

INFLUENCE TEMPERATURE 2021

by Anton Irawan

Submission date: 05-Apr-2023 03:50PM (UTC+0700)

Submission ID: 2056457313

File name: 2021_Influence_Temperature.pdf (884.81K)

Word count: 4949

Character count: 26227

Research Paper

Influence Temperature and Holding Time of Empty Fruit Bunch Slow Pyrolysis to Phenolic in Biocrude Oil

Anton Irawan^{1,2}, Teguh Kurniawan^{1,2}, Hafid Alwan^{1,2}, Darisman¹, Dina Pujianti¹, Yazid Bindar^{2,3}, Muhammad Saifullah Abu Bakar⁴, Asep Bayu Dani Nandiyanto⁵

¹ Department of Chemical Engineering, Universitas Sultan Ageng Tirtayasa, 42435, Indonesia

² Rumah Teknologi Aksiatama, Cilegon, 42443, Indonesia

³ Department of Chemical Engineering, Institut Teknologi Bandung, 40132, Indonesia

⁴ Faculty of Integrated Technologies, Universiti Brunei Darussalam, Gadong BE1410, Brunei Darussalam

⁵ Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia, Bandung 40154, Indonesia

antonirawan@untirta.ac.id

<https://doi.org/10.31603/ae.5049>



Published by Automotive Laboratory of Universitas Muhammadiyah Magelang collaboration with Association of Indonesian Vocational Educators (AIVE)

Abstract

Article Info

Submitted:

10/05/2021

Revised:

10/07/2021

Accepted:

28/07/2021

Online first:

12/09/2021

Indonesia is an abundance of biomass from agricultural, plantation, and domestic waste products. Biomass can be converted into fuels and chemicals that are environmentally friendly. Empty fruit bunches (EFB) are biomass from abundant palm oil processing. Pyrolysis was a thermal process with free oxygen at temperatures between 400-600°C. Generally, pyrolysis was carried out under fast pyrolysis to produce a product that leads to bio-crude oil. One of the main components of bio-crude oil was phenol, which had been produced from further processing of crude oil. With the limitations of crude oil, the production of phenol from biomass pyrolysis was an option for the future, especially for fuels and fuel additives. Thus, it is necessary to investigate the effect of heating rate, temperature pyrolysis, and holding time on pyrolysis products including phenols in bio-crude oil. Slow pyrolysis of EFB was performed at various parameters, including temperatures (400, 450, and 500°C) and holding time (5, 10, and 15 min). Slow pyrolysis of oil palm EFB with variations in temperature and holding time has been carried out by producing liquid between (40 - 42 % weight), gas (19 - 21 % weight), and solid products (38 - 39 % weight). Biocrude oil liquid product showed the highest yield compared to biochar and bio pyrolysis gas. Temperature plays an important role in controlling the production of bio-crude oil as a liquid product, including a component in bio-crude oil. Phenol recovery was more affected by temperature instead of holding time.

Keywords: Biomass; Empty fruit bunches (EFB); Slow pyrolysis; Bio-crude oil; Phenol

1. Introduction

Fuels and chemicals are very important needs today along with technological advances. Nowadays, most of the fuel and chemicals used are derived from petroleum, which is a non-renewable material. This condition required alternative raw materials for fuels and chemicals that are more sustainable for a long time. Furthermore, the fossil fuel resources such as petroleum, natural gas, and coal have large impacts on the environment due to gas emission and large waste issues. Hence, the alternative

resource should be sustainable and friendly to the environment. Biomass is an alternative raw material for the manufacture of sustainable fuels and chemicals because biomass is a material produced from agricultural or plantation processing waste and its less impact on the environment [1]-[3].

Palm oil processing produces high solid waste around 23 %-wt. for every ton of fresh fruit bunches (FFB) [4]. Indonesia produces around 50 million crude palm oil and 50 million empty palm fruit bunches (EFB) tons every year [5]. The EFB



This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

was used for fuel in boilers of palm oil plants or returned to oil palm land. The high effort required for returning the EFB to the land of palm oil plantation. It is also expensive for transporting and unloading the EFB. Thus, it is necessary to optimize the use of EFB either as fuel or chemicals at the palm oil processing plant location.

Biomass can be converted to fuels or chemicals through a thermochemical or biochemical process [6]–[8]. Thermochemical of biomass produces fuels and chemicals in a shorter time than biochemical and more favorable to be commercialized for replacing fossil-based resources [3] [9]. There are various thermochemical routes to convert biomass into chemicals and fuels such as pyrolysis, gasification, and combustion [10]–[13]. The promising thermochemical to convert biomass and produce more products was pyrolysis [12][14][15]. Pyrolysis is the thermochemical of hydrocarbon of solid in absence of oxygen and it can take place from temperature 200 to 850°C. In the pyrolysis of biomass with a temperature range between 200–300°C, the aim was to remove some volatile matter so that the product was mostly in a solid state [16]. At low temperature, pyrolysis was often called torrefaction to change the character of the biomass from hydrophilic to hydrophobic [17]. Then at temperatures between 300–650°C, biomass pyrolysis aims to produce liquid, solid, and gas products. Then the temperature is 650 to 850°C, the resulting product is more towards gas. Generally, the pyrolysis of biomass was performed at temperatures 350–600°C [12].

During pyrolysis, the long and complex structure of carbon-hydrogen-oxygen molecules in the biomass decomposed into smaller molecules in the gas, liquid, and solid products [14]. The main constituent components of biomass are hemicellulose, cellulose, and lignin. Hemicellulose was the first component that undergoes decomposition in pyrolysis at temperatures of 200–300°C. Then, the second component to be converted in pyrolysis was

cellulose around temperature 300 – 400°C. The last component was lignin to be converted around temperature 400–700°C [18].

The composition of the gas, liquid, and solid products produced by biomass pyrolysis is very dependent on the mode and conditions of pyrolysis as shown in Table 1. From this table, it can be seen that the slow pyrolysis process can produce almost even product distribution between liquid, liquid, and gas products. Liquid products from biomass pyrolysis can be used for chemicals, while solid products and gases can be used for fuel in the pyrolysis process as auto-fuel. The liquid products derived from rapid pyrolysis that are used for chemicals generally contain up to 87% phenol [19]. Palm biomass was able to produce phenol products higher than wood species because of the high lignin content in palm biomass [20].

