oil as main products of pyrolysis and benefits of bio-oil. Searching of journals were done based on related keywords, namely biomass, bio-oil, modifier and pyrolysis. Selection or retrieval of source journals is based on the following conditions: the journal year ranges from 2005-2021, in the form of international journals. The source journal contains data on pyrolysis as the research object.

RESULTS AND DISCUSSION

The various of thermochemical processes, which is one of the best processes for converting biomass is pyrolysis because of its speed and simplicity (Samburova et al., 2016). In addition, pyrolysis produces versatile products, one of which is bio-oil which can be used as an alternative fuel for daily life (Lee et al., 2008; Park et al., 2010; Eom et al., 2013). The products produced from this pyrolysis process are liquid products such as bio-oil, gaseous products such as syngas, and carbon-rich solid residues such as bio-char (Bridgwater, 2012). There are several classifications of pyrolysis based on differences in operating conditions, namely, fast pyrolysis, slow pyrolysis, catalytic pyrolysis, hydrolytic pyrolysis, microwave-assisted, and flash pyrolysis.

Table 1. The effect of type of material and pyrolysis temperature on the products yield.

Material	Temperature	Bio-Oil	Bio-Char
Oat Straw	600°C	56.9%	-
Sawdust	500°C	41.05%	27.59%
Microalgae	185-570°C	39.99%	-
Rice straw Water hyacinth	400°C	44.4%	-
Wood Sawdust	500°C	44.16%	-
Plastic Seaweed	500°C	68.9%	-

The material and yield of Pyrolysis

Waste biomass using a wheat straw is high potential raw material to produce renewable energy in Poland. The experimental results obtained, that increase temperature causes the increase in gas and liquid yields. At 600◦C, the tar content was 56.9% and accumulated gases were 19.0%. The opposite condition occurs in charcoal production, the higher temperature produce less charcoal. At 300 ºC, the yield of charcoal is 48.0%, decrease become 24.0% at temperature of 600 ºC (Mlonka-Medrala et al., 2021).

Waste sawdust were used in in batch and continuous process (Soni, 2020). The batch pyrolysis produce the bio-oil yield of 34.9 wt% of and the biochar yield of 38.6% wt. On the other hand, the bio-oil yield of 41.05 wt% bio-oil and the biochar yield of 27.59 wt% was gotten from continuous pyrolysis. The continuous process has the potential to be used to produce to the industrial-scale production of bio-oil and bio-char. Varma et al. (2019) used a semi-batch reactor. The sawdust size used was 0.6<dp<1 mm. The maximum yield of bio oil obtained was 44.16 wt% with a flow rate of 100 cm^3/minute and temperature of 500 °C. The increasing temperature will decrease bio-oil yield, increased gas product yields and reduced bio-char yields with increasing temperature. The flow rate rise will increases the yield of bio oil and decreases the yield of biochar.

Co-pyrolysis of rice straw and water hyacinth in a 5:5 ratio, at an ideal temperature of 400 °C gives a yield of bio-oil higher than 44.4% by weight. The pyrolysis liquid produced from that mixed contains more aliphatic compounds and aromatic protons than the liquid obtained from each ingredient individually. This has been an additional FF determined through Gand C-MS analysis. Further studies are needed to get the reaction conditions to improve the applicability and feasibility of co-pyrolysis (Xu-Jin et al. 2019). Plastic waste and naturally-grown seaweed can be convert into crude vegetable oil using microwave vacuum pyrolysis. The ratio of ttwo compounds is 25:75 and the temperature is 500°C to get yield of bio-oil up to 68.9 wt% (Abomohra et al., 2021).

Parameters Influencing Biomass Pyrolysis

From various types of biomass, it's known that biomass affects the pyrolysis process and product. In addition, the mineral content and composition of the biomass also can be a reason that greatly affects the distribution and properties of the product because of its catalytic effect during the pyrolysis of biomass (Fahmi et al., 2008; Fahmi et al., 2007). The use of straw as raw material for pyrolysis is beneficial in obtaining bio-oil yields and reducing the cost of producing charcoal and gas (Guo et al., 2010).

