Catalytic Process in Producing Green Aromatics through Fast Pyrolysis of Wood of Five Tropical Fast Growing Trees Species

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Abstract

The generation of liquid fuels and chemicals is potential through a catalytic fast pyrolysis (CFP) which is a rapid, inexpensive, and promising method utilizing tropical wood biomass as starting material. There is a little known in the potential of wood biomass from tropical fast-growing trees as starting materials for the production of liquid fuel and chemicals. The pyrolysis of five species (balsa, eucalyptus, jabon, mangium, and sengon) was performed with a single-shot mode pyrolyzer. In this study the formation of aromatics by pyrolytic-gas chromatography/mass spectroscopy (Py-GC/MS) is evaluated on the effect of wood species with different characteristics and its cellulose component to the formation of aromatics. ZSM-5 zeolite catalyst was used to evaluate aromatic production on balsa and ecualyptus samples. Fast pyrolysis of eucalyptus wood characterized with low content of ash and high percentages of hollocellulose and α-cellulose produced much high relative peaks of levoglucosan and small relative peaks of lignin derived products. Meanwhile high content of vollatile matter and high crystallinity of cellulose attributed balsa and jabon woods as feedstock for fast pyrolysis. The catalytic process in fast pyrolysis of eucalyptus decomposed the most of oxygenated compound such as levoglucosan and furfural into aromatics in the presence of ZSM-5. Coke formation on the surface catalyst might lead partly of decomposition of levoglucosan and furfural to form aromatics in the catalytic fast pyrolysis of balsa wood. Cellulose component was determined on the formation of benzene, toluene, styrene, p-xylene, indane, indene, and naphthalene in catalytic fast pyrolysis of wood.

Keywords: aromatics, catalytic fast pyrolysis, Py-GC/MS, wood characteristics, ZSM-5 catalyst.

Introduction

The production of fuels and chemicals from renewable resources is currently generating new interest. In contrast to fossil fuels, the use of renewable resources such as biomass for energy provides significant environmental advantages. Woody biomass which is available in a large amount in many parts of the world especially in tropical area is potential starting materials for liquid fuel and chemicals. One of the woody biomass sources is from the harvesting of industrial plantation and community forests which is mainly composed of fast-growing tree species. Renewable biomass has the potential to generate inexpensive fuels and organic chemicals if they are efficiently converted via an appropriate processing route. Therefore, clean energy development could turn away from fossil fuel towards regenerative energy sources such as wood biomass.

Fast pyrolysis thermal decomposition of biomass feedstock using a relatively high heating rate can yield liquids of up to 70~75% of the weight of the starting material (Gurgens *et al*. 2014). The crude pyrolysis liquid product is potential energy product because of its high energy density (Bridgwater 1996). However, the pyrolytic oil product requires full deoxygenation which can be accomplished by hydro-treating and catalytic vapor cracking (Czernik and Bridgwater 2004) and also by catalytic upgrading (Vitolo *et al.* 2001) to obtain a conventional transport fuels. Carlson *et al.* (2009) have developed a single step catalytic fast pyrolysis to produce aromatics including benzene, toluene, and naphthalene from biomass in a single reactor with a short residence time. The aromatic production and selectivity are found as a function of catalyst to feedstock weight ratio, heating rate, and reaction temperature (Carlson *et al*. 2010). French and Czernik (2010) performed a study on the efficiency of various catalyst for aromatic production and found that the highest yield of aromatics from wood, around 16 wt% including 3.5 wt% of toluene were obtained by ZSM-5 zeolite catalyst. Mihalcik *et al*. (2011) screened acidic zeolites for catalytic fast pyrolysis of biomass and its components and found that H-ZSM-5 zeolite lead to an increased production of aromatic hydrocarbons. Besides improving the quality of bio oil, impregnation of 10 wt% Fe to ZSM-5 can increase in the amount of phenolic compound, aromatic and aliphatic hydrocarbon (Saracoglu *et al.* 2017).

There is less study on the development of liquid fuel and aromatics production through the catalytic fast pyrolysis utilizing wood biomass from tropical fast growing trees as starting material. In a previous study, it was found that aromatics including benzene, toluene, styrene, naphthalenes, and indanes were formed by a catalytic fast pyrolysis of red meranti (*Shorea leprosula*) biomass (Sulistyo *et al.* 2013). Since there are many fast-growing trees available in tropical area with different characteristics of wood, so selection of the potential woody biomass and cellulose component as starting material is useful. The objective of the study is to use Py-GC/MS to evaluate five tropical wood species and their cellulose components against ZSM-5 catalysts to determine relative abilities to deoxygenated pyrolytic condensable components and produce aromatics.