Phenol is a chemical product that has many benefits, among others, for fine chemical and resin manufacturing which was called phenolic resin. The phenolic resin was a combination of phenol components with formaldehyde to create large networks of permanently bonded molecules. The phenolic resin was widely used in the plywood industry because it has strong mechanical properties and highly resistant to fire [20]. Phenol is also one of the alternative materials for fuels and fuel additives.

Phenol is commercially produced via the reaction of benzene to cumene through three stages. By using benzene produced from crude oil processing, phenol will face obstacles in its supply. In connection with this, it is necessary to find alternative raw materials that are more sustainable and environmentally friendly, which one of the potential route is slow pyrolysis of EFB biomass. The products of slow pyrolysis was influenced by pyrolysis temperature and holding time [21]. Temperature and holding time have a strong relationship for slow pyrolysis so that the volatile matter (VM) in biomass can be escaped

Table 1. Typical conditions and product of biomass pyrolysis [22].

Method	Condition	Products %-Weight		
		Liquid	Solid	Gas
Torrefaction	~300°C, solid, 10 -60 min	0	80	20
Carbonization (slow pyrolysis)	~400°C, vapour, 15 -12 min	30	35	35
Intermediate pyrolysis	~500°C, hot vapour, 10 -30 s	50	25	25
Fast pyrolysis	~500°C, shot hot vapour, ~ 1 s	75	12	13

from the pores to produce phenol. The aims of this study are to investigate the effect of temperature and holding time on phenol products of EFB biomass pyrolysis in bio-crude liquids. Knowing the effect of temperature and holding time will be the basis for designing bio-crude oil production equipment from EFB pyrolysis to produce phenol products as a disinfectant.

2. Material and Method

2.1. Materials

In this research, the material was empty palm fruit bunches (EFB) with the proximate analysis presented in Table 2. The volatile matter of the EFB was high and this condition was suitable for the pyrolysis route. EFB was obtained from a palm oil mill in Lebak - Banten. Then, the EFB was crushed to reduce the size to 32 mesh.

2.2. Methods

An amount of 200 g EFB was weighted (m_{initial}) and feed into the pyrolysis reactor as shown on Figure 1. During slow pyrolysis, the heating rate was controlled around $0.120 - 0.265^{\circ}\text{C}/\text{s}$. Then,

the EFB was heated until reached pyrolysis temperature (400, 450, and 500°C). At those temperatures, the heater was controlled for 5, 12, and 15 min as holding time. In this study, the pressure in the pyrolysis reactor was assumed to be atmospheric because, during the EFB pyrolysis process, the gas produced was directly cooled in the condenser without being held. The temperature in the pyrolysis reactor was recorded every 60s during the pyrolysis reactor heating process to determine the pyrolysis heating rate at different holding times. Later, the liquid product container was prepared so that when the gas pyrolysis condensation process takes place, the liquid product can be obtained and weighted (m_{bco}). At the end of the slow pyrolysis, the solid product inside of the reactor was taken to be weighed (m_{biochar}). The composition of the liquid product of bio-crude oil was analyzed by GC-MS. The type of GC-MS used was Shimadzu Type QP2010 with the DB5-MS column from Agilent. The correlation of the relationship between the percent yield of products can be seen in equations (1) to (4).

Table 2. Proximate analysis of Empty Palm Fruit Bunches (EFB)

Analysis parameters proximate	Sample EFB	
	% wt	Method
Moisture in air dried	10.68	ASTM D 7582 -15
Ash	6.73	ASTM D 7582 -15
Volatile matter	64.05	ASTM D 7582 -15
Fixed carbon	18.54	ASTM D 3172 - 13

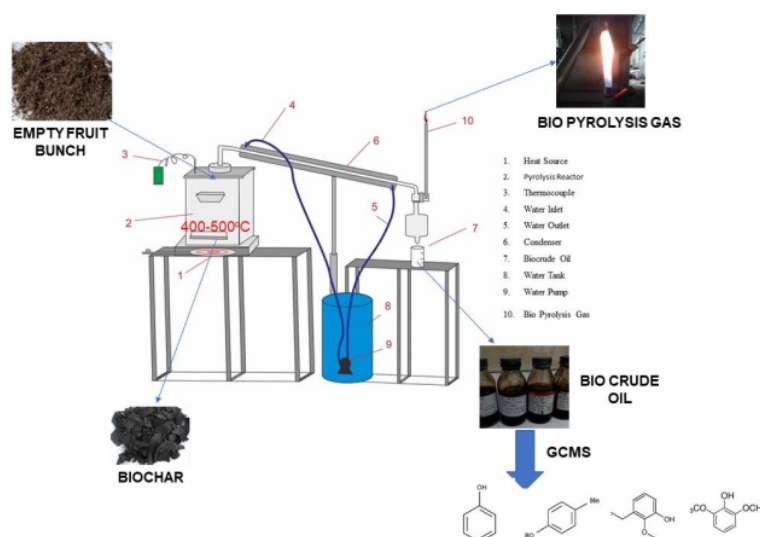


Figure 1. Pyrolysis Empty Fruit Bunch (EFB) experimental setup

$$m_{EFB} = m_{pygas} + m_{bco} + m_{biochar} \quad (1)$$

$$\% x_{bco} = \frac{m_{bco}}{m_{EFB}} \times 100\% \quad (2)$$

$$\% x_{biochar} = \frac{m_{biochar}}{m_{EFB}} \times 100\% \quad (3)$$

$$\% x_{pygas} = 100\% - \% x_{bco} - \% x_{biochar} \quad (4)$$

3. Result and Discussion

3.1. Empty Fruit Bunch (EFB) pyrolysis

Figure 2 showed the operation process of EFB pyrolysis with several stages. The initial stages were removing the water content from the biomass EFB and heating the EFB from atmospheric temperature to pyrolysis temperature (400, 450, 500°C). Furthermore, at the pyrolysis temperature (400, 450, 500°C) the holding temperature was called the holding time (5, 10, 15 min). After that the process of decreasing the temperature until it reaches the atmospheric temperature. During the EFB pyrolysis process, the pressure of the pyrolysis reactor was estimated to be slightly above atmospheric pressure because the product gas produced flows directly through the pipe. With the product gas flowing out of the pyrolysis reactor, the reactor pressure does not increase too high so that the product composition was more influenced by temperature.

Slow pyrolysis was pyrolysis with temperature rise slowly over a long time and heating rate. Under these conditions, the liquid product was produced from slow pyrolysis tends to produce a low carbon chain so it is necessary to adjust the heating rate so that the resulting product can lead to liquids, especially phenol components. In this experiment, the heating rate was controlled around slow pyrolysis between 0.126 – 0.160°C/s as represented by holding time (Figure 2). Low heating rate (0.125°C/s) was controlled by holding time 15 min and high heating rate (0.16°C/s) was controlled by holding time 5 min. At a lower heating rate than the above conditions, it produced more biochar products than the components of bio-crude oil or bio-pyrolysis gas [23].

