TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 4557 - 4563

The Comparison of Bio-oil Production from Sugarcane Trash, Napier Grass, and Rubber Tree in The Circulating Fluidized Bed Reactor

Ilham. Mufandi[1], Wasakorn. Treede[2], Piyapong. Singbua[3], Ratchaphon. Suntivarakorn[4]

[1,2,3,4]Department of Mechanical Engineering, Faculty of Engineering, KhonKaen University, Nai-Muang, Muang District, KhonKaen

Article Info
Volume 82
Page Number: 4557 - 4563
Publication Issue:
January-February 2020

Article History
Article Received: 18 May 2019
Revised: 14 July 2019
Accepted: 22 December 2019
Publication: 22 January 2020

Abstract

This experiment is to compare the bio-oil production from sugarcane trash, napier grass, and rubber tree. Three of biomass were used in this experiment. The feed rate of biomass at 45 kg/h, 60 kg/h, and 75 kg/h was installed in the fast pyrolysis process, the temperature ranging from 440 ^oC to 520 ^oC and the superficial velocity of 7 m/s. The influence on temperature, bio-oil properties, cold efficiency and energy conversion were studied. The result indicated that the sugarcane trash is the best condition to produce the bio-oil yield and is higher than that of napier grass and rubber tree. The bio-oil yield from sugarcane trash was 49.47

wt% while the bio-oil yield from Napier grass and rubber tree were 43.73 wt% and 26.33 wt%, respectively. the properties of bio-oil include Oxygen, carbon, hydrogen, and nitrogen in which the best properties are sugarcane trash with percentage of 52.185%, 37.573%, 9.653% and 0.589%, respectively. The heating value (HHV) of sugarcane trash was 16.417 MJ/kg while High Heating Value (HHV) of Napier grass and rubber tree were 11.088 MJ/kg and 8.288 MJ/kg, respectively. The sugarcane trash was able to producing the cold efficiency and energy conversion at33.33% and 26.48%, respectively.

I. INTRODUCTION

The consumption of fossil fuel has influenced on the environment issue. In addition, the fossil fuel also is very expensive and unrenewable energy. Most of countries in the world have started reform fossil fuel to biomass conversion as the renewable energy. Bio-oil as the renewable energy from pyrolysis prosess is uncontributed to CO2 emission and global warming as the environmental issue. Bio-oil can be generated from Biomass materials such as agriculture waste and industrial waste through pyrolysis, gasification, and liquefication [1,2]. The thermal decomposition occur without oxygen is called pyrolysis in which the pyrolysis consist of fast pyrolysis and slow pyrolysis [3][4].

The familiar process to produce bio-oil from biomass mainly into liquid product, solid product and Non-condensable gas is fast pyrolysis [5]. The relationship between slow pyrolysis and fast pyrolysis has reported by [5–7]. For this reason, fast pyrolysis process was better than that slow pyrolysis. Biomass was very quick heated without

January - February 2020
ISSN: 0193 - 4120 Page No. 4557 - 4563

oxygen in the fast pyrolysis and it had advantages such as very high heating transfer, short hot vapor residence, rapid removal of char and more bio-oil production. The reactor configuration was important in the heating section. Some experiments about reactor were investigated by [8–11]. For this reason, the circulating fluidized bed reactor was better than that other reactors such as conical spouted bed reactor, induction-heating reactor, free-fall reactor, and rotating cylindrical reactor. The circulating fluidized bed reactor had a high heating rate, high char abrasion, solid recycle required, possible liquid cracking by hot gas, and greater reactor wear possible.

However, the condenser unit was important to produce the bio-oil that must be quickly condensed the hot gas to a liquid: Otherwise, some condensable gas become into non-condensable gas. most of the technology on condenser unit were used shell and tube in which the condenser unit was set two fluids that are different temperatures. the shell and tube depend on diameter inside and outside, amount of tube, and temperature on the system.

