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Utilization of oil palm empty fruit bunches biomass through slow pyrolysis process

D E Rahayu[1], N Karnaningroem[2], A Altway[3], A Slamet[4]

[1] Department of Environmental Engineering,Faculty of Engineering, Mulawarman University Samarinda, 75123
[2,4] Department of Environmental Engineering Faculty of Civil Planning and Geo Engineering, Institut Teknologi Sepuluh November, Surabaya, 60111
[3]Department of Chemical Engineering, Faculty of Industrial Technology and System Engineering, Institut Teknologi Sepuluh November, Surabaya, 60111

Corresponding author's e-mail *dwiermarahayu@gmail.com*

Abstract. The agricultural sector produces solid waste biomass abundantly. However, this biomass potential has not been utilized optimally. Indonesia as the world's number one producer of oil palm plantations produces enormous biomass potential. Oil palm empty fruit bunches (EFB) are the largest solid waste with a fraction of around 20-23% of fresh fruit bunches. Conventionally, it is only used as plant mulch in plantations areas. However, this biomass can still provide added value to bioenergy products through thermochemical pyrolysis conversion. The study was conducted with EFB raw materials that have been chopped with a size of <2mm, heating rate of 10C/minute with temperature variations of 350°C, 400°C, 450°C, 500°C, and 550°C. The results showed that the EFB pyrolysis at low temperatures produced biochar products, and at high temperatures, it produced maximum product in the form of bio-oil. In the EFB pyrolysis process, biochar with an optimum yield of 36.92% was produced at 350°C, and bio-oil with an optimum yield of 46.60% was produced at a temperature of 550°C.

1. Introduction

The extent of oil palm plantation land makes Indonesia becoming the largest palm oil producer in the world. The total area of oil palm plantations reached 11.26 million hectares in 2015 and was expected to be 12.31 million hectares in 2017. The total palm oil production produced was 31.07 million tons and the palm kernel was 6.21 million tons [1]. The amount of productivity of palm oil has the potential as a source of biomass waste. Production activities in oil palm agro-industrial in addition to producing the main product also producing byproducts, namely solid waste. Various types of solid waste are generated from the activities of palm oil processing plants and from plantation activities. Palm Kernell shells, mesocarp fibers, and empty fruit bunches are the main solid waste produced during the milling process while leaves and stems are obtained from plantations in the harvesting, pruning, and logging process [2]. EFB biomass is the waste with the largest fraction (20-23% of FFB). Biomass waste is the fourth largest source of energy after coal, petroleum, and natural gas so it can contribute greatly to the supply of renewable and sustainable energy sources. Utilization of this waste can be done by conversion through thermochemical processes, namely pyrolysis.

The utilization of conversion technology needs to be applied in accordance with the characteristics of biomass. Palm oil biomass waste contains hemicellulose, cellulose, and lignin with varying compositions. Biochemical processes are not suitable for palm oil biomass waste because its characteristics are lignocellulosic materials with a high enough lignin content that it is more difficult to be degraded [3]. Conversion technology that can be applied is a thermochemical conversion technology namely pyrolysis. Thermochemical conversion is preferred because biological conversion will be more difficult with the characteristics of complex structures and biomass chemical mechanisms [4]. The pyrolysis process can convert raw materials containing cellulose components as much as 81.41% and 44.2% hemicellulose into bio-oil while 40.33% lignin will become char [5].

Research related to the conversion of biomass to bioenergy through the thermochemical pyrolysis conversion process has been widely conducted by researchers with various variations. Pyrolysis research uses different types of biomass such as biomass residue of pyrolysis or Euryale ferox [6], orange peel biomass [7], wood waste of Paulownia elongate [8], empty fruit bunch (EFB) [9], soybean stover and peanut shells [10], sawdust and giant *Miscanthus* [11], safflower seed [12], peanut and soybean skins [10], etc. The researchers mostly analyzed and reviewed factors that affected the pyrolysis conversion process: temperature, heating rate, particle size, residence time, raw material characteristics [13] [14] [15] [16] [17]. Analysis was also performed on the characteristics of the bio-oil product, the resulting biochar [18] [19] [20] [21] [22] [23].