Materials and Methods

A wood disc sample was collected from the bottom part of trees of jabon (*Antocephalus cadamba*), sengon (*Paraserianthes mollucana*), and balsa (*Ochroma* sp) grown in community forest managed by PT. Partawood in Probolinggo – East Java Province, Indonesia. The present study used three trees for each wood species. Two other wood species i.e. mangium (*Acacia mangium*) and eucalyptus (*Eucalyptus pellita*) grown in Wanagama experimental forest of Universitas Gadjah Mada in Gunung Kidul District - Yogyakarta were used without replication. Part of the wood disc sample was milled into powder and sieved with wire mesh screens to obtain particles with size range of 0.25 ~ 0.42 mm (passing through 40 mesh sieve and retained by 60 mesh sieve). ZSM-5 catalyst (Zeolyst International, CVB 3024E, nominal cation form: ammonium) was used in this study.

The moisture and volatile contents were determined by a gravimetric method according to ASTM D2867-17 and D1762-64, respectively. For moisture content, the sample was heated at 105 °C for 2 h in the oven. The sample for volatile matter was heated to 950 °C for 7 min in muffle furnace. The ash content was obtained by heating the samples at 600 °C for 1 h in air to constant weight in muffle furnace according to ASTM D2866-94, the fixed carbon content was estimated by difference as follows :

Fixed carbon content (%) = [100 - (% ash content + % volatile matter content)] ....(1)

For determining of holocellulose and α-cellulose contents, wood powder equal to dry weight of 2 g was determined according to chlorite acid method (Browning 1967) and ASTM D1103-60, respectively. The hemicellulose content was determined by substraction. Extractive soluble in alcohol-toluene was determined according to ASTM D1107-96. The crystallinity level of the wood sawdust were measured with an X-ray diffractometer (Shimadzu MAXima XRD 7000) for wide angle X-Ray Difraction (XRD). The equipment settings were 40 mA and 30 kV with a Cu K_α radiation wavelength of 1.54 Å. The receiving slits were 0.3 mm, and the intensity was measured as a function of the scattering angle 2θ by θ-2θ scan. The angle range was 10-40 degrees and the step was 0.02 degree. The measuring time was chosen so the maximum intensity was about 84 counts, and it was typically 0.60s per point. The crystallinity profiles of the wood sawdust are explained in terms of wood sawdust content. Crystallinity Index (CI) is calculated as the ratio between the area of the crystalline contribution and the total area according to equation:

CI (%) = $[(I_{002} – I_{am})/ I_{002}] \times 100$ .... (2)

where I_{002} is the diffraction peak intensity of the (002) plane, I_{am} is the amorphous part of diffraction intensitylocated at 2θ between 18°–19°.

The pyrolysis of wood (0.05 mg) was performed with a single-shot mode pyrolyzer (PY-2020, Frontier Lab.) directly interfaced to a GC/MS system Shimadzu (QP-5000) equipped with DB - 5HT capillary column with a length of 30 m × diameter of 0.250 mm (Agilent Technologies). The effect of catalyst was evaluated on balsa and eucalyptus only. Wood meal and catalyst powder were mixed in a 1 (balsa or eucalyptus wood) : 9 (ZSM-5) (0.5 mg) or 1 (balsa cellulose or eucalyptus cellulose) : 9 (ZSM-5) (0.5 mg) ratio. The interface temperature was set to 310 °C. The mass spectra of samples were then compared to values in NIST library and literatures. The relative area percentage was expressed as percentages obtained by a computerized integrator based on the peak area from total ion chromatography.

The fast pyrolysis was performed by raising the temperature of pyrolyzer furnace to 600 °C without heating the sample. When the condition had stabilized, then the sample in steel sampling cup, 5 mm in diameter and 7 mm in height, was dropped to the furnace and kept at 600 °C for 0.2 min under the He gas flow rate of 50 ml/min. The column temperature was set to 70 °C and the injection temperature was 320 °C with a flow pressure of 1000 °C kPa. The oven temperature was held at 90 °C for 3 min and then increased up to 190 °C at 10 °C/min and kept for 5 min. The temperature increased from 190 °C to 320 °C at 10 °C/min and isothermal at 320 °C for 35 min. The carrier gas used was helium with a controlled flow of 50 ml/min. The data was analyzed using one way analysis of variance (ANOVA) followed by Tukey test (p = 0.05). All statistical calculations were conducted using SPSS-Win 16.0.