From the varied types of materials used, it can be seen that wheat straw biomass produces

Table 2. Material and Method

References	Raw Material	Analysis	T (^{0}C)	Results
Xu-Jin et al., 2019	Rice straw and water hyacinth	TGA, GC-MS, FT-IR, NMR	400 ^{0}C	Bio-Oil : 44,4%
Varma et al., 2019	Wood sawdust	TA, FT-IR, GC-MS, NMR, FESEM	500 ^{0}C	Bio-Oil : 44,16%
Soni et al., 2020	Sawdust	TGA, GC-MS, FT-IR, NMR, SEM	500 ^{0}C	Bio-Oil : 41,05% Bio-Char : 27,59%
Gong et al., 2020	Microalgae	TGA, FTIR	570 ^{0}C	Bio-Oil : 39,99%
Mlonka-Medrala et al., 2021	Oat straw	TA, FTIR, micro-GC	600 ^{0}C	Bio-Oil : 56,9% Gas : 19%
Abomohra et al., 2021	Plastic Seaweeds	Analyzer, GC-MS, HHV	500 ^{0}C	Bio-Oil : 68,9%

Table 3. The reactor type and heating rate

References	Reactor type	Particle Size	Heating rate
Xu Jin et al., 2019	Fixed bed	-	20 ^{0}C/min
Varma et al., 2019	Semi batch	< 0.25 to > 1.7 mm	10 ^{0}C
Soni et al., 2020	Fixed bed	< 2 mm	-
Gong et al., 2020	Tube furnace	-	10 ^{0}C
Mlonka-Medrala et al., 2021	Semi-batch vertical	< 1 mm	50 ml/s
Abomohra et al., 2021	Fixed bed	< 3 mm	20 ^{0}C/min

the highest bio-oil products by 56.9% and gas by 19% with a temperature of 600 °C. Additionally, the highest biomass product was produced from a mixture of plastic and seaweed materials of 68.9% with a temperature of 500 °C.

The temperature in the pyrolysis process greatly affects the distribution and properties of the resulting a product (Horne & Williams, 1996; Westerhof et al., 2010) When the pyrolysis temperature exceeds 700°C, the amount carbon in the bio-oil increase in the form of polycyclic aromatic hydrocarbons, like pyrene and phenanthrene. This is due to decarboxylation and dehydration reactions (Akhtar & Amin, 2012). While the yield of bio-oil which reaches the highest concentration is at a temperature between 400°C and 500°C, which then the yield of the bio-oil will decrease after continued heating. When the temperature is above 600°C, the product in the sort of the bio-oil and charcoal becomes gas because of the dominant secondary cracking reaction (Li et al., 2007).

Particle size during the pyrolysis process greatly affects the ultimate result, therefore milling biomass into smaller particles is common way to prepare biomass before input to the reactor and increase pyrolysis performance, because the gradient of temperature across the particles will affect the mechanism of the pyrolysis of the biomass produced. To extend the resulting bio-oil product, The particle size must be smaller to get higher yield. Bigger diameter will increase the yield of charcoal and gas also because the density of charcoal and reduce the yield of bio-oil.

The heating rate wont to support the rapid fragmentation of the biomass produces more gas and produces less charcoal. Bio-oil production is increased at a quick heating rate because of reduced heat and mass transfer restrictions, and short time available for secondary reactions. The typical heating rate used during pyrolysis is 10 °C/min and 20°C/min. Many methods are used to analyze the pyrolysis products i.e Thermogravimetric analysis (TGA), gas chromatography and mass spectroscopy (GCMS), scanning electron microscope (SEM, thermal analysis (TA) and Fourier-transform infrared spectroscopy (FTIR). The use of different materials causes the yield obtained are also different.

Products of The Co-Pyrolysis Process

The liquid product of pyrolysis is bio-oil, dark brown natural liquid and can emerge as fuel for an extensive form of packages and emerge as a popular cloth for generating hydrocarbons that may be comfortably incorporated into current oil refineries or destiny biorefineries (Aysu & Sanna, 2015). These traits can motive destructive

Table 4. The raw material and their parameters

Raw Material	Analysis	Parameter
Rice straw Water hyacinth	TGA, GC–MS, FT-IR, NMR	• TGA : Weight (mg), Temperature (°C), heat rate (°C/menit). • GC-MS : Ratio, Temperature • FT-IR : Temperature • NMR : Chemical Shift (ppm)
Wood sawdust	TA, FT-IR, GC–MS, NMR, FESEM	• TA : Temperature (°C), heat rate (°C/menit). • FT-IR : Temperature • GC-MS : Ratio, Temperature • NMR : Chemical Shift (ppm) • FESEM : -
Sawdust	TGA, GC–MS, FT-IR, NMR, SEM	• TGA : Temperature (°C), Initial Weight Loss, Fluid Level • GC–MS : Ratio, Temperature, Retention Time • FT-IR : Wavenumber/cm, Transmitance (%) • NMR : Chemical Shift (ppm) • SEM :-
Microalgae	TGA, FTIR	• TGA : Temperature (°C), heat rate (°C/menit). • FTIR : Mass Recovery (%), Temperature (°C)
Oat straw	TA, FTIR, micro-GC	• TA : Temperature (°C), heat rate (°C/menit). • FTIR : Mass Recovery (%), Temperature (°C) • micro-GC : Ratio, Temperature, Retention Time
Plastic Seaweeds	TGA, Elemental Analyzer, GC–MS, HHV	• TGA : Temperature (°C), Mass loss rate (%/°C) • Elemental Analyzer : Temperature (°C), heat rate (°C/menit). • GC–MS : Temperature • HHV : Ratio

consequences on gasoline traits, together with low calorific value, decreased combustion efficiency, corrosion, and instability (Abnisa & Wan Daud, 2015). Furthermore, the highest yield of the bio-oil can be achieved with reformulate new methods or using putting off the oxygen (Hassan et al, 2016).