Pyrolysis research with EFB raw materials was conducted by [24] using high temperatures of 450-800°C, [20] at 460-520°C, and [25] at 352-452°C. In this study, the study was conducted in the low to high temperature range to determine the effectiveness of temperature against the resulting product. So, it can provide input to the selection of the right operating process to produce the desired product in accordance with the characteristics of EFB raw materials. With the abundant volume of EFB biomass produced by the palm oil industry but its utilization is not optimal yet, this study becomes important. Pyrolysis technology as a method of converting EFB into new products can be used as an alternative solution for the utilization of EFB in the future.

2. Materials and Methods

2.1. Raw Material

EFB raw materials were taken from the palm oil mill of PT. TSB in Saliki Village, Muara Badak Subdistrict, Kutai Kartanegara Regency. Early characteristics of EFB analyzed included chemical components (cellulose, hemicelluloses, and lignin), ultimate analysis (C, H, O, N) proximate analysis (fixed carbon, volatile matter, ash levels, moisture content, and HHV). Then EFB was chopped with a size of <2mm and then tested the size distribution. After that, the EFB was dried for 24 hours until the water content was <10%.

2.2. Pyrolysis Reactor

The pyrolysis reactor consisted of a tube with a capacity of 0.4kg with dimensions of 0.5m and a diameter of 0.15m equipped with a jacket. Pyrolysis outlet reactors were connected with condensers used to condense pyrolysis gases into bio-oil.

2.3. Pyrolysis Experiment

This study used EFB raw materials as much as 400 grams according to the capacity of the pyrolysis reactor. Pyrolysis raw materials that have undergone a pretreatment process with the process of enumeration and drying were incorporated into the reactor. Pyrolysis surgery was carried out with temperature variations of 350 °C, 400 °C, 450 ° C, 500 ° C, and 550 ° C and the heating rate of 10 ° C / minute. The resulting products in the form of biochar and bio-oil were tested characteristically based on proximate and ultimate tests. The production of biochar, bio-oil, and gas was calculated based on the equation:

The char yield = $\frac{\boldsymbol{mass\ of\ char\ (g)}}{\boldsymbol{mass\ of\ EFB\ (g)}}\boldsymbol{x100\%}$...(1)

The bio-oil yield = $\frac{\boldsymbol{mass\ of\ bio-oil\ (g)}}{\boldsymbol{mass\ of\ EFB\ (g)}} \boldsymbol{x100\%}$…………………….……………(2)

The gaseous yield = $\boldsymbol{100\% - oil\ yield - char\ yield}$…………… …….. (3)

3. Results and Discussion

3.1. Characteristic of EFB

Knowledge of the characteristics of EFB raw materials is essential in the optimization and the efficiency of thermochemical conversion processes. The proximate, ultimate, and chemical characteristics of EFB in this study are shown in table 1 column a). Some studies have been conducted by [26] [27][28] [20] [13] [17][29][11][22][30][18][19] on the raw material of EFB as shown in Table 1.