Presently, many research studies on bio-oil production using shell and tube as the condenser unit. Ateş 2004 [13] studied that The condenser unit was used a cold trap maintained at 0oC. Pütün 2006 [13–15] have investigated that the cold traps with salty ice was used to condenser proses. Pollard 2012 [17] has conducted that technology of condenser unit was used the modification of heat exchanger with five stages of bio-oil recovery. According to [18]–[21] investigated that heat recovery was used the preheat and condenser. Asadullah 2013 [21–23] have studied that The condenser unit was used dry ice bath with temperature of 10oC using dry ice bath. The results from study on technology of condenser using shell and tube have indicated that the condenser unit was not able to condense all hot gases into a liquid because residence time of vapor is very fast through the system

Therefore, the propose of this experiment was to compare the biomass from sugarcane trash, napier grass, and rubber tree by using addition of condenser unit in the system. The hot gas was input in a condenser unit and directly contact with some heat exchangers. The vapor was condensed and the bio-oil was accumulated in the storage tank. The experiment with varying the temperature form 440 oC to 550 oC and the feed rate from 45 to 75 kg/h were conducted. Furthermore, the bio-oil properties, cold efficiency and energy consumption for bio-oil production was also analyzed.

II. EXPERIMENTAL MATERIALS, EXPERIMENTAL DEVICES, EXPERIMENTAL METHODS

A. Experimental materials

Sugarcane trash, napier grass, rubber tree as the material were used in this experiment. to make the uniform size and the consistent feeding in the system, three of biomass was crushed using a crashing machine about 1-3 mm in particle size. The High Heating Value (HHV) from three of biomass based on ASTM D240 are shown in Table 1.

Table 1 the experimental materials of raw material

Properties	Sugarcane trash	Napier grass	Rubber tree	Units
Mean diameter	0.249	0.249	0.249	Mm
Heating value (ASTJ D240)	16.336	15.999	14.005	MJ/kg

B. Experimental devices

Fig. 1 shows that a Fluidized Bed Reactor, a hopper, two cyclones, thermocouple and pressure meters was installed. The contain feedstock was used hopper. A reactor was used rapidly heated the biomass for pyrolysis process by using LPG. Two cyclones were used to separate some charcoals and ash. Two condenser unit was able directly to cooling the gas into a liquid (bio-oil) in which the first condenser operated to trap the hot gas from 100

January - February 2020
ISSN: 0193 - 4120 Page No. 4557 - 4563

C to 60 C while the second condenser was able to trap the hot gas from 60 C to 25 C. The condenser was equipped with the water flow to cooling the hot gas. The monitor and control the pyrolysis system was used thermocouple and pressure matter