Results and Discussion

Chemical Characteristics

Table 1 shows the proximate analysis of wood of five potential fast growing species. All wood species possessed high volatile contents, on the other hand showing a low content of fixed carbon and ash content that is comparable with Meincken and Tyhoda (2014). Analysis of variance showed that there is no significant differences on the volatile matters, fixed carbon, and ash contents of jabon, sengon, and balsa. The volatile contents of jabon, sengon and balsa woods are higher than that of eucalyptus and that of rockrose wood reported by Gomez-Serrano *et al.* (1993). Eucalyptus wood contained lesser ash than those of jabon, sengon, and balsa woods. It is expected that slight ash content in eucalyptus wood influences on the high in yields of anhydro-sugars and high molecular furan and pyran products and also on the slight in the yield of lignin derived products such as vinyl guaiacol and syringol (Azeez *et al.* 2011). Strezov *et al.* (2007) reported that sugar pine wood containing 80.7% of volatile matter through a pyrolysis at temperature of 500 and 900 °C with a heating rate of 50 °C/min yielded a double gaseous product than that of bagasse and macadamia nut shell containing volatile matter of 72.7% and 72.6%, respectively. The different content of volatile matters in different wood species supposed to influence on the formation of aromatics from a catalytic fast pyrolysis process.

Table 2 shows the significant differences at 0.01 levels in the hollocellulose, α-cellulose, hemicellulose and extractive soluble in alcohol-toluene contents in jabon, sengon and balsa. Mangium dan eucalyptus woods possessed higher content of holocellulose and α-cellulose but lower content of extractive than those of jabon, sengon and balsa. In thermochemical decomposition, cellulose degraded into anhidrocellulose and levoglucosan, meanwhile hemicellulose degraded mostly into volatile matter (Mohan *et al.* 2006). Sharma *et al.* (2015) emphasized that cellulose and hemicellulose components produce more volatile and gas products, while lignin predominantly forms a charred residue. Therefore mangium and eucalyptus woods were potential to be used in fast pyrolysis for aromatic production. Jabon and balsa woods with high content of hemicellulose 30.9% and 34.6%, respectively, were reasonable to yield high volatile matter contents of 92.2% and 95.0%, respectively as shown in Table 1.

Table 1. Proximate analysis of the wood of five potential fast growing trees.

	Proximate analysis (wt.%, dry basis)		
Species	Volatile matter	Fixed carbon	Ash
Mangium (*Acacia mangium*)	-	-	-
Ekaliptus (*Eucalyptus pellita*)	82.6	16.94	0.41
Jabon (*Antocephalus cadamba*)	93.2	5.33	2.13
Sengon (*Paraserianthes mollucana*)	89.8	8.85	1.34
Balsa (*Ochroma sp.*)	95.0	3.16	1.85

Remark: jabon, sengon and balsa showed no significantly different; (-) : not determined

Table 2. Chemical components of the wood of five potential fast growing trees

	Components analysis (wt%, dry basis)			
Species	Holocellulose	α-cellulose	Hemicellulose	Extractive
Mangium (*Acacia mangium*)	87.7	54.7	33.0	12.1
Ekaliptus (*Eucalyptus pellita*)	81.8	56.1	25.7	11.2
Jabon (*Antocephalus cadamba*)	72.9^{a}	42.0^{a}	30.9^{b}	14.1
Sengon (*Paraserianthes mollucana*)	77.9^{b}	51.5^{b}	26.5^{a}	16.3
Balsa (*Ochroma sp.*)	78.4^{b}	43.9^{a}	34.6^{c}	14.2

Remark: values followed by the same letter on the same column are not significantly different at 0.01 level (Tukey test). Extractive soluble in alcohol-toluene.

Crystallinity Characteristics

Figure 1 shows the X-ray diffractogram of the wood samples studied. There are two major diffraction peaks at approximately 16° and 22° comparable with Poletto *et al.* (2012). The peak intensities differ from one species to another. The clearer difference occurred at the peak range between 21.80° and 22.66° 2θ reflection. The peak area at 21.80~22.66° 2θ reflection follow the sequence mangium > eucalyptus > sengon > balsa > jabon, as can be seen in Figure 1.

The crystallinity of five wood using XRD varied from 26% to 41%. The highest crystallinity was mangium (41.37%), then followed by balsa (34.2%), sengon (33.6%), jabon (33%), and the lowest was eucalyptus (26.2%). The comparatively high level of lignin content along with crystalinity index in mangium wood is not expected. The reason might be due to the large amount of crystalline regions present in cellulose. In addition, these results are corresponding with Poletto *et al.* (2012) that the eucalyptus crystallinity was lower than other wood. The differences are influenced by the crystallite size along the crystallographic planes. The crystallinity index increased with increasing crystallite size because the crystallite surface corresponding to the amorphous cellulose region reduced (Kim *et al.* 2010; Poletto *et al.* 2012).