Table 1. Empty Fruit Bunches Characteristic as A Feedstock of Pyrolysis Process

EFB Characteristics	Reference										Average	StDev
	1	2	3	4	5	6	7	8	9	a)		
						Proximate						
Volatile matter	81.90	80.89	72.88	81.01	83.86	70.64	71.2	65.00	70.86	89.39	75.36	6.62
Fixed Carbon	12.60	12.60	12.56	12.23	10.78	18.42	18.30	18.30	14.92	17.48	6.14	3.05
Ash	3.10	4.02	11.10	6.76	5.36	4.55	7.54	1.50	2.36	9.33	39.48	2.97
Moisture	2.40	2.4	3.47	8.86	7.95	6.39	8.26	15.20	11.86	9.13	7.42	4.34
						Ultimate						
C	53.78	44.71	55.89	50.10	49.07	43.6	45.0	49.10	40.98	54.04	48.03	4.98
H	4.37	6.76		6.31	6.48	6.31	6.4	5.80	6.67	6.21	6.14	0.72
O	41.50		42.44	42.99	38.29	49.23	47.3	41.40	52.19	38.21	44.42	4.85
N	0.35	0.21		0.60	0.7	0.73	0.25	0.50	0.16	0.98	0.44	0.28
S		0.41			<0.1	0.13	1.06				0.40	0.48
Caloric value	17.08								16.83		16.96	
HHV MJ kg−1		21.77	19.65	20.85	20.85	18.96	18.1	16.40			19.51	1.86
LHV MJ kg−1						17.47					17.47	
						Lignocellulose analysis (wt %)						
	3	7	10	11	12							
Cellulose	24.23	23.70	26.60	38.52	23.83					37.5	29.06	7.024
Hemicelluloses	38.46	21.60	26.90	33.52	15.90					19.31	25.95	8.70
Lignin	37.32	29.20	25.40	20.36	39.51					30.33	30.35	7.18
Extravis	15.66											

1. (Sukiran *et al,* 2009) 2. (Binti *et al,* 2014) 3. [28] 4. (Mantilla *et al*, 2014) 5. (Abdullah dan Gerhauser, 2008) 6. (Sembiring *et al*, 2015) 7. (Omar *et al*, 2011) 8. (Yong *et al,* 2019) 9. (Sukiran *et al*, 2018) 10. (Loong *et al*, 2018) 11. (Khor *et al*, 2009) 12. (Solikhah *et al*, 2018)

a) Laboratory analysis data

The average data obtained was the empirical formula of EFB namely $CH_{1.52}O_{0.69}N_{0.008}$. Proximate analysis showed that raw EFB fiber has a rather high volatile content, moderate levels of ash content, and a relatively low fixed carbon content. But the elemental analysis showed that raw EFB fiber is an environmentally friendly material with a small nitrogen and sulfur content. The water content of raw EFB is so high (49.64%) that it requires pretreatment before converting the pyrolysis process.

FB raw materials were taken from the palm oil mill of PT. TSB in Saliki Village, Muara Badak Subdistrict, Kutai Kartanegara Regency. Early characteristics of EFB analyzed included chemical components (cellulose, hemicelluloses, and lignin), ultimate analysis (C, H, O, N) proximate analysis (fixed carbon, volatile matter, ash levels, moisture content, and HHV). Then EFB was chopped with a size of <2mm and then tested the size distribution. After that, the EFB was dried for 24 hours until the water content was <10%.

3.2. Influence of temperature to pyrolysis product

Pyrolysis uses EFB as raw material at various temperature variations over the resulting product as shown in Table 2 and Figure 1.

Table 2. Results of Measurement and Calculation of Pyrolysis Product Yield

Temperature	Bio-oil Measurement (g)	Biochar measurement (g)	% Bio-oil yield	% Biochar yield	% Gas yield
350	13.26	147.66	32.82	36.92	30.27
400	132.06	130.64	33.02	32.66	34.33
450	142.97	105.41	35.74	26.35	37.91
500	180.06	112.43	45.02	28.11	26.88
550	186.40	112.09	46.60	28.02	25.38