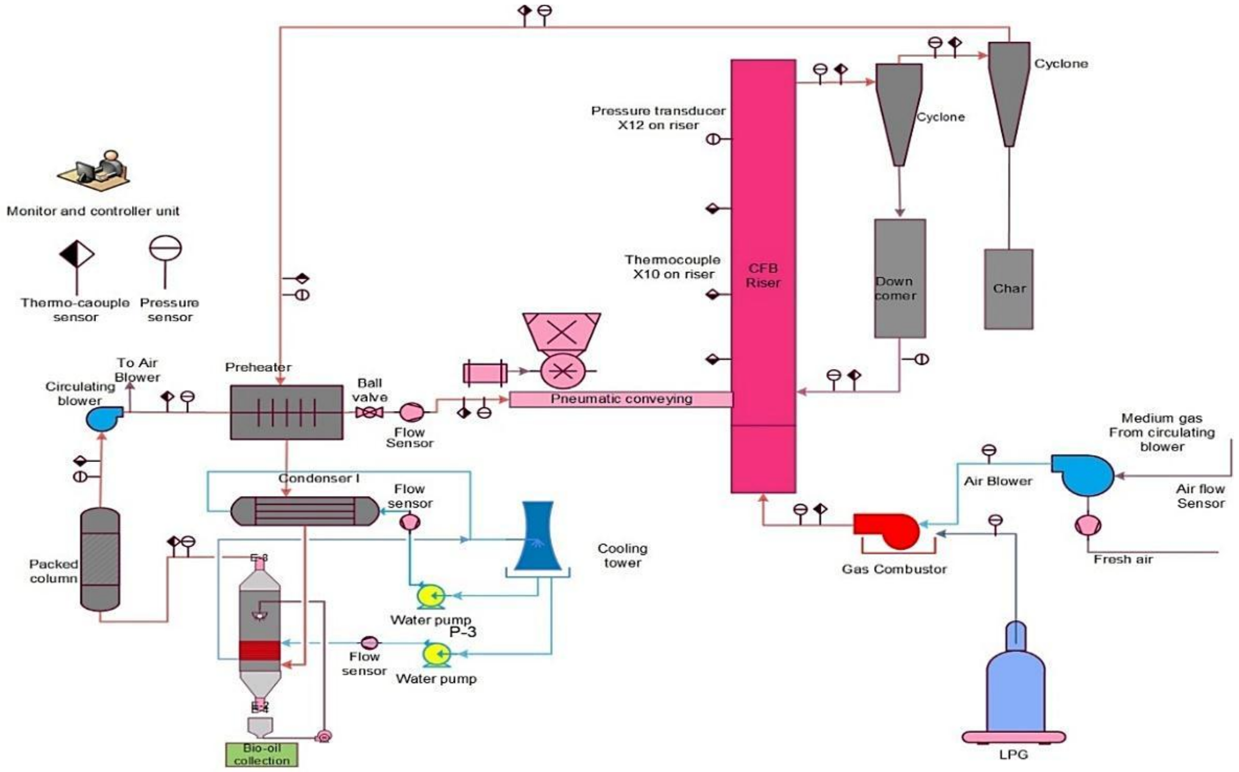


Figure 1 Flowchart of the pyrolysis of production system

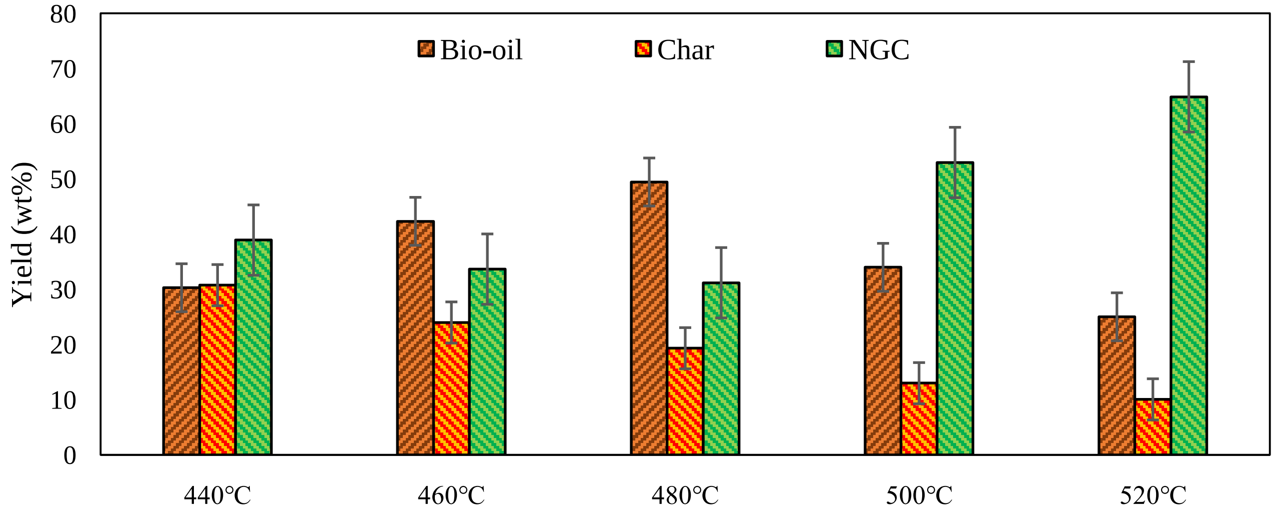
C. Experimental methods

The experimental methods had four parameters as follows pyrolysis temperature, superficial velocity, and feed rate of sugarcane trash. The pyrolysis process was performed at bed temperature ranging from 440oC to 520oC. The superficial velocity was installed at 7 m/s in every biomass. In all parameter, the bed temperature was installed feed rate from 45 kg/h to 75 kg/h. The fast pyrolysis system was set with the condenser unit with heat transfer rate (Q) of 3.1 kw. The hot gas was input in a condenser unit and directly contact with some heat exchangers. The vapor was trapped and the bio-oil was accumulated in the storage tank under the condenser unit. The experiment with varying the temperature form 440oC to 550oC and the feed rate of biomass at 45 kg/h, 60 kg/h, and 75 kg/h were conducted. The bio-oil yield, bio-oil properties, energy conversion efficiency and energy consumption ware studied.