At short holding time (5 min) in this slow pyrolysis, the operation time was longer than holding time 10 and 15 min so the heating rate (°C/s) at short holding time higher than 10 and 15 min. Thus, the holding time can be used to control

the heating rate in the pyrolysis process [24]. Due to the slow heating rate at high temperature (500°C), the product of EFB pyrolysis can produce bio pyrolysis gas (BPG), bio-crude oil (BCO), and biochar. Biochar has the benefit of being used directly as fuel in slow pyrolysis because biochar had a calorie content of between 5500-5800 kcal/kg [25].

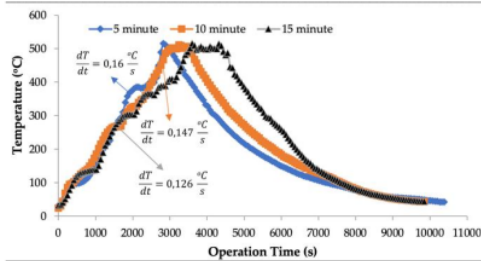


Figure 2. Temperature profile throughout the operating time of EFB Slow pyrolysis at various holding times at temperature 500°C

In this investigation, the slow pyrolysis of EFB produced more liquid products than biochar and bio-pyrolysis gas due to a high heating rate of more than 6°C/min (Figure 3). At short holding time (5 min) and high temperature (500°C) had the highest yield of bio-crude oil products like fast pyrolysis. The gasses were difficult to condense in atmospheric condition so that the longest holding time (15 min) produce more pyrolysis gas at temperature 500°C (Figure 3) [26].

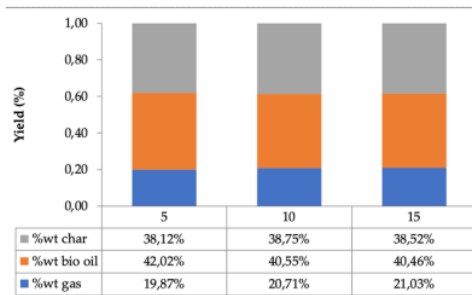


Figure 3. Effect of holding time to distribution of yield (solid, liquid and gas) of slow pyrolysis EFB at temperature 500°C

In all pyrolysis temperature and holding, time produced more bio-crude oil (BCO) products than gas and biochar products. This is because the temperature of pyrolysis occurred above 400°C which the lignin component experienced

depolymerization into smaller components such as guaiacol, phenol, syringol and others [27]. At a temperature of 400°C, only a small of the lignin component occurred depolymerization and an increase in temperature will further increase the rate of BCO formation in the biomass pyrolysis process because more lignin was depolymerized. The short holding time and low temperature (400°C) produced a low yield of bio-crude oil around 34%-wt (Figure 56). Increasing pyrolysis temperature to 450 and 500°C resulted in a high bio-crude oil product yield because the high temperature caused a greater amount of depolymerized lignin.

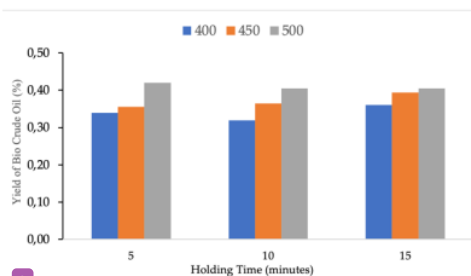


Figure 4. Effect of Holding Time and Temperature to the Yield of Biocrude Oil in Slow Pyrolysis of EFB

Holding time was carried out to maintain the pyrolysis operating conditions so that more biomass was converted at that temperature to BCO or BPG [28]. An increase in the holding time above 30 minutes at temperatures above 400°C will cause a decrease in the amount of BCO

because most of the product leads to BPG [29]. In this experiment, increasing holding time at the highest temperature would decrease the yield of bio-crude oil products (Figure 3) due to more volatile matter decomposed to the smaller pyrolysis gas. BCO products increase at temperatures of 400 and 450°C along with the increase in holding time because the depolymerization process of lignin is still not high and does not lead to BPG components. Thus, pyrolysis temperature was more dominant in producing more liquid products than holding time.

3.2. Bio Crude Oil Components Analysis

Biocrude oil products produced from the EFB biomass pyrolysis process can reach 42% which occurred at a temperature of 500°C and a holding time of 5 minutes. The reaction pathway of the EFB pyrolysis process was shown in Figure 5 that biomass composed of hemicellulose, cellulose, and lignin components were thermally decomposed.

In this study, pyrolysis was carried out at temperatures between 400 to 500°C so that more lignin would be decomposed into smaller components. In some literature, it is said that the depolymerization process of the components that make up biomass was more influenced by temperature [30]–[32]. The pyrolysis temperature will affect heat transfer, polymerization reactions, mass transfer, and phase changes. The length of the process is very dependent on the holding time

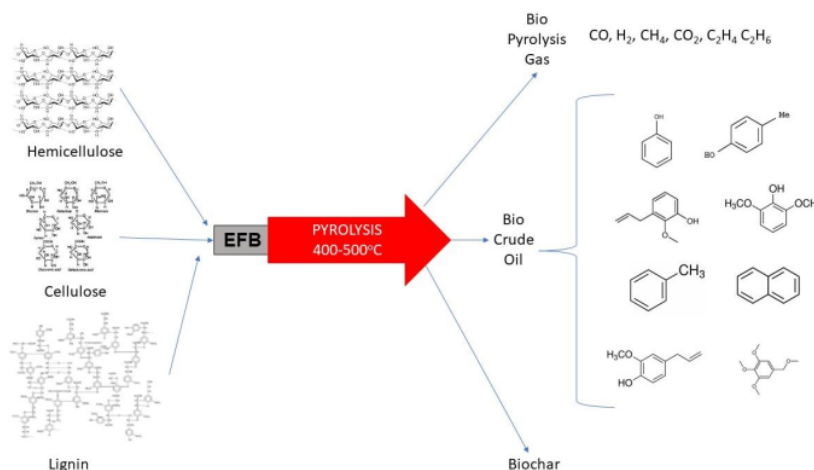


Figure 5. Reaction pathway for EFB pyrolysis at 400, 450 500°C

³⁶ of the pyrolysis process to decompose the constituents of the biomass. Slow pyrolysis of EFB at temperature 400-500°C produced BPG, BCO, and biochar products. Bio Pyrolysis gas is a light gas containing, among others, CO, H₂, CH₄, CO₂, C₂H₄, C₂H₆, and other gas components which are small in quantity [33]. Bio Pyrolysis gas can be used as fuel for the pyrolysis process which requires heat so that fuel consumption in the pyrolysis process can be reduced.