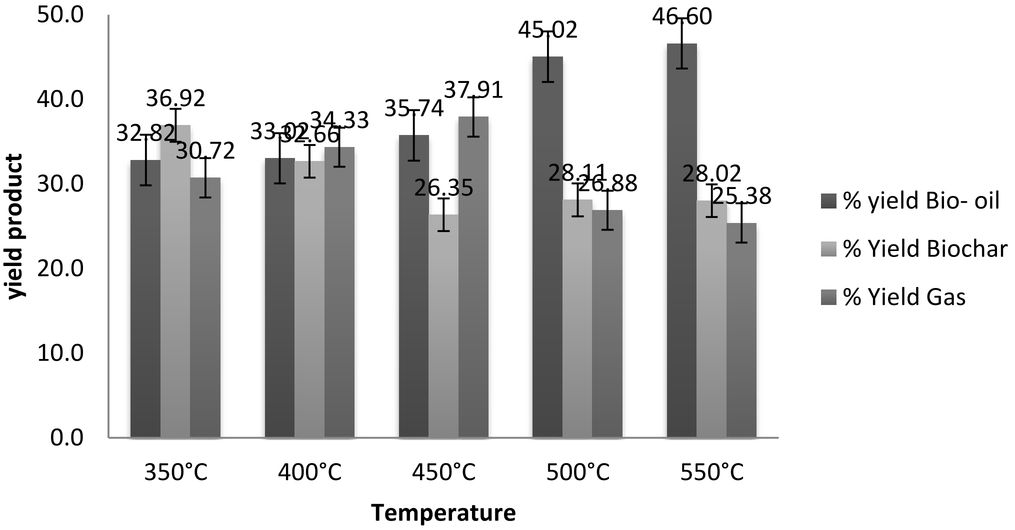

Figure 1. Slow Pyrolysis Product Yield

The analysis data shows that biochar is formed maximum at low temperatures of 350-400 ° C and will decrease along with the increase in temperature. While bio-oil is formed at a higher temperature of 500-550 ° C and will decrease along with the increase in temperature. Several studies have also shown similar patterns in temperature parameters and residence time [15]. In one of the studies of [32], the bio-oil yield of 27% at 400 °C increased to 54% at 550 °C and decreased to 51% at 600 °C. The study of [10] using bean and soybean peels produced 36.91% of biochar and 37.03% at 300°C. Besides, the study of [33] using tea tree branches showed a yield of 47.94% at 300°C. Moreover, the study of [34] using wood pallet raw materials and spruce wood slats showed a temperature condition of 350 °C as the optimal temperature by producing >40% of biochar yield. Research using EFB also showed similar results, including the study of [26] where at 300°C, it produces biochar yields of 41.56%, the study of [21] in which at 350°C, it produces biochar yields of 37.57%, and research of [9] where it produces a yield of >30% at 450°C. While the study of [35] shows that it produces the highest bio-oil yield of 47% at 500 °C

the pyrolysis reactor consisted of a tube with a capacity of 0.4kg with dimensions of 0.5m and a diameter of 0.15m equipped with a jacket. Pyrolysis outlet reactors were connected with condensers used to condense pyrolysis gases into bio-oil.

3.3. Characteristic pyrolysis product

Table 3 is a biochar characteristic of EFB raw materials resulting from pyrolysis processes. The main factors that influence the formation of biochar yields are temperature, residence time, and biomass composition. Slow pyrolysis with heating rate and low gas flow is perfect for biochar formation. Characteristics of biomass with low water content, high lignin, large particle size are highly recommended to increase biochar yield (Tripathi *et al*, 2016). Biomass raw materials that are high in cellulose are highly recommended if people want to obtain bio-oil products and biomass containing high lignin for high biochar production (Zaman *et al*, 2017). The resulting biochar characteristics allow it to be used as a soil amendment. Besides, it can also be used as an active carbon forming material through the activation process.