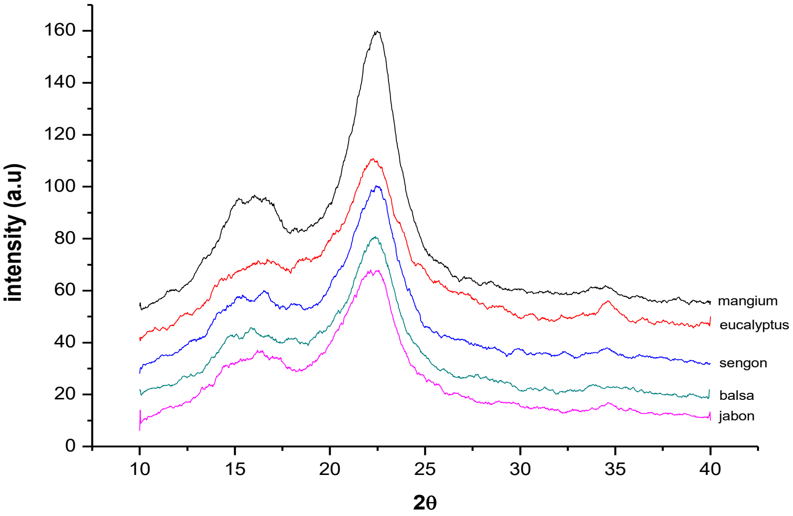

Figure 1. X-ray diffractograms of five wood species.

Non-Catalytic Fast Pyrolysis

Figure 2 display the ion chromatograms from non-catalytic fast pyrolysis of wood of the five potential fast growing species. Non-catalytic fast pyrolysis mangium, eucalyptus, balsa, jabon, and sengon woods at 600 °C formed vapours which was analyzed with GC/MS using DB - 5HT column showing major peaks of hydroxyl acetaldehyde, furfural, guaiacol, 4-methylguaiacol, 4-vinylguaiacol, syringol, levoglucosan, vinylsyringol, and acetoyringon (Tsuge *et al.* 2011).

Fast pyrolysis increased the decomposition of wood through rapid and simultaneous depolymerizing and fragmenting of cellulose, hemicellulose, and lignin with rapid increase in temperature (Mohan *et al.* 2006). Under fast pyrolysis at 600 °C, cellulose depolymerizes to miscellaneous oxygenated fragments such as hydoxyacetaldehyde, furfural, and levoglucosan, at retention time of 7.49, 9.25 and 11.97 min, respectively. Lignin depolymerized to guaiacol, 4-methylguaiacol, 4-vinylguaiacol, and syringol, at retention time of 9.73, 10.3, 10.8 and 11.2 min respectively (Shen and Gu 2009; Azeez *et al.* 2010; Boateng *et al.* 2010). The relative major peaks of chromatogram of non-catalytic fast pyrolysis are shown in Table 3. The relative peaks of levoglucosan from non-catalytic fast pyrolysis of eucalyptus wood much higher than other peaks including furfural, 4-vinylguaiacol, vinylsyringol, and acetosyringon. The high content of α-cellulose and a small content of ash in eucalyptus wood, as shown in Table 1 and 2, might influence on the high relative peak of levoglucosan, as the yield of levoglucosan is affected by the source of the cellulose (Azeez *et al*. 2011). The small content of ash in eucalyptus wood might also play an important role in producing a slight yield of lignin derived products such as guaiacol, 4-methylguaiacol, syringol and acetosyringon (Azeez *et al.* 2011). The relation of small ash content to the promoting of high yield of levoglucosan from the low crystallinity of eucalyptus wood were opposite with the previous finding that cellulose with high crystallinity degree tends to produce levoglucosan in a higher yield during cellulose pyrolysis (Wang *et al.* 2013; Jiang *et al.* 2016; Zheng *et al.* 2016). They reported that the cellulose with low crystallinity degree seems to have thermally decomposed through the formation of a liquid intermediate contained dehydration reactions. Meanwhile the relative major peaks were found on non-catalytic fast pyrolysis of balsa, jabon, and sengon woods. It is might be affected by high content of volatile matter which is came from cellulose and hemicellulose in these three wood species as shown in Table 1 and their high crystallinity of cellulose.