Then, BCO was further analyzed using GC-MS with a chromatographic shown in Figure 8, Figure

7, and Figure 8, respectively. In this figures, the peaks of the chromatographic showed certain components identified by the GC-MS. The number of peaks that can be detected for low pyrolysis temperature (400°C) was 23 peaks while at medium pyrolysis temperature (450°C) was 25 peaks and high pyrolysis temperature (500°C) was 15 peaks. It can be seen that high-temperature pyrolysis has lower components than medium and low temperature. Then, Components composition of biocrude oil from EFB pyrolysis is presented in Table 3.

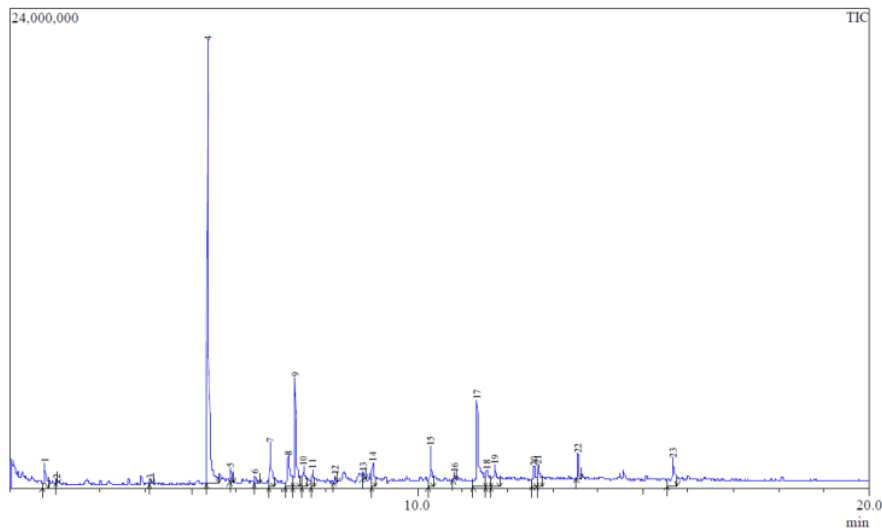


Figure 6. Chromatographic peak identification of EFB pyrolysis by G-CMS: T=400°C and Δt=10 min

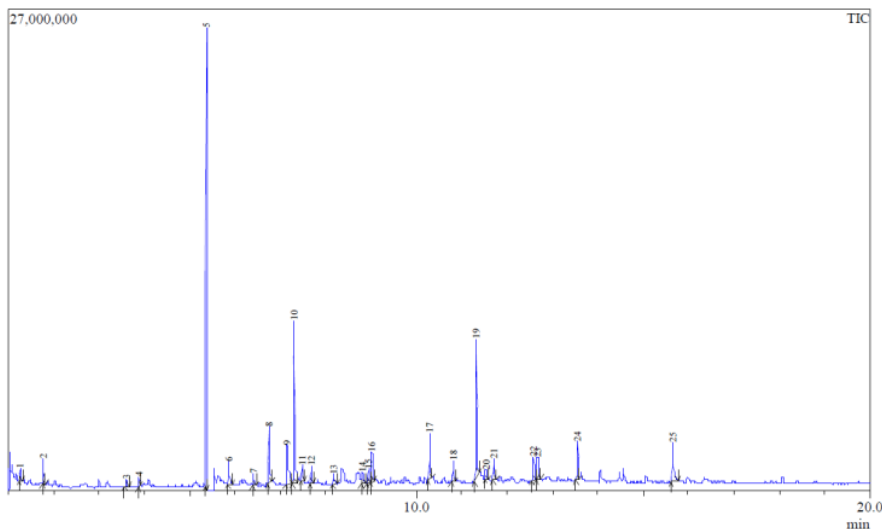


Figure 7. Chromatographic peak identification of EFB pyrolysis by G-CMS: T=450°C and Δt=10 min

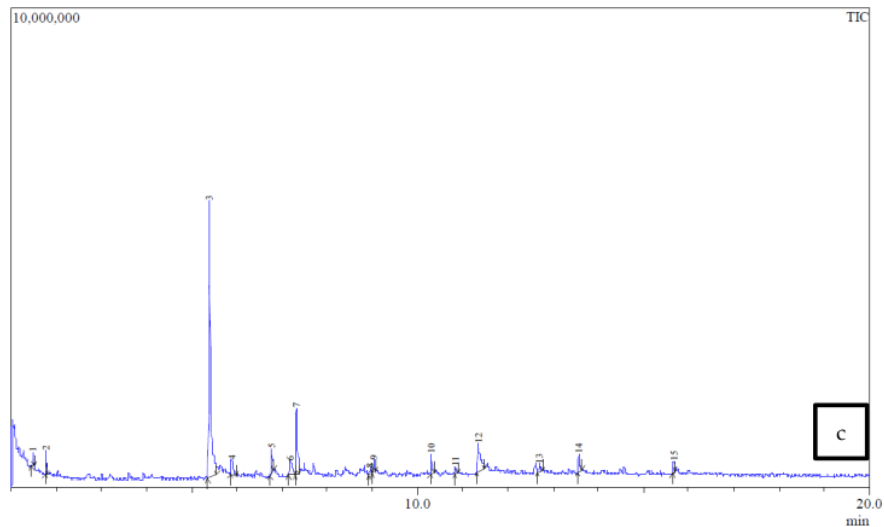


Figure 8. Chromatographic peak identification of EFB pyrolysis by G-CMS: T=500°C and $\Delta t=10$ min