Table 3. Characteristic of Biochar

Parameter	Percentage	Operation Temperature				
		350°C	**400°C**	**450°C**	**500°C**	**550°C**
C	%	48.21	47.00	45.24	44.82	48.84
O	%	29.00	28.37	27.14	26.95	31.28
H	%	5.54	5.40	5.20	5.15	3.26
N	%	0.367	0.257	0.425	0.355	0.835
S	%	-	-	-	-	-
K	%	3.190	2.856	4.115	4.412	2.569
Ca	%	1.666	0.854	0.785	0.481	0.387
Mg	%	0.645	0.584	1.037	1.164	0.931
Si	%	7.46	9.22	10.87	12.99	35.06
P	%	0.576	0.618	0.839	1.108	0.931
Na	%	0	0	0	0	0.153

The parameter of the residence time has no significant effect on the characteristics of the calorific value of bio-oil [15]. As data on some characteristics of EFB bio-oil obtained from pyrolysis processes as shown in Table 5.7, the quality is lower when compared to the characteristics of fuel oil. Bio-oil of EFB has pH, moisture content, ash content, and calorific value that are not as good as fuel oil [14] [13], and diesel fuel [18]. So, bio-oil still requires upgrading if it will be used as transportation fuel and other chemicals [38][39].

While the gases produced from the pyrolysis process are mainly CO_2 (26.9%), CO (54.1%), H_2(2.5%), and CH_4 (4.9%) [9]. It is different from syngas produced from gasification with the main characteristics including the higher gas CO_2, H_2 dan CH_4 [40][41].

4. Conclusion

In EFB pyrolysis, if the expected result is the maximum biochar yield, then the operation process is carried out at low temperature and heating. Meanwhile, if the expected maximum yield of bio-oil, then the operating process carried out is at a high temperature and heating rate. In EFB biochar with an optimum yield of 36.92% were produced at a temperature of 350C, heating rate of 10°C / minute, with the particle size <2mm.

References

[1] D.J. Perkebunan, Statistik Perkebunan Indonesia 2015-2017 Kelapa Sawit, Sekretariat Direktorat Jendral Perkebunan, Direktorat Jendral Perkebunan, Kementrian Pertanian, 2016.
[2] F. Abnisa, A. Arami-niya, W.M.A.W. Daud, J.N. Sahu, I.M. Noor, Utilization of oil palm tree residues to produce bio-oil and bio-char via pyrolysis, Energy Convers. Manag. 76 (2013) 1073–1082.
[3] P. Basu, Biomass Gasification and Pyrolysis Practical Design and Theory, 10th ed., Elsevier Inc., Oxford, 2010.
[4] Y. Huang, P. Chiueh, S. Lo, Mini review A review on microwave pyrolysis of lignocellulosic biomass, Sustain. Environ. Res. 26 (2016) 103–109.