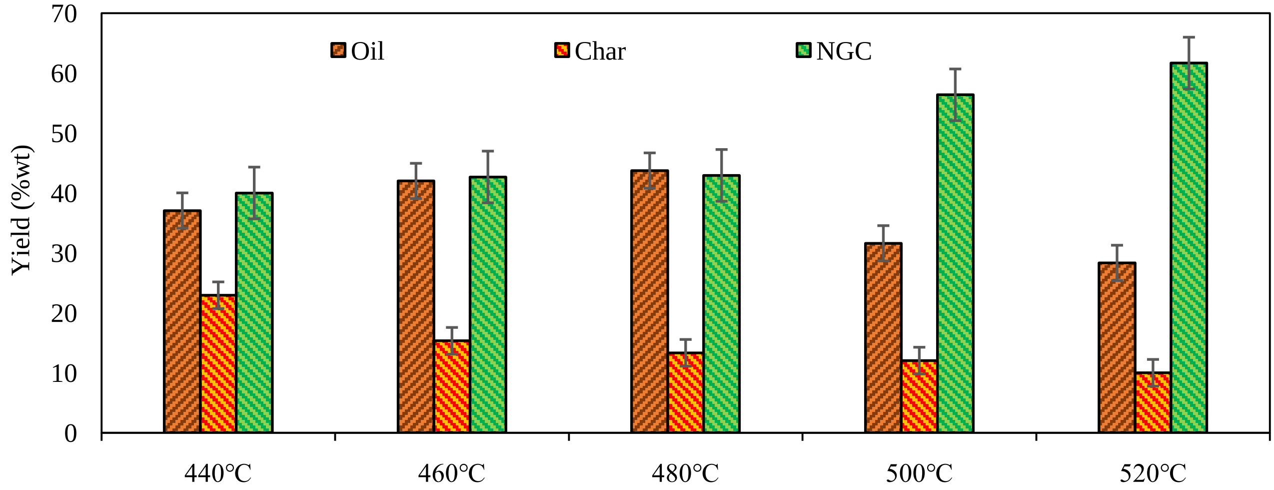
III. RESULTS AND DISCUSSIONS

A. Temperature effect of three biomass

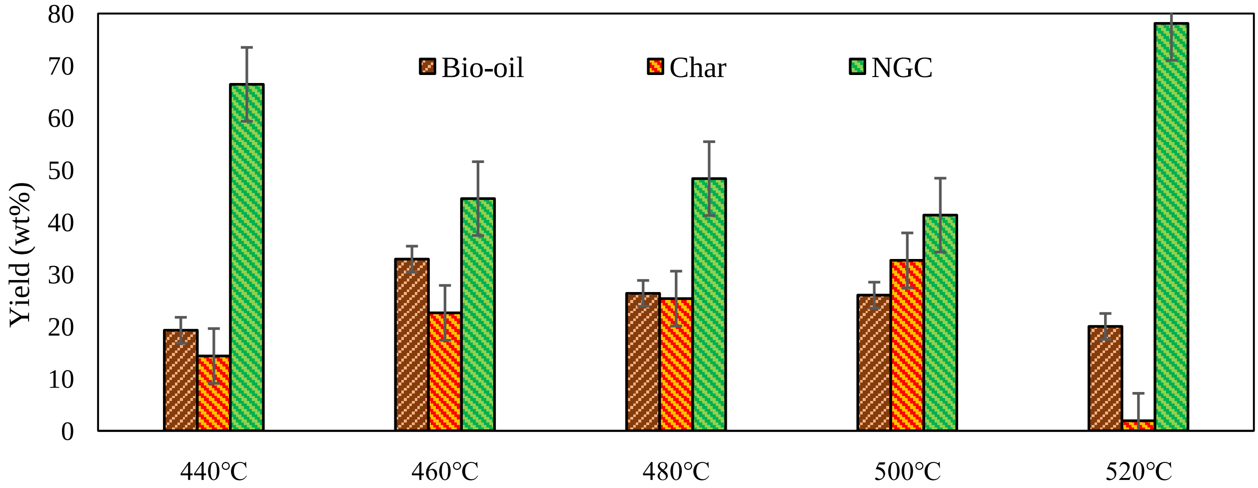
From the experiment, the bed temperature was installed at temperature 440oC, 460oC, 480oC, 500oC, and 520oC which it can be able to the maximum yield were at bed temperature of 480oC and 60 kg/h of feed rate .as shown in Figure 3. Moreover, it was found that: (1) the pyrolysis oil was increase and then it was decrease with the increase the bed temperature ;(2) Charcoal yields was always decrease with the increase the bed temperature; and (3) Non-condensable gas (NCG) was always increase with the varying temperature. The temperature effect on bio-oil yield can be described taht the high temperature was produce secondary cracking reacktion and it was influenced the bio-oil yield always decresea. According to the temperature effect on bio-oil , these result was similar with the previous result from A. Pattiya, 2012 [25] and Lee, 2010 [26]. However, in our experiment, the maximum yield of bio-oil yield is higher than that of the previous result.