Table 3. Components composition of biocrude oil from EFB pyrolysis

No	Components	Composition (%)		
		Pyrolysis EFB at 400°C and holding time 10 minutes	Pyrolysis EFB at 450°C and holding time 10 minutes	Pyrolysis EFB at 500°C and holding time 10 minutes
1	Ethane, 1,1-diethoxy-	0	0	1.22
2	Toluene	2.56	1.94	2.35
3	Benzene, 1,3-dimethyl-	0	0.85	0.00
4	2-Cyclopenten-1-one, 2-methyl-	0	1.04	0.00
5	Benzene, methoxy-	0.32	0	0.00
6	Phenol	30.99	18.16	51.04
7	Benzoic acid, 2-propenyl ester	0	2.51	2.69
8	2-Cyclopenten-1-one, 2,3-dimethyl-	0	1.10	0.00
9	Phenol, 2-methyl-	4.08	5.12	3.82
10	Phenol, 4-methyl-	5.21	6.85	5.09
11	Phenol, 2-methoxy-	9.58	15.23	11.41
12	Benzoic acid, methyl ester	2.94	1.31	0.00
13	2-Propenal, 3-phenyl-	1.96	1.60	0.00
14	Phenol, 2-ethyl-	0.57	1.21	0.00
15	Phthalene	0	0	1.27
16	Phenol, 2-methoxy-4-methyl-	2.53	0	0.00
17	Phenol, 4-ethyl-2-methoxy-	4.20	4.38	3.10
18	2-Methoxy-4-methylphenol	0	0	1.42
19	2-Methoxy-4-vinylphenol	0.53	0	1.20
20	Phenol, 2,6-dimethoxy-	11.25	12.82	9.21
21	Phenol, 2-methoxy-4-propyl-	3.01	0.89	0.00
22	Benzoic acid, 4-methoxy-, methyl ester	4.35	2.15	0.00
23	Phenol, 4-methoxy-3-(methoxymethyl)-	2.52	2.29	0.00
24	Eugenol	3.53	2.59	1.80
25	Benzene, 1,2,3-trimethoxy-5-methyl-	1.95	3.67	2.97
26	Phenol, 2,6-dimethoxy-4-(2-propenyl)-	5.21	4.90	1.43

Table 3 shown phenolic components are the main compounds found in bio-crude oil (BCO) components. These phenolic compounds are formed from the breakdown of lignin found at

process temperatures above 400°C. Then at temperatures higher than 500°C, the phenolic compounds will decrease due to thermal cracking into lower single components [34]. From this table, it can be seen that there is an increase in the phenol content at the pyrolysis temperature of 500°C compared to the pyrolysis temperature of 400°C (Figure 9a). Phenolic compounds are categorized into 3 types, namely H-phenol, G-phenol, and S-phenol. At temperatures above 450°C, the hydroxylation of the benzene process can occur to form phenol components which are included in the H-phenol category (Figure 9b-7d) [35].

At a longer holding time (15 min), the phenol content was lower than the 10 min holding time which had a higher temperature. It can be seen in Table 3 that the pyrolysis temperature is more dominant than the holding time of the product composition in bio-crude oil. Phenol products are maximally produced at a temperature of 500°C with a residence time of 10 min (51% (Figure 9). This condition shows that the increase in temperature will cause an increase in the low carbon product of phenolics [36]. An increase in residence time of up to 15 min causes the phenol content to decrease at temperatures of 500°C [37]. The low pyrolysis temperature (400°C) causes low recovery of phenol (Figure 9a).

The observation of temperature and residence time on bio-crude components showed that temperature was very influential in producing phenol products [24]. Then the phenolic product in the form of methoxy was produced higher at temperatures of 450°C for almost the entire temperature holding time (Figure 9b-7c). The increase in temperature to 500°C causes a decrease in the acquisition of phenol methoxy due to the demethoxylation reactions [19].

4. Conclusion

Slow pyrolysis of oil palm empty fruit bunches (EFB) with variations in temperature and holding time has been carried out by producing liquid, and solid products. Pyrolysis temperature played an important role in directing the product to bio-crude oil, including its components phenolic. The longer holding time at higher temperatures makes the phenol component decrease. Temperature played an important role in heat transfer, reaction, and mass transfer during pyrolysis of EFB to decompose the cellulose, hemicellulose, and lignin. In the future, it is necessary to investigate the influence of the reactor pressure on the product composition by holding the gas flow rate before condensing into liquid and gas products.

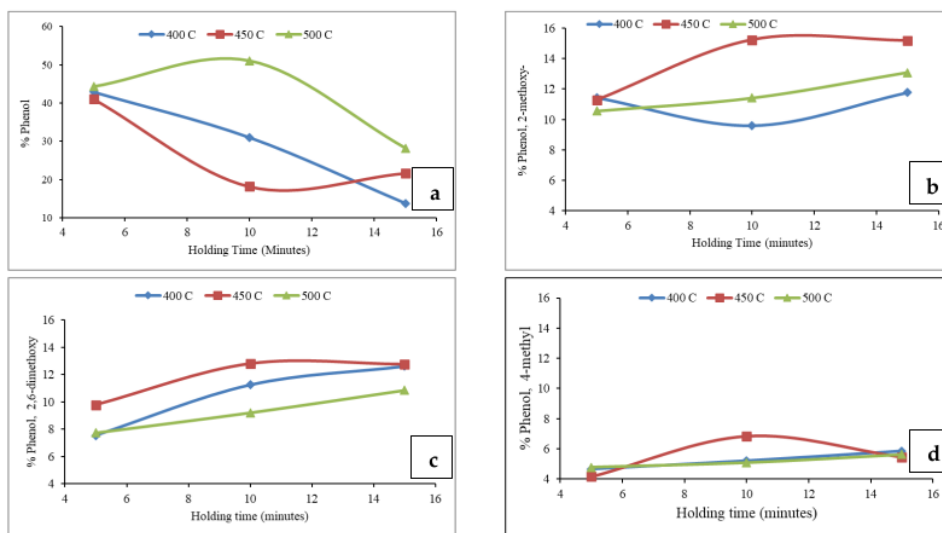


Figure 9. Effect of holding time and temperature of slow pyrolysis EFB in yield of bio-crude oil for (a) phenol (b) phenol-2-methoxy (c) phenol-2,6-dimethoxy, and (d) phenol-4-methyl

Acknowledgement

The authors would like to thank the financial support from Badan Pengelola Dana Perkebunan Kelapa Sawit (BPDPKS).

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

Funding

This research has been funded by Badan Pengelola Dana Perkebunan Kelapa Sawit (BPDPKS).