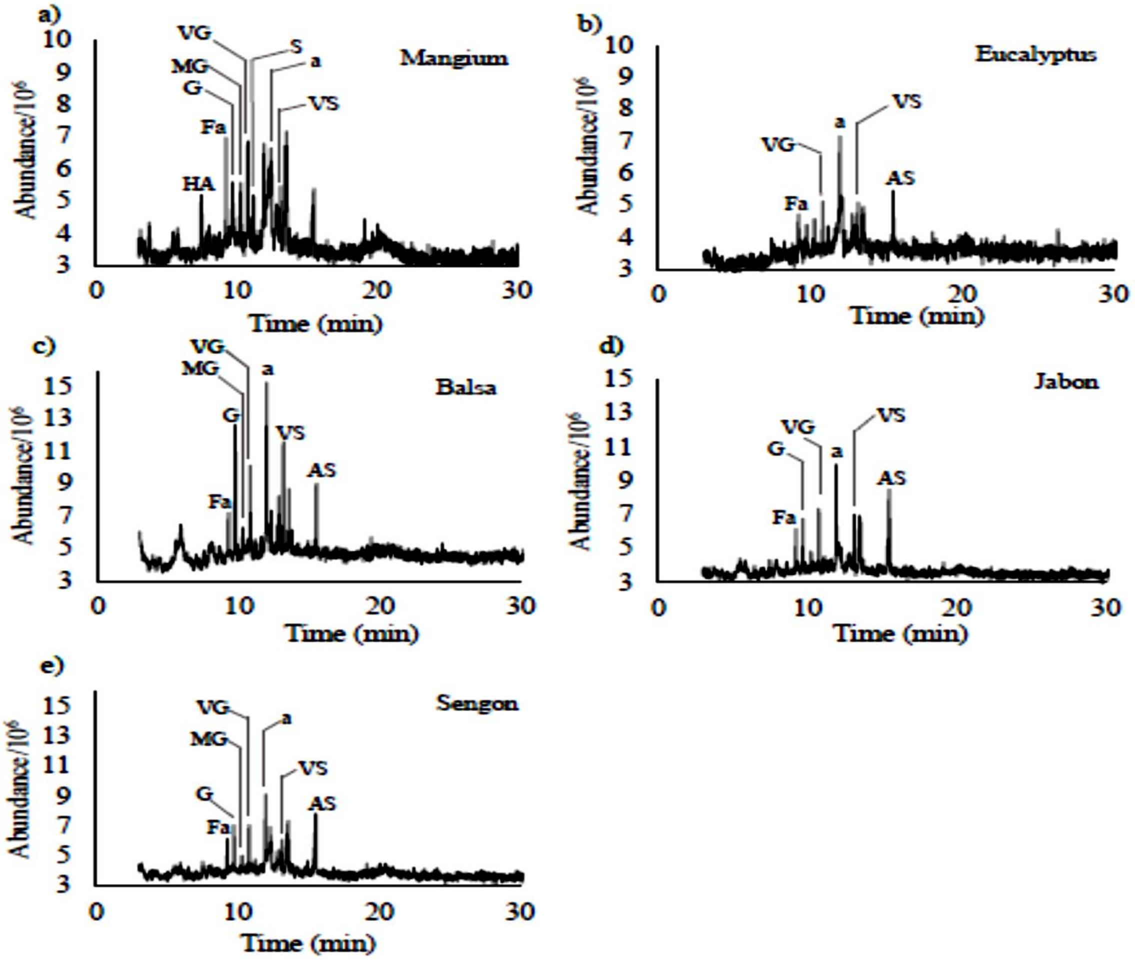

Figure 2. The ion chromatograms from non-catalytic fast pyrolysis of a) mangium, b) eucalyptus, c) balsa, d) jabon and e) sengon wood species. HA – Hydroxy acetaldehyde, Fa – Furfural, G – Guaiacol, MG – 4-Methylguaiacol, VG – 4-Vinylguaiacol, S – Syringol, a – Levoglucosan, VS – Vinylsyringol, AS – Acetosyringon.

Table 3. Relative major peaks (%) from non-catalytic fast pyrolysis of the wood of five potential fast growing trees

RT (min)	Compound	Mangium	Eucalyptus	Balsa	Jabon	Sengon
7.49	Hydroxy acetaldehyde	2.84	-	-	-	-
9.25	Furfural	13.12	9.54	6.44	8.67	6.19
9.73	Guaiacol	2.88	-	24.54	10.30	17.01
10.30	4-Methylguaiacol	4.88	-	1.47	-	0.45
10.81	4-Vinylguaiacol	4.18	7.75	7.79	0.53	6.22
11.22	Syringol	2.65	(-)	-	-	-
11.97	Levoglucosan	13.95	70.92	33.65	16.74	22.60
13.17	Vinylsyringol	16.97	10.58	11.02	8.40	10.41
15.51	Acetosyringon	-	1.21	3.10	15.04	10.30
	Unidentified	38.53	-	11.99	40.32	26.83