a) The experiment on sugarcane trash



b) The experiment on napier grass



c) The experiment on rubber tree

Figure 3 The Bio-oil result from three biomass at a feed rate of 60 kg/h

January - February 2020
ISSN: 0193 - 4120 Page No. 4557 - 4563

Based on our research, the temperature below 440oC can produce more charcoal and ash. In addition, temperature above 520oC is too high reduce quickly the bio-oil yield. Therefore, in this study the temperature optimum to pyrolysis was in the range of 440oC and 520oC. The sugarcane trash became the best condition to produce the bio-oil yield that Napier grass and rubber tree because the effect of High Heating Value (HHV) in every biomass where High Heating Value (HHV) of sugarcane trash was higher than napier grass and rubber tree. Heating value on biomass made the biomass easy to burn in reactor. The bio-oil yield from sugarcane trash was 49.47wt% while the bio-oil yield from Napier grass and rubber tree were 43.73 wt% and 26.33 wt%, respectively.

B. The chemical properties from three biomass

Table 5 shows the main properties of bio-oil by using a modification of condenser unit. The result shown that the bio-oil properties consist of oxygen, carbon, hydrogen, and nitrogen in which the highest yield is sugarcane trash with percentage of 52.185%, 37.573%, 9.653% and 0.589%, respectively. The heating value (HHV) of sugarcane trash was 16.417 MJ/kg while High Heating Value (HHV) of Napier grass and rubber tree were 11.088 MJ/kg and 8.288 MJ/kg, respectively. The GC/MS analysis was conducted to test the chemical composition of bio-oil.

Table 5 Main properties from three biomass

Properties	**Pyrolysis Oil**		
	Sugarcane Trash	**Napier Grass**	**Rubber Tree**
HHV (MJ/kg)	16.417	11.088	8.288
Carbon (%wt)	37.573	21.080	21.454
Hydrogen (%wt)	9.653	8.015	8.010
Nitrogen (%wt)	0.589	0.181	0.174
Oxygen (%wt)	52.185	59.817	61.983

C. Energy conversion and cold efficiency

Bio-oil production system in this study used the LPG as heat resource and some electrical devices were used such as feed motor, three blowers, cooling tower, the spark ignition, and cooling pump. Cold efficiency (μc) is the comparison of the energy from pyrolysis oil (Qb) per energy of feedstock (Qf). The equation was displayed as bellow:

$$\mu c = \frac{Qb}{Qf}\ x\ 100\% \qquad (3)$$

when Qb = mb x HHVb and Qf = mf x HHVf. mb and mf are mass of bio-oil and feed stock, HHVb and HHVf are heating value of bio-oil and feed stock, respectively. The energy conversion efficiency is obtained from energy output (Qb) divided by energy input (Qt). Table 6 shows the energy consumption of bio-oil from sugarcane trash, napier grass, and rubber tree at 480oC of bed temperature and the feed rate of 60 kg/h. The best result of cold efficiency and energy conversion is sugarcane trash.

Table 6 Energy consumption from sugarcane trash, napier grass, and rubber tree.