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

References

- [1] P. Elisa *et al.*, "Environmental and climate change impacts of eighteen biomass-based plants in the alpine region: A comparative analysis," *Journal of Cleaner Production*, 2020, doi: 10.1016/j.jclepro.2019.118449.
- [2] S. Pang, "Advances in thermochemical conversion of woody biomass to energy, fuels and chemicals," *Biotechnology Advances*. 2019, doi: 10.1016/j.biotechadv.2018.11.004.
- [3] F. B. Ahmad, Z. Zhang, W. O. S. Doherty, and I. M. O'Hara, "The outlook of the production of advanced fuels and chemicals from integrated oil palm biomass biorefinery," *Renewable and Sustainable Energy Reviews*. 2019, doi: 10.1016/j.rser.2019.04.009.
- [4] J. P. Susanto, A. D. Santoso, and N. Suwedi, "Perhitungan Potensi Limbah Padat Kelapa Sawit untuk Sumber Energi Terbaharukan dengan Metode LCA," *Jurnal Teknologi Lingkungan*, 2017, doi: 10.29122/jtl.v18i2.2046.
- [5] Directorate General of Estates, "Statistik Perkebunan Indonesia Komoditas Kelapa Sawit Tahun 2018 - 2020," pp. 1-82, 2019.
- [6] A. Demirbaş, "Biomass resource facilities and biomass conversion processing for fuels and chemicals," *Energy Conversion and Management*, 2001, doi: 10.1016/S0196-8904(00)00137-0.
- [7] S. Y. Lee *et al.*, "Waste to bioenergy: a review on the recent conversion technologies," *BMC Energy*, 2019, doi: 10.1186/s42500-019-0004-7.
- [8] A. Akhtar, V. Krepl, and T. Ivanova, "A Combined Overview of Combustion, Pyrolysis, and Gasification of Biomass," *Energy and Fuels*. 2018, doi: 10.1021/acs.energyfuels.8b01678.
- [9] M. Verma, S. Godbout, S. K. Brar, O. Solomatnikova, S. P. Lemay, and J. P. Larouche, "Biofuels production from biomass by thermochemical conversion technologies," *International Journal of Chemical Engineering*. 2012, doi: 10.1155/2012/542426.
- [10] A. V. Bridgwater, "Renewable fuels and chemicals by thermal processing of biomass," *Chemical Engineering Journal*, 2003, doi: 10.1016/S1385-8947(02)00142-0.
- [11] A. Pandey, T. Bhaskar, M. Stöcker, and R. K. Sukumaran, *Recent Advances in Thermochemical Conversion of Biomass*. 2015.
- [12] P. Basu, *Biomass gasification, pyrolysis and torrefaction: Practical design and theory*. 2018.
- [13] S. Mujiarto, B. Sudarmanta, H. Fansuri, and A. R. Saleh, "Comparative Study of Municipal Solid Waste Fuel and Refuse Derived Fuel in the Gasification Process Using Multi Stage Downdraft Gasifier," *Automotive Experiences*, vol. 4, no. 2, 2021, doi: 10.31603/ae.4625.
- [14] D. Neves, H. Thunman, A. Matos, L. Tarelho, and A. Gómez-Barea, "Characterization and prediction of biomass pyrolysis products," *Progress in Energy and Combustion Science*. 2011, doi: 10.1016/j.pecs.2011.01.001.
- [15] X. Hu and M. Gholizadeh, "Biomass pyrolysis: A review of the process development and challenges from initial researches up to the commercialisation stage," *Journal of Energy Chemistry*. 2019, doi: 10.1016/j.jechem.2019.01.024.
- [16] A. Irawan, S. Latifah Upe, and I. P. Meity Dwi, "Effect of torrefaction process on the coconut shell energy content for solid fuel," in *AIP Conference Proceedings*, 2017, vol. 1826, doi: 10.1063/1.4979226.
- [17] A. Irawan, T. Riadz, and N. Nurmalisa, "Proses torefaksi tandan kosong kelapa sawit

- untuk kandungan hemiselulosa dan uji kemampuan menyerap air," *Reaktor*, 2015, doi: 10.14710/reaktor.15.3.190-194.
- [18] S. Wang, G. Dai, H. Yang, and Z. Luo, "Lignocellulosic biomass pyrolysis mechanism: A state-of-the-art review," *Progress in Energy and Combustion Science*, vol. 62, 2017, doi: 10.1016/j.pecs.2017.05.004.
- [19] C. Liu, J. Hu, H. Zhang, and R. Xiao, "Thermal conversion of lignin to phenols: Relevance between chemical structure and pyrolysis behaviors," *Fuel*, 2016, doi: 10.1016/j.fuel.2016.05.104.
- [20] L. T. Nguyen, D. P. Phan, A. Sarwar, M. H. Tran, O. K. Lee, and E. Y. Lee, "Valorization of industrial lignin to value-added chemicals by chemical depolymerization and biological conversion," *Industrial Crops and Products*, vol. 161, 2021, doi: 10.1016/j.indcrop.2020.113219.
- [21] C. Zhao, A. Chen, E. Jiang, and L. Qin, "Pyrolysis of industrial waste lignin: Analysis of product yields and character," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, vol. 39, no. 5, 2017, doi: 10.1080/15567036.2016.1217293.
- [22] G. Greco, C. Di Stasi, F. Rego, B. González, and J. J. Manyà, "Effects of slow-pyrolysis conditions on the products yields and properties and on exergy efficiency: A comprehensive assessment for wheat straw," *Applied Energy*, 2020, doi: 10.1016/j.apenergy.2020.115842.
- [23] S. Nanda, P. Mohanty, J. A. Kozinski, and A. K. Dalai, "Physico-Chemical Properties of Bio-Oils from Pyrolysis of Lignocellulosic Biomass with High and Slow Heating Rate," *Energy and Environment Research*, vol. 4, no. 3, 2014, doi: 10.5539/eer.v4n3p21
- [24] D. Mohan, C. U. Pittman, and P. H. Steele, "Pyrolysis of wood/biomass for bio-oil: A critical review," *Energy and Fuels*, vol. 20, no. 3, 2006, doi: 10.1021/ef0502397.
- [25] F. Febriyanti, N. Fadila, A. S. Sanjaya, Y. Bindar, and A. Irawan, "Pemanfaatan limbah tandan kosong kelapa sawit menjadi bio-char, bio-oil dan gas dengan metode pirolisis," *Jurnal Chemurgy*, 2019, doi: 10.30872/CMG.V3I2.3578.
- [26] S. Al Arni, "Comparison of slow and fast pyrolysis for converting biomass into fuel," *Renewable Energy*, vol. 124, 2018, doi: 10.1016/j.renene.2017.04.060.
- [27] M. P. Pandey and C. S. Kim, "Lignin Depolymerization and Conversion: A Review of Thermochemical Methods," *Chemical Engineering and Technology*, vol. 34, no. 1, 2011, doi: 10.1002/ceat.201000270.
- [28] A. R. Mohamed, Z. Hamzah, M. Z. M. Daud, and Z. Zakaria, "The effects of holding time and the sweeping nitrogen gas flowrates on the pyrolysis of EFB using a fixed bed reactor," in *Procedia Engineering*, 2013, vol. 53, doi: 10.1016/j.proeng.2013.02.024.
- [29] W. Peng, Q. Wu, and P. Tu, "Effects of temperature and holding time on production of renewable fuels from pyrolysis of *Chlorella protothecoides*," *Journal of Applied Phycology*, vol. 12, no. 2, 2000, doi: 10.1023/A:1008115025002.
- [30] Y. Le Brech *et al.*, "The mechanism of biomass pyrolysis revealed by various analytical methods," *Hal*, vol. 26, no. 10, 2014.
- [31] T. J. Hilbers *et al.*, "Cellulose-Lignin interactions during slow and fast pyrolysis," *Journal of Analytical and Applied Pyrolysis*, vol. 114, 2015, doi: 10.1016/j.jaap.2015.05.020.
- [32] T. Hosoya, H. Kawamoto, and S. Saka, "Cellulose-hemicellulose and cellulose-lignin interactions in wood pyrolysis at gasification temperature," *Journal of Analytical and Applied Pyrolysis*, vol. 80, no. 1, 2007, doi: 10.1016/j.jaap.2007.01.006.
- [33] T. Kan, V. Strezov, and T. J. Evans, "Lignocellulosic biomass pyrolysis: A review of product properties and effects of pyrolysis parameters," *Renewable and Sustainable Energy Reviews*, 2016, doi: 10.1016/j.rser.2015.12.185.
- [34] H. Paysepar, K. T. Venkateswara Rao, Z. Yuan, H. Shui, and C. Xu, "Production of phenolic chemicals from hydrolysis lignin via catalytic fast pyrolysis," *Journal of Analytical and Applied Pyrolysis*, vol. 149, no. May, p. 104842, 2020, doi: 10.1016/j.jaap.2020.104842.
- [35] Z. Liu, L. Wang, Y. Li, and Z. Li, "Study On Phenolic Content In Fast Pyrolysis Oil