Remark: RT= Retention time; (-) = not detected

Catalytic Fast Pyrolysis of Wood

Figure 3 shows ion chromatogram non-catalytic and catalytic pyrolysis of eucalyptus and balsa woods. The catalytic processes in fast pyrolysis of eucalyptus and balsa wood released the aromatics peaks including benzene, toluene, styrene, p-xylene, o-xylene, indane, indene, and naphthalene, following the decreasing the relative peaks of oxygenated compounds such as furfural, guaiacol, 4-vinylguaiacol, syringol, levoglucosan, vinylsyringol and acetosyringon (Tsuge *et al.* 2011; Schultz *et al.* 2016) as shown in Table 4. Therefore catalytic fast pyrolysis decomposed carbohydrates and lignin to produce bio-oil (Mohan *et al.* 2006) containing furfural, levoglucosan, guaiacol, 4-vinylguaiacol, syringol, vinylsyringol, and acetosyringon which were then diffused into ZSM-5 pores and through a series of decarbonylation, decarboxylation, dehydration, and oligomeration reactions, aromatics were formed (Carlson *et al.* 2009) which were not detected on the non-catalytic fast pyrolysis of wood. ZSM-5 catalyst with a potential ideal pore size in the range of 0.52~0.55 nm (Mihalcik *et al.* 2011) and Brönsted acid sites (Corma *et al.* 2009) leads to the production of aromatics in this study. The mechanism of aromatic formation from carbohydrates and lignin through a catalytic fast pyrolysis was explained elsewhere (Carlson *et al*. 2009; Shen and Gu 2009; Shen *et al*. 2010).

Relative major peaks from non-catalytic and catalytic fast pyrolysis of balsa and eucalyptus wood is shown in Table 4. There is much different between relative peaks of levoglucosan and furfural from non-catalytic and catalytic fast pyrolysis of eucalyptus wood i.e. 70.9 ~ 0.98 and 9.54 ~ 1.44, respectively. Meanwhile there is lesser different between those from non-catalytic and catalytic fast pyrolysis of balsa wood i.e. 33.6 ~ 12.6 and 6.4 ~ 1.2, respectively. The catalytic process in fast pyrolysis of eucalyptus decomposed the most of oxygenated compound such as levoglucosan and furfural into aromatics in the presence of ZSM-5. The potential aromatics species formed from catalytic fast pyrolysis of eucalyptus wood were including toluene, styrene, p-xylene, o-xylene, indane, indene and naphthalene. On the other hand, it was found that partly of levoglucosan and furfural generated to form aromatics in the fast pyrolysis of balsa wood. The fast pyrolysis of balsa wood released abundance volatiles as shown in Table 1, that might be intermediate species from carbohydrate vapors (Jia *et al*. 2017). The abundance intermediate species might cause the formation of unsaturated coke on the surface of the catalyst. The coke is formed through intermediate polymers, which ultimately decompose to unsaturated coke (Carlson *et al*. 2010b). The coke formation on the external surface are responsible for deactivation of zeolites, and the coke deposition within the zeolite pore reduce the capillary and diffusion flow of reactants and finally decrease the aromatic yield (Shen *et al.* 2015; Galadima and Muraza 2015; Rahman *et al.* 2018). Therefore it might require more ZSM-5 catalyst to react with all oxygenated compounds from fast pyrolysis of balsa wood to form aromatics, as aromatics production is found as a function of catalyst to feedstock weight ratio (Carlson *et al*. 2010a).

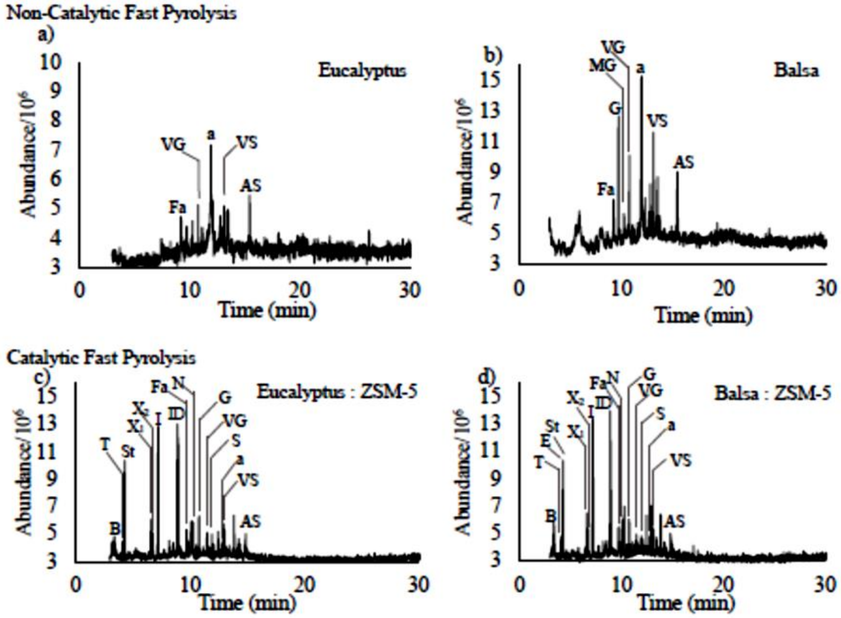

Figure 3. The ion chromatograms non-catalytic fast pyrolysis of a) eucalyptus and b) balsa woods, and catalytic fast pyrolysis of c) eucalyptus and d) balsa woods. B – Benzene, T – Toluene, St – Styrene, X_1 – P-Xylene, X_2 – O-Xylene, I – Indane, ID – Indene, Fa – Furfural, N – Naphthalene, G – Guaiacol, VG – 4-Vinylguaiacol, S – Syringol, a – Levoglucosan, VS – Vinylsyringol, AS – Acetosyringon.