Wood-primarily based biomass, the use of a better lignin content material may also have a particularly better charcoal output. The impact of lignocellulosic compounds with inside the manufacturing of unstable substances has been studied appreciably through many researchers (Asadullah et al., 2008; Qu et al., 2011). The quantity of liquid product primarily based totally at the co-pyrolysis system may be predicted (low or excessive) while the biomass composition and the combination co-feed composition were stimulated typically the use of the proximate characterization evaluation method, which identifies 4 number-one biomass compositions: unstable be counted, constant carbon, moisture content material. , and ash content material. Volatile be counted and ash content material is the number one element which has an effect at the manufacturing of liquid output at some stage in pyrolysis. Many researchers said that the accelerated unstable era desired the manufacturing of massive quantities of pyrolysis oil and led to excessive reactivity, however excessive ash content material (alkali metals) contributed to the lower in oil output, (Fei et al., 2012; Fahmi et al., 2008). The effects of the proximate evaluation of lignocellulosic biomass defined that the composition consists of cellulose, hemicellulose, and lignin as the number one component. Cellulose and hemicellulose play a crucial function in making unstable substances at some stage in pyrolysis however cellulose extra unstable than hemicellulose (Asadullah et al., 2008), main to a boom in oil output.

Production of bio-oil is the number one made from interest (Czernik et al., 1994), Bio-oil has been significantly examined as a candidate for combustion gasoline for the manufacturing of energy and warmth in boilers, furnaces, and combustion chambers (Freel et al., 1996; Gust, 1997), fuel line turbines (Crayford et al., 2010; Strenziok et al., 2001), and diesel engines (Chiaramonti et al., 2003), and. Bio-oil changed into effectively introduced to the diesel take a look at engine the usage of restricted working time, while long-time period operation changed into now no longer feasible because of negative bio-oil quality, eg negative volatility, excessive viscosity, excessive corrosiveness, and coke (Jembatan air, 1999).

Properties of Bio-Oil

The physical properties of bio-oil that need to be considered are solid content, pH, viscosity, and density (Soni & Karmee, 2020).

Table 5. The measurement for physical properties of bio-oil.

Parameter	measurement
Solid content	ASTM D7579-09
pH	pH meter
viscosity	ASTM D 445
density	density analyzer

Bio-oil contains more than 400 components such as aldehydes, ketones, alcohols, phenols and oligomers (Joshi & Lawal, 2012) and usually contains wood biomass materials such as 30% of phenolics, 20% of aldehydes and ketones, 15% of alcohol and 30% of water. The other properties of bio-oil are high oxygen content, bio-oil and water emulsion, low energy density, low pH and the presence of trapped char (Perkins et al., 2018).

Crude bio-oil is generally contained 20-30 %wt. of water from total product (Lede et al., 2006). Bio-oil can also be relied on to be a 2-phase microemulsion using pyrolytic lignin macromolecules dispersed in a continuous liquid phase. Hydrochloric acids, aldehydes, and oligomers cause water and oxygen content in crude bio-oil higher, which makes up the low energy density (Perkins et al., 2018).

Benefits of Bio-Oil

Bio-oil can be used as diesel fuel or used as raw material in the petrochemical industry (Varma et al., 2019), power generation, transportation, and chemical production (Anil et al., 2019). The bio-oil containing chemicals such as phenol, furfural, and cresol can be used as a standard material in various applications. Phenol and its derivatives can be used to make phenolic resins, bisphenol-A, and caprolactam, intermediate products to produce nylon adhesives, synthetic fibers, and plywood (Lazzari et al., 2016). Bio-oil can be used as a binder for the manufacture of briquettes and pallets based on combustible organic waste. In general, bio-oil can now be used as fuel for combustion, power generation, transportation, and chemical production (Anil et al., 2019).