[5] H. Yang, R. Yan, H. Chen, D.H. Lee, D.T. Liang, Mechanism of Palm Oil Waste Pyrolysis in a Packed Bed, 44 (2006) 1321–1328.
[6] A. Kumar, H. Mohan Jena, High surface area microporous activated carbons prepared from Fox nut (Euryale ferox) shell by zinc chloride activation, Appl. Surf. Sci. 356 (2015) 753–761.
[7] K.Y. Foo, B.H. Hameed, Bioresource Technology Microwave-assisted preparation and adsorption performance of activated carbon from biodiesel industry solid reside : Influence of operational parameters, Bioresour. Technol. 103 (2012) 398–404.
[8] S. Yorgun, D. Yıldız, Preparation and characterization of activated carbons from Paulownia wood by chemical activation with H3PO4, J. Taiwan Inst. Chem. Eng. 53 (2015) 122–131.
[9] S. Fukuda, Bio-oil Production from Vacuum Pyrolysis of Palm Empty Fruit Bunch : Effect of Operating Conditions and Process Energy Balance, 4 (2013) 27–31.
[10] M. Ahmad, S.S. Lee, X. Dou, D. Mohan, J.-K. Sung, J.E. Yang, Y.S. Ok, Effects of pyrolysis temperature on soybean stover- and peanut shell-derived biochar properties and TCE adsorption in water, Bioresour. Technol. 118 (2012) 536–544.
[11] J. Yong, J. Kim, C. Oh, J. Park, E.E. Kwon, Production of bio-oil from fast pyrolysis of biomass using a pilot-scale circulating fl uidized bed reactor and its characterization, J. Environ. Manage. 234 (2019) 138–144.
[12] O. Onay, Influence of Pyrolysis Temperature and Heating Rate on the Production of Bio-Oil and Char From Safflower Seed by Pyrolysis , Using a Well-Swept Influence of pyrolysis temperature and heating rate on the production of bio-oil and char from safflower seed b, Fuel Process. Technol. 88 (2018) 523–531.
[13] N. Abdullah, H. Gerhauser, Bio-oil derived from empty fruit bunches, 87 (2008) 2606–2613.
[14] D. Mohan, C.U. Pittman, P.H. Steele, Pyrolysis of Wood / Biomass for Bio-oil : A Critical Review, (2006) 848–889.
[15] C.K. Ling, H.P. San, E.H. Kyin, L.S. Hua, L.W. Chen, Yield and Calorific Value of Bio Oil Pyrolysed from Oil Palm Biomass and its Relation with Solid Residence Time and Process Temperature, (2015) 1–8.
[16] T. Kan, V. Strezov, T.J. Evans, Lignocellulosic biomass pyrolysis : A review of product properties and effects of pyrolysis parameters, Renew. Sustain. Energy Rev. 57 (2016) 1126–1140.
[17] K.C. Sembiring, N. Rinaldi, S.P. Simanungkalit, Bio-oil from Fast Pyrolysis of Empty Fruit Bunch at Various Temperature, Energy Procedia. 65 (2015) 162–169.
[18] K.H. Khor, K.O. Lim, Z.A. Zainal, P. Pinang, N. Tebal, Characterization of Bio-Oil : A By-Product from Slow Pyrolysis of Oil Palm Empty Fruit Bunches School of Physics , School of Mechanical Engineering , Engineering Campus , 6 (2009) 1647–1652.
[19] M.D. Solikhah, F.T. Pratiwi, Y. Heryana, A.R. Wimada, F. Karuana, A.A. Raksodeanto, A. Kismanto, Characterization of Bio-Oil from Fast Pyrolysis of Palm Frond and Empty Fruit Bunch Characterization of Bio-Oil from Fast Pyrolysis of Palm Frond and Empty Fruit Bunch, (2018).
[20] S.V. Mantilla, P. Gauthier-maradei, P.Á. Gil, S.T. Cárdenas, Journal of Analytical and Applied Pyrolysis Comparative study of bio-oil production from sugarcane bagasse and palm empty fruit bunch : Yield optimization and bio-oil characterization, J. Anal. Appl. Pyrolysis. 108 (2014) 284–294.
[21] N. Claoston, A.W. Samsuri, M.H.A. Husni, M.S.M. Amran, Effects of pyrolysis temperature on the physicochemical properties of empty fruit bunch and rice husk biochars, (2014). https://doi.org/10.1177/0734242X14525822.
[22] M.A. Sukiran, S.O.H.K. Loh, N.A.B.U. Bakar, Conversion of Pre-Treated Oil Palm Empty Fruit Bunches Into Bio-Oil and Bio-Char Via Fast Pyrolysis, 30 (2018) 121–129.
[23] F. Tinwala, P. Mohanty, S. Parmar, A. Patel, K.K. Pant, Bioresource Technology Intermediate pyrolysis of agro-industrial biomasses in bench-scale pyrolyser : Product yields and its characterization, Bioresour. Technol. 188 (2015) 258–264.
[24] K.H. Khor, K.O. Lim, Slow Pyrolysis of Oil Palm Empty Fruit Bunches, 9 (2008) 181–188.
[25] A.R. Mohamed[a], Z. Hamzah[a], M. Zulkali, M. Daud, The Effects of Holding Time and The