Table 4. Relative major peaks (%) from non-catalytic and catalytic fast pyrolysis of balsa and eucalyptus woods.

	Balsa				Eucalyptus			
Compound	RT (min)	Non-Catal.	RT (min)	Catal.	RT (min)	Non-Catal.	RT (min)	Catal.
Benzene		-	3.42	0.78		-	3.40	0.14
Toluene		-	4.12	1.57		-	4.12	1.17
Ethylbenzene		-	4.30	12.59		-		0.01
Styrene		-	4.31	11.84		-	4.30	16.16
P-xylene		-	6.62	3.79		-	6.62	4.19
O-Xylene		-	6.73	1.83		-	6.73	1.46
Indane		-	7.23	13.43		-	7.23	19.90
Indene		-	8.94	13.19		-	8.98	21.07
Furfural	9.28	6.44	9.75	1.23	9.24	9.54	9.72	1.44
Naphthalene		-	10.13	2.48		-	10.17	2.29
Guaiacol	9.76	24.54	10.80	0.88		-	10.79	2.63
4-Methylguaiacol	10.30	1.47		-				
4-Vinylguaiacol	10.81	7.79	11.51	0.25	10.82	7.75	11.50	0.64
Syringol		-	11.96	0.25		-	11.95	0.95
Levoglucosan	11.99	33.65	12.97	12.62	11.97	70.92	12.96	0.98
Vinylsyringol	13.18	11.02	13.17	0.19	13.17	10.58	13.03	0.51
Acetosyringon	15.51	3.10	14.90	0.26	15.49	1.21	14.83	1.17
Unidentified		11.99		22.81		-		25.3

Remark: RT = Retention time; (-) = not detected

Catalytic Fast Pyrolysis of Cellulose Component

Ion chromatogram of catalytic fast pyrolysis of cellulose of eucalyptus and balsa woods is shown in Figure 4. Relative major peaks from catalytic fast pyrolysis of cellulose of eucalyptus and balsa woods are presented in Table 5. Catalytic fast pyrolysis of both celluloses of eucalyptus and balsa woods released major peaks of aromatics including benzene, styrene, p-xylene, indane, indene, and naphthalene along with the disappearing oxygenated compound derivates of cellulose i.e. furfural and levoglucosan (Tsuge *et al.* 2011). The catalytic process decomposed all cellulose derivates from fast pyrolysis of cellulose of eucalyptus wood to form aromatics. On the other hand, partly cellulose derivates of cellulose of balsa wood were degraded to form aromatics. As discussed previously, the formation of unsaturated coke from abundance intermediate species on the surface of ZSM-5 catalyst influenced on the deactivation of the catalyst (Carlson *et al.* 2010b; Jia *et al.* 2017). Deactivation of ZSM-5 catalyst might determine the partial degradation of cellulose of balsa wood. The abundance vapor products from fast pyrolysis of balsa wood, corresponding to the high volatile matter content of balsa wood in Table 1, might require more availability of ZSM-5 catalyst.

Selectivity distribution of aromatics from catalytic fast pyrolysis of cellulose of eucalyptus wood from were styrene > indene > p-xylene = indane > benzene. Meanwhile cellulose of balsa wood released aromatics with the selectivity distribution was from indane > indene > styrene > benzene > p-xylene > o-xylene > naphthalene > toluene that was similar with the selectivity distribution from catalytic fast pyrolysis of balsa wood.