No	**Description**	**Energy consumption (kg/hr) (MJ)**		
		Sugarcane Trash	Napier Grass	Rubber Tree
- Energy input to the system (MJ)				
1	Energy from feedstock (Q_f)	913.80	913,80	913,80
2	Circulating blower	4.32	4,32	4,32
3	blower 1	7.02	7,02	7,02
4	blower 2	6.30	6,30	6,30
5	Feed motor	0.79	0,79	0,79
6	Water pump	5.22	5,22	5,22
7	Cooling tower motor	1.26	1,26	1,26
8	Spark ignition	0.05	0,05	0,05

January - February 2020
ISSN: 0193 - 4120 Page No. 4557 - 4563

9	LPG	211.34	211,34	211,34
Total Energy (*Qt*)		1150.11	1150.11	1150.11
Energy from bio-oil				
10	Bio-oilfrom three biomass (Q_b)	304.55	82,78	82,78
Cold efficiency (%) (Q_f / Q_b)		33.33	26.01	9,06
Total energy conversion to bio-oil (%) (Q_b / Q_t)		26.48	20.66	7,20

IV. CONCLUSION

Bio-oil oil from sugarcane trash, napier grass and rubber tree had different result that three of biomass was able to product the bio-oil at 60 kg/h of feed rate and at 4800^{o}C of bed temperature while the best condition is sugarcane trash to produce the bio-oil yield, High Heating Value (HHV), cold efficiency and energy conversion more than that Napier grass and rubber tree because the effect of High Heating Value (HHV) in every sample where High Heating Value (HHV) of sugarcane trash was higher than that of napier grass and rubber tree. Heating value on biomass made the biomass easy to burn in reactor.

The bio-oil yield from sugarcane trash was 49.47 wt% while the bio-oil of Napier grass and rubber tree were 43.73 wt% and 26.33 wt%, respectively. The temperature had an effect on the bio-oil condition that the temperature effect on bio-oil yield can be described taht the high temperature was produced secondary cracking reacktion. The Higher Heating Value (HHV), cold efficiency, and energy conversion from sugarcane trash as the best condition both of biomass in this experiment of pyrolysis system were 16.417 MJ/kg, 33.33%, and 26.48%, respectively. The GC/MS has conducted to test the bio-oil properties which the result shown that the bio-oil properties consist of oxygen, carbon, hydrogen, and nitrogen and the highest yield is sugarcane trash with percentage of 52.185%, 37.573%, 9.653% and 0.589%, respectively.

V. ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Engineering KhonKaen University, Thailand has given the research grant and the Farm Engineering and Automation Technology (FEAT) Research Group, KhonKaen University, Thailand for financial and technical support.

REFERENCES

[1] A. V. Bridgwater, D. Meier, and D. Radlein, "An overview of fast pyrolysis of biomass," Org. Geochem., vol. 30, no. 12, pp. 1479–1493, 1999.
[2] P. Adams, T. Bridgwater, A. Lea-Langton, A. Ross, and I. Watson, Biomass Conversion Technologies. Report to NNFCC. Elsevier Inc., 2017.
[3] A. V. Bridgwater, "Renewable fuels and chemicals by thermal processing of biomass," Chem. Eng. J., vol. 91, no. 2–3, pp. 87–102, 2003.
[4] I. Mufandi, W. Treedet, P. Singbua, and R. Suntivarakorn, "Produksi Bio-Oil dari Rumput Gajah dengan Fast Pyrolysis menggunakan Circulating Fluidized Bed Reactor (CFBr) dengan Kapasitas 45 Kg/H," Chem. J. Tek. Kim., vol. 5, no. 2, p. 37, 2019.
[5] A. V. Bridgwater, "Principles and practice of biomass fast pyrolysis processes for liquids," J. Anal. Appl. Pyrolysis, vol. 51, no. 1, pp. 3–22, 1999.
[6] X. Wang and J. Jia, "Effect of heating rate on the municipal sewage sludge pyrolysis character," Energy Procedia, vol. 14, no. 2011, pp. 1648–1652, 2012.
[7] D. Angin, "Effect of pyrolysis temperature and heating rate on biochar obtained from pyrolysis of safflower seed press cake," Bioresour. Technol., vol. 128, pp. 593–597, 2013.
[8] N. Ibrahim, P. A. Jensen, D. M. Johansen, R. R. Ali, and M. R. Kasmani, "Influence of Reaction Temperature and Water Content on Wheat Straw Pyrolysis," World Acad. Sci. Eng. Technol., vol. 6, no. 10, pp. 10–21, 2012.
[9] P. Singbua, W. Treedet, P. Duangthong, V. Seithtanabutara, and R. Suntivarakorn, "Bio-Oil