- Obtained From The Model Compounds Of Three Major Components In Biomass," 2016, doi: 10.2991/aeecs-16.2016.46.
- [36] C. Setter, F. A. Borges, C. R. Cardoso, R. F. Mendes, and T. J. P. Oliveira, "Energy quality of pellets produced from coffee residue: Characterization of the products obtained via slow pyrolysis," *Industrial Crops and Products*, vol. 154, 2020, doi: 10.1016/j.indcrop.2020.112731.
- [37] M. S. Safdari, E. Amini, D. R. Weise, and T. H. Fletcher, "Heating rate and temperature effects on pyrolysis products from live wildland fuels," *Fuel*, vol. 242, 2019, doi: 10.1016/j.fuel.2019.01.040.

INFLUENCE TEMPERATURE 2021

ORIGINALITY REPORT

17%

SIMILARITY INDEX

11%

INTERNET SOURCES

13%

PUBLICATIONS

7%

STUDENT PAPERS

PRIMARY SOURCES

1	umpir.ump.edu.my Internet Source	1%
2	Aan Yudianto, Peixuan Li. "Influence of Compression Ratio on Flywheel Dimension for a Naturally Aspirated Spark Ignition Engine: A Numerical Study", Automotive Experiences, 2020 Publication	1%
3	Submitted to School of Business and Management ITB Student Paper	1%
4	Liu Bing, Zehui Zhang, Kejian Deng. "Efficient One-Pot Synthesis of 5-(Ethoxymethyl)furfural from Fructose Catalyzed by a Novel Solid Catalyst", Industrial & Engineering Chemistry Research, 2012 Publication	1%
5	Submitted to University of Newcastle upon Tyne Student Paper	<1%

6	Internet Source	<1 %
7	jultika.oulu.fi Internet Source	<1 %
8	kth.diva-portal.org Internet Source	<1 %
9	Anton Irawan, Latifah Upe S., Meity Dwi I. P.. "Effect of torrefaction process on the coconut shell energy content for solid fuel", AIP Publishing, 2017 Publication	<1 %
10	Korkut Açıklan, Fatma Karaca. "Fixed-bed pyrolysis of walnut shell: Parameter effects on yields and characterization of products", Journal of Analytical and Applied Pyrolysis, 2017 Publication	<1 %
11	ejournal.upi.edu Internet Source	<1 %
12	ris.utwente.nl Internet Source	<1 %
13	digitalcommons.lsu.edu Internet Source	<1 %
14	M.M. Parascanu, M. Puig Gamero, P. Sánchez, G. Soreanu, J.L. Valverde, L. Sanchez-Silva. "Life cycle assessment of olive pomace	<1 %

valorisation through pyrolysis", Renewable Energy, 2018

Publication

15

Submitted to Universiti Malaysia Perlis

Student Paper

<1 %

16

patents.google.com

Internet Source

<1 %

17

C. Setter, F.A. Borges, C.R. Cardoso, R.F. Mendes, T.J.P. Oliveira. "Energy quality of pellets produced from coffee residue: Characterization of the products obtained via slow pyrolysis", Industrial Crops and Products, 2020

Publication

<1 %

18

Submitted to Universitas Samudra

Student Paper

<1 %

19

Submitted to Universiti Putra Malaysia

Student Paper

<1 %

20

Submitted to University of Stellenbosch, South Africa

Student Paper

<1 %

21

studentsrepo.um.edu.my

Internet Source

<1 %

22

Jian Li, Yingquan Chen, Haiping Yang, Danchen Zhu, Xu Chen, Xianhua Wang, Hanping Chen.