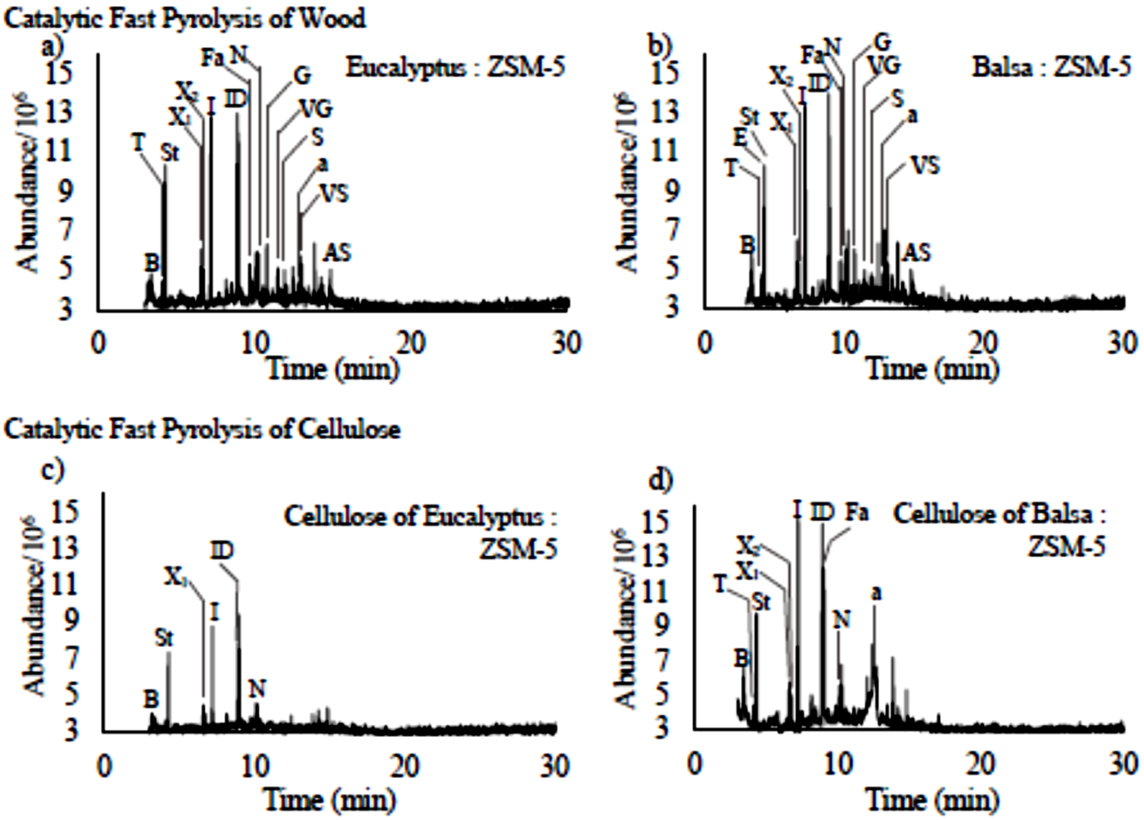

Figure 4. The ion chromatograms catalytic fast pyrolysis of a) eucalyptus and b) balsa wood, and cellulose of c) eucalyptus and d) balsa wood species. The meaning of peak is the same as that in Figure 3.

Table 5. Relative major peaks (%) from catalytic fast pyrolysis of wood and cellulose of balsa and eucalyptus woods.

Compound	Balsa		Eucalyptus	
	Wood	Cellulose	Wood	Cellulose
Benzene	0.78	3.15	0.14	0.21
Toluene	1.57	0.95	1.17	-
Ethylbenzene	12.59	-	0.00	-
Styrene	11.84	10.90	16.16	24.14
P-xylene	3.79	2.05	4.19	2.83
O-xylene	1.83	1.72	1.46	-
Indane	13.43	17.65	19.90	2.83
Indene	13.19	13.08	21.07	11.55
Furfural	1.23	3.69	1.44	-
Naphthalene	2.48	1.23	2.29	6.42
Guaiacol	0.88	-	2.63	-
4-Methylguaiacol	-	-	0.00	-
4-Vinylguaiacol	0.25	-	0.64	-
Syringol	0.25	-	0.95	-
Levoglucosan	12.62	9.30	0.98	-
Vinylsyringol	0.19	-	0.51	-
Acetosyringon	0.26	-	1.17	-
Unidentified	22.81	36.28	25.30	52.02

Remark: (-) = not detected

Conclusions

Fast pyrolysis of eucalyptus wood characterized with low content of ash and high percentages of hollocellulose and α-cellulose produced much high relative peaks of levoglucosan followed by furfural and also small relative peaks of lignin derived products. Meanwhile high content of vollatile matter and high crystallinity of cellulose attributed balsa and jabon woods in fast pyrolysis. The catalytic processes in fast pyrolysis of eucalyptus and balsa wood released the aromatics peaks including benzene, toluene, styrene, p-xylene, o-xylene, indane, indene, and naphthalene, following the decreasing the relative peaks of oxygenated compounds such as furfural, guaiacol, 4-vinylguaiacol, syringol, levoglucosan, vinylsyringol and acetosyringon. The catalytic process in fast pyrolysis of eucalyptus decomposed the most of oxygenated compound such as levoglucosan and furfural into aromatics in the presence of ZSM-5. In contrary, coke formation on the surface catalyst might cause partly of decomposition of levoglucosan and furfural to form aromatics in the catalytic fast pyrolysis of balsa wood. Cellulose component was determined on the formation of benzene, toluene, styrene, p-xylene, indane, indene, and naphthalene in catalytic fast pyrolysis of wood.

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