Sweeping Nitrogen Gas Flowrates On The Pyrolysis Of EFB Using A Fixed Bed Reactor, 53 (2013) 185–191.
[26] M.A. Sukiran, Pyrolysis of Empty Oil Palm Fruit Bunches Using The Quartz Fluidised-Fixed Bed Reactor, University of Malaya, 2008.
[27] N. Binti, N. Ibrahim, M. Kamaruddin, A. Hamid, Pyrolysis of empty fruit bunch by thermogravimetric analysis, Energy Procedia. 61 (2014) 2532–2536.
[28] X. Jiat, L. Yee, S. Gan, S. Thangalazhy-gopakumar, H. Kiat, Bioresource Technology Biochar potential evaluation of palm oil wastes through slow pyrolysis : Thermochemical characterization and pyrolytic kinetic studies, Bioresour. Technol. 236 (2017) 155–163.
[29] R. Omar, A. Idris, R. Yunus, K. Khalid, M.I.A. Isma, Characterization of empty fruit bunch for microwave-assisted pyrolysis, Fuel. 90 (2011) 1536–1544.
[30] C. Loong, S. Yusup, A.T. Quitain, Y. Uemura, M. Sasaki, T. Kida, Bioresource Technology Thermogravimetric analysis and kinetic modeling of low-transition- temperature mixtures pretreated oil palm empty fruit bunch for possible maximum yield of pyrolysis oil, Bioresour. Technol. 255 (2018) 189–197.
[31] M.A. Sukiran, C.M. Chin, N.K. Abu Bakar, Bio-oils from Pyrolysis of Oil Palm Empty Fruit Bunches, Am. J. Appl. Sci. 6 (2009) 869–875.
[32] R. Soysa, Y.S. Choi, S.K. Choi, S.J. Kim, S.Y. Han, Synergetic effect of biomass mixture on pyrolysis kinetics and biocrude-oil characteristics, 33 (2016) 603–609.
[33] S. Zhao, N. Ta, X. Wang, Effect of Temperature on the Structural and Physicochemical Properties of Biochar with Apple Tree Branches as Feedstock Material, (2017).
[34] P. Brownsort, A. Cross, S. Sohi, Influence of production conditions on the yield and environmental stability of biochar, 103 (2013) 151–155.
[35] M.A. Sukiran, S.K. Loh, N.A. Bakar, Production of Bio-oil from Fast Pyrolysis of Oil Palm Biomass using Fluidised Bed Reactor, 6 (2016) 52–62.
[36] M. Tripathi, J.N. Sahu, P. Ganesan, Effect of process parameters on production of biochar from biomass waste through pyrolysis : A review, Renew. Sustain. Energy Rev. 55 (2016) 467–481.
[37] C.Z. Zaman, K. Pal, W.A. Yehye, S. Sagadevan, S.T. Shah, G.A. Adebisi, E. Marliana, R.F. Rafique, R. Bin Johan, Pyrolysis: A Sustainable Way to Generate Energy from Waste, in: Entry from IntechOpen 25 January 2020, 2017.
[38] P.K. Kanaujia, Y.K. Sharma, M.O. Garg, D. Tripathi, R. Singh, Journal of Analytical and Applied Pyrolysis Review of analytical strategies in the production and upgrading of bio-oils derived from lignocellulosic biomass, J. Anal. Appl. Pyrolysis. 105 (2014) 55–74.
[39] A. Krutof, Upgrading of biomass sourced pyrolysis oil review : focus on co-pyrolysis and vapour upgrading during pyrolysis, (2018) 775–787.
[40] N. Couto, A. Rouboa, V. Silva, E. Monteiro, K. Bouziane, Influence of the biomass gasification processes on the final composition of syngas, Energy Procedia. 36 (2013) 596–606.
[41] S. Sivasangar, Z. Zainal, A. Salmiaton, Y.H. Taufiq-yap, Supercritical water gasification of empty fruit bunches from oil palm for hydrogen production, FUEL. 143 (2015) 563–569.