<1 %

"Correlation of Feedstock and Bio-oil Compound Distribution", Energy & Fuels, 2017

Publication

23

Zhongliang Yao, Xiaoqian Ma. "Effects of hydrothermal treatment on the pyrolysis behavior of Chinese fan palm", Bioresource Technology, 2018

Publication

<1 %

24

A A Rahman, A F P Harahap, I N Sadrina, M Gozan. "Optimization of microwave assisted dilute ammonia pretreatment of oil palm empty fruit bunch using response surface methodology", IOP Conference Series: Materials Science and Engineering, 2019

Publication

<1 %

25

Ortega, J.V.. "Physical and chemical characteristics of aging pyrolysis oils produced from hardwood and softwood feedstocks", Journal of Analytical and Applied Pyrolysis, 201105

Publication

<1 %

26

Ozgur Kaplan, Cenk Celik. "An experimental research on woodchip drying using a screw conveyor dryer", Fuel, 2018

Publication

<1 %

27

insightsociety.org

Internet Source

<1 %

28

"Production of Biofuels and Chemicals with Pyrolysis", Springer Science and Business Media LLC, 2020

Publication

<1 %

29

Baint Singh, Shivam Rawat, Kishore Natte, Anand Narani. "Thermochemical methods for upgrading of lignin to aromatic chemicals", Elsevier BV, 2022

Publication

<1 %

30

Dekui Shen, Rui Xiao, Sai Gu, Huiyan Zhang. "Chapter 9 The Overview of Thermal Decomposition of Cellulose in Lignocellulosic Biomass", IntechOpen, 2013

Publication

<1 %

31

Farah B. Ahmad, Zhanying Zhang, William O.S. Doherty, Ian M. O'Hara. "The outlook of the production of advanced fuels and chemicals from integrated oil palm biomass biorefinery", Renewable and Sustainable Energy Reviews, 2019

Publication

<1 %

32

Hui Wang, Radhakrishnan Srinivasan, Fei Yu, Philip Steele, Qi Li, Brian Mitchell. "Effect of Acid, Alkali, and Steam Explosion Pretreatments on Characteristics of Bio-Oil Produced from Pinewood", Energy & Fuels, 2011

Publication

<1 %

33

Ian M. O'hara, Zhanying Zhang, Philip A. Hobson, Mark D. Harrison, Sagadevan G. Mundree, William O.S. Doherty. "Fuels and Chemicals from Lignocellulosic Biomass", Wiley, 2013

Publication

<1 %

34

amsdottorato.unibo.it

Internet Source

<1 %

35

api-depositonce.tu-berlin.de

Internet Source

<1 %

36

asset-pdf.scinapse.io

Internet Source

<1 %

37

catalog.lib.kyushu-u.ac.jp

Internet Source

<1 %

38

eprints.uad.ac.id

Internet Source

<1 %

39

hdl.handle.net

Internet Source

<1 %

40

"Sustainable Technologies for the Management of Agricultural Wastes", Springer Science and Business Media LLC, 2018

Publication

<1 %

41

Algal Biorefineries, 2015.

Publication

<1 %

42 Bijoy Biswas, Rawel Singh, Bhavya B Krishna, Jitendra Kumar, Thallada Bhaskar. "Pyrolysis of azolla, sargassum tenerrimum and water hyacinth for production of bio-oil", Bioresource Technology, 2017
Publication

43 Chenxi Zhao, Enchen Jiang, Aihui Chen. "Volatile production from pyrolysis of cellulose, hemicellulose and lignin", Journal of the Energy Institute, 2017
Publication

44 Jorge Montoya, Carlos Valdés, Hernando Chaquea, M. Brennan Pecha, Farid Chejne. "Surplus electricity production and LCOE estimation in Colombian palm oil mills using empty fresh bunches (EFB) as fuel", Energy, 2020
Publication

45 Karen Lopez Camas, Aman Ullah. "Depolymerization of lignin into high-value products", Biocatalysis and Agricultural Biotechnology, 2022
Publication

46 M. Faisal, Asri Gani, Farid Mulana, Hera Desvita, S. Kamaruzzaman. "EFFECTS OF PYROLYSIS TEMPERATURE ON THE COMPOSITION OF LIQUID SMOKE DERIVED

FROM OIL PALM EMPTY FRUIT BUNCHES",
Rasayan Journal of chemistry, 2020

Publication

47

M.M. Hasan, M.G. Rasul, N. Ashwath, M.M.K. Khan, M.I. Jahirul. "Fast pyrolysis of Beauty Leaf Fruit Husk (BLFH) in an auger reactor: Effect of temperature on the yield and physicochemical properties of BLFH oil", Renewable Energy, 2022

Publication

48

Neeha Brojolall, Dinesh Surroop. "Improving fuel characteristics through torrefaction", Energy, 2022

Publication

49

Wu-Jun Liu, Hong Jiang, Han-Qing Yu. "Development of Biochar-Based Functional Materials: Toward a Sustainable Platform Carbon Material", Chemical Reviews, 2015

Publication

50

Xuanmin Yang, Kang Kang, Ling Qiu, Lixin Zhao, Renhua Sun. "Effects of carbonization conditions on the yield and fixed carbon content of biochar from pruned apple tree branches", Renewable Energy, 2020

Publication

51

bcc.bas.bg
Internet Source

<1 %

<1 %

<1 %

<1 %

<1 %

52	biblio.ugent.be Internet Source	<1 %
53	cyberleninka.org Internet Source	<1 %
54	www.ijrer.com Internet Source	<1 %
55	Nur Nasulhah Kasim, Khudzir Ismail, Alina Rahayu Mohamed, Mohd Azlan Mohd Ishak, Razi Ahmad, Wan Izhan Nawawi Wan Ismail. "Characteristic, Thermochemical Behaviors and Kinetic of Demineralized and Torrefied Empty Fruit Bunches (EFB)", Advances in Science, Technology and Engineering Systems Journal, 2018 Publication	<1 %
56	Patrick Brassard, Stéphane Godbout, Vijaya Raghavan. "Pyrolysis in auger reactors for biochar and bio-oil production: A review", Biosystems Engineering, 2017 Publication	<1 %
57	Mehmet Sait Çay, İlhan Tekin Öztürk. "Mechanical dewatering characteristics of a Turkish Lignite", International Journal of Coal Preparation and Utilization, 2019 Publication	<1 %
58	Xu Chen, Qingfeng Che, Shujuan Li, Zihao Liu, Haiping Yang, Yingquan Chen, Xianhua Wang,	<1 %

Jingai Shao, Hanping Chen. "Recent developments in lignocellulosic biomass catalytic fast pyrolysis: Strategies for the optimization of bio-oil quality and yield", Fuel Processing Technology, 2019

Publication

59

Yanqin Huang, Huacai Liu, Hongyou Yuan, Hao Zhan, Xiuzheng Zhuang, Song Yuan, Xiuli Yin, Chuangzhi Wu. "Relevance between chemical structure and pyrolysis behavior of palm kernel shell lignin", Science of The Total Environment, 2018

Publication

<1 %

60

iopscience.iop.org

Internet Source

<1 %

Exclude quotes On

Exclude matches Off

Exclude bibliography On