Production of Napier Grass by Using Rotating Cylindrical Reactor," Energy Procedia, vol. 138, pp. 641–645, 2017.
[10] J. lu Zheng, W. ming Yi, and N. na Wang, "Bio-oil production from cotton stalk," Energy Convers. Manag., vol. 49, no. 6, pp. 1724–1730, 2008.
[11] J. Piskorz, P. Majerski, D. Radlein, D. S. Scott, and A. V. Bridgwater, "Fast pyrolysis of sweet sorghum and sweet sorghum bagasse," J. Anal. Appl. Pyrolysis, vol. 46, no. 1, pp. 15–29, 1998.
[12] J. Alvarez, G. Lopez, M. Amutio, J. Bilbao, and M. Olazar, "Bio-oil production from rice husk fast pyrolysis in a conical spouted bed reactor," Fuel, vol. 128, pp. 162–169, 2014.
[13] F. Ateş, E. Pütün, and A. E. Pütün, "Fast pyrolysis of sesame stalk: yields and structural analysis of bio-oil," J. Anal. Appl. Pyrolysis, vol. 71, no. 2, pp. 779–790, Jun. 2004.
[14] A. E. Pütün, E. Apaydm, and E. Pütün, "Rice straw as a bio-oil source via pyrolysis and steam pyrolysis," in Energy, 2004.
[15] B. B. Uzun, A. E. Pütün, and E. Pütün, "Fast pyrolysis of soybean cake: Product yields and compositions," Bioresour. Technol., vol. 97, no. 4, pp. 569–576, 2006.
[16] N. Özbay, A. E. Pütün, B. B. Uzun, and E. Pütün, "Biocrude from biomass: Pyrolysis of cottonseed cake," Renew. Energy, vol. 24, no. 3–4, pp. 615–625, 2001.
[17] A. S. Pollard, M. R. Rover, and R. C. Brown, "Characterization of bio-oil recovered as stage fractions with unique chemical and physical properties," J. Anal. Appl. Pyrolysis, vol. 93, pp. 129–138, 2012.
[18] W. Treedet and R. Suntivarakorn, "Sugar Cane Trash Pyrolysis for Bio-oil Production in a Fluidized Bed Reactor," pp. 140–147, 2011.
[19] W. Treedet and R. Suntivarakorn, "Design and operation of a low cost bio-oil fast pyrolysis from sugarcane bagasse on circulating fluidized bed reactor in a pilot plant," Fuel Process. Technol., vol. 179, no. March, pp. 17–31, Oct. 2018.
[20] W. Treedet and R. Suntivarakorn, "Fast Pyrolysis of Sugarcane Bagasse in Circulating Fluidized Bed Reactor - Part A: Effect of Hydrodynamics Performance to Bio-Oil Production," Energy Procedia, vol. 138, pp. 801–805, 2017.
[21] R. Suntivarakorn, W. Treedet, P. Singbua, and N. Teeramaetawat, "Fast pyrolysis from Napier grass for pyrolysis oil production by using circulating Fluidized Bed Reactor: Improvement of pyrolysis system and production cost," Energy Reports, vol. 4, pp. 565–575, 2018.
[22] M. Asadullah et al., "Jute stick pyrolysis for bio-oil production in fluidized bed reactor," Bioresour. Technol., vol. 99, no. 1, pp. 44–50, 2008.
[23] M. Asadullah et al., "Production of bio-oil from fixed bed pyrolysis of bagasse," Fuel, vol. 86, no. 16, pp. 2514–2520, 2007.
[24] M. Asadullah, N. S. Ab Rasid, S. A. S. A. Kadir, and A. Azdarpour, "Production and detailed characterization of bio-oil from fast pyrolysis of palm kernel shell," Biomass and Bioenergy, vol. 59, pp. 316–324, 2013.
[25] S. Suttibak, K. Sriprateep, and A. Pattiya, "Production of bio-oil via fast pyrolysis of cassava rhizome in a fluidised-bed reactor," Energy Procedia, vol. 14, pp. 668–673, 2012.
[26] M. K. Lee, W. T. Tsai, Y. L. Tsai, and S. H. Lin, "Pyrolysis of napier grass in an induction-heating reactor," J. Anal. Appl. Pyrolysis, vol. 88, no. 2, pp. 110–116, 2010.