CONCLUSION

Biomass waste is a promising energy source and has high potential as a liquid, solid, or gas energy source. Then pyrolysis is a promising technology to convert various lignocellulosic biomass into renewable energy. The pyrolysis products and their properties vary widely based on the composition and structure of the feedstock, and the process temperature, heating rate, and residence time. The advantages of this pyrolysis process are that it can reduce biomass waste in the environment into a fuel product or energy source, then the drawbacks of the pyrolysis process are that it cannot use a high oxygen content, has a low ph due to the presence of carboxylic acids, and if the temperature is too high, high, the production of bio-oil obtained will decrease and produce people will increase. Accelerated instability requires the manufacture of large quantities of pyrolysis oil and causes excessive reactivity, but excessive ash content (alkali metals) contributes to lower oil production.

Table 5. Raw material, parameter and the products

Author	Raw Material	Parameter Involved	Information Extracted	C
Mlonka-Medrala et al., 2021	oat straw	• Particle Size : <1 mm • residence time : 1-38 s • heating rate 50 ml/s • Reactor : semi-batch vertical • pressure • heating time on the yield of pyrolysis products • Temperature : 300°C, 400°C, 500°C, 600°C	• The material was collected from the Polish market • Increase temperature will increase the quality of the pyrolysis gas. The highest concentrations of the most valuable compounds such as methane and hydrogen were obtained at 600◦C. • The elements that detected in the raw fuel and chars are carbon (43.97 wt.%), hydrogen (6.16 wt.%), a little nitrogen and sulfur (0.11 wt.%) • The identification of the chemical bonds in the raw biomass and chars, and analysis of the changes in functional groups was done by FTIR and GCMS	57%
Soni et al., 2020	sawdust	• Effect of temperature variations 400-600°C • Particle Size : <2 mm • Reactor : fixed bed • heating rate • flow rate is constant • the split ratio was 20:1 • types of batch and continuous reactors on the yield of bio-oil, bio-char and pyrogas	• Raw material is from India • higher lower heating value (LHV, over 21MJ/kg, much higher than that of Ba) • elemental composition shows significant difference. Ba contains much higher oxygen content (43.18 wt.%) • The optimum temperature for sawdust pyrolysis was found at 500 °C using a batch reactor; produce bio-oil (34.9 wt%), bio-char (38.6 wt%) and pyro-gas (26.5 wt%) • Use of a vertical moving bed type continuous reactor with temperature of 500 °C increase yields	41%

Author	Raw Material	Parameter Involved	Information Extracted	C
			of products to bio-oil (41.05 wt%), bio-char (27.59 wt%) and pyro-gas (31.36 wt%)	
Gong et al., 2020	Microalgae	• Effect of temperature at 400-600°C • heating rate: 10°C /min • flow rate: 100 mL/min • Reactor : Tube furnace • The blending ratio of catalysts was 5 wt % • catalyst on bio-oil yield	• Oil components were get at 600 °C . • The content of gasoline components in pyrolysis oil rise with addition of KCl, MgO and Al_2HAI_3 • The addition of catalysts can effectively enhance the amount of CO and CHs and diminish CO_2 in the same time • elements (Na, K, Ca, Mg, Fe, Al) • HHV-High heating value : 8.98 MJ/Kg	-
Xu Jin et al., 2019	• Rice straw • Water hyacinth	• Temperature: 300 °C, 350°C, 400°C, 450°C • Reactor : fixed bed • stream rate for the segment: 1 mL/min • the split ratio: 20:1 • heating rate of 20°C/min and residence time	The yield of bio-oil increased by 24.7 wt% for WH and 28.2 wt% RH at temperature of 300 °C to 400 °C. At temperature above 400 °C, bio-oil was decreased • Co-pyrolysis of rice straw and water hyacinth in a 5:5 ratio, at temperature of 400 °C.is a valid technique for bio-oil preparation which gives higher yields than 44.4%	44,4%
Varma et al., 2019	• wood sawdust	• Temperature : 350-650°C • heating rate : 10 °C/min • flow rate : 200 cm3/min • particle size : <0.25 to >1.7 mm • Reactor : semi batch	• The gaseous products with composition (mol): 46.6% CO, 34.8% CO_2, 6.7% H_2, and 11.9% CH_4.were achieved at pyrolysis temperature of 500°C. • alkenes, alkanes, aromatics and many other chemical compounds were found with analyzing by FTIR	-
Abomohra et al., 2021	• Plastic • seaweeds	• Temperature : 400-600°C	• . HHV of bio-oil quality is influenced by the elemental composition	-

Author	Raw Material	Parameter Involved	Information Extracted	C
		• heating rate : 20 °C/min • particle size : < 3 mm • Reactor : fixed bed	• HHV of the bio-oil from 75% LDPE blend ratio is 2.3%, 10.0% higher than the maximum values of diesel and petroleum oil and 2.1% higher than the maximum HHV obtained from co-pyrolysis of HDPE with seaweeds	

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