THERMAL EVOLUTION PROFILE ANALYSIS FOR PYROLYSIS OF COAL – ACACIA MANGIUM WOOD BLENDS

By Barlin Oemar

THERMAL EVOLUTION PROFILE ANALYSIS FOR PYROLYSIS OF COAL – *ACACIA MANGIUM* WOOD BLENDS

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ABSTRACT

Due to critical environmental issues, increasing future energy supplies and decreasing reserved energy resources are currently the subject of comprehensive research. The use of biomass as a renewable energy resource may be helpful in solving current energy shortfalls, particularly for countries that have abundant biomass resources. In this study, pyrolysis of coal, *Acacia Mangium* wood, and their respective blend samples were investigated using proximate analysis and Thermogravimetric (TG–DTG). A mixture of coal and *A. Mangium* wood with a weight ratio 100:0, 90:10, 50:50, 10:90, and 0:100, were used and non-isothermal conditions at a constant heating rate of 5, 15, and 30°C/min were applied. Thermal evolution profile analysis of the pyrolysis process confirms that the reactivity of the fuel increased with the increasing proportion of the biomass in the fuel. The reactivity and maximum temperatures increased with the increasing heating rates. Proximate analysis showed the potential of biomass of *A. Mangium* wood to be used as a mixture with coal in terms of low ash and high volatile matter content.

Keywords: Acacia Mangium; Biomass; Coal; Pyrolysis; Thermogravimetric

1. INTRODUCTION

Undesirable environmental influences due to growing fossil fuels consumption are driving some researchers to explore innovative methods to develop these energy resources. One of the advantages of coal as a fuel compared to other fossil fuels, such as gasoline, kerosene, and diesel, is its widespread availability and low cost. Potential resources of coal as a source of fossil fuel in Indonesia is abundant. The National Geological Agency estimates that Indonesia still has 21 billion tons of coal reserves that have yet to be explored, and approximately 86.4% is classified as low energy (<6100 kcal/kg gad basis). These reserves are mostly located in East Kalimantan and South Sumatra provinces (Stanford, 2013). However, the drawback of coal combustion is its undesirable influences on the environment by releasing waste products such as NO_2, SO_2, and particles during its combustion process. In addition, a high percentage of metal such as arsenic and mercury that can be harmful to humans can sometimes be found in coal. Co-firing of coal and biomass is an advanced method for reducing coal combustion to decrease the NO_2 and SO_2 emissions, where biomass becomes a clean, sustainable, and abundant energy resource.

Biomass is the term used to cover any organic material derived from plants that are available on a renewable basis. *Acacia Mangium* biomass is a prospective energy resource material that is most encouraging, which comes from evergreen and rapidly growing tree species native to

tropical rainforests in Indonesia, Papua New Guinea and Australia. It is also the most appropriate tree species planted in marginal sites (Arisman, 2002). *A. Mangium* is one of the most important tree species cultivated in the development of forest plantations in Indonesia. It has been reported that approximately 67% of total world *A. Mangium* plants are grown in Indonesia (FAO, 2002). South Sumatera province has an extensive tropical rainforest with a variety of plantations that are prospective biomass resources, including *A. Mangium* biomass (Lukman & Sipahutar, 2015). *A. Mangium* biomass proportion components are approximately 55-80% (stems), 10-22% (branch), 7-10% (bark), and 2-9% (leaves).

Pyrolysis or devolatilization could play a significant role in the first step of producing energy from coal or biomass. It involves a number of complex decomposition processes of material chemical composition that occurs without existence of oxygen. Research on pyrolysis of coal/biomass blends is a relatively new field; however, some researchers have conducted coal and biomass blends with pyrolysis behavior (Biagini et al., 2002; Yanfen & Xiaoqian, 2010). Coal/biomass blends of Turkish lignite from the Elbistan region and hazelnut shell showed a significant synergy in terms of devolatilization yield at temperatures of between 400 and 600 K; however, they lack activation energy synergy (Haykiri-Acma & Yaman, 2007). Likewise, pyrolysis using thermogravimetric analysis (TGA) behavior of palm oil biomass (kernel shell, empty fruit bunches, and mesocarp fiber), Malaysian sub-bituminous coal (Mukah Balingian), and their respective blends have also been revealed (Idris et al., 2010). These findings show that there is no significant interaction between the coal and palm biomass. This can be seen from the linear relation of thermal evolution profile (TEP) with a percentage of biomass added. In another work, derivative thermogravimetric curves pyrolysis of blends of West Virginia coal and biomass (i.e. cherry pit) show two distinct peaks corresponding to temperature evolution profiles of both coal and cherry pits. This suggests that the blending of the cherry pit biomass could stimulate devolatilization of the coal at lower temperatures (Yangali et al., 2014).

The purpose of this paper was to analyze the Thermal Evolution Profile (TEP) that occurs during pyrolysis of coal, *A. Mangium* wood and their respective blends. The effect of varying heating rates on TEP and weight loss will be reported.

2. METHODOLOGY

The coal used in this study was low-rank coal from Tanjung Enim, South Sumatra province, Indonesia, and *A. Mangium* wood obtained from a plantation in Inderalaya. As shown on the schematic of methodology in Figure 1, after two days drying under an air-conditioner, the material was separately crushed and sieved to a size below 200 µm. Particle sizes greater than 200 µm are not desirable because they affect mass transfer in pyrolysis due to the temperature gradient in the particle. A higher heating and larger pyrolysis rate during the pyrolysis process effects smaller particles (Wang et al., 2015). Coal and *A. Mangium* wood with a weight ratio of 100:0, 90:10, 50:50, 10:90, and 0:100 were mixed. The mixture of biomass was oven dried at 110°C. Furthermore, the samples were pyrolyzed using a Simultaneous Thermogravimetric Analyzer STA7000 Hitachi. Briefly, each of the samples with different compositions was loaded into alumina crucible and the pyrolysis studies were carried out under pure nitrogen so as to purge gas with flow of approximately 150 ml/min. The samples were heated from room temperature to 900°C under non-isothermal conditions at a constant heating rate of 5, 15 and 30°C/min. Proximate analysis was conducted based on ASTM standards as listed in Table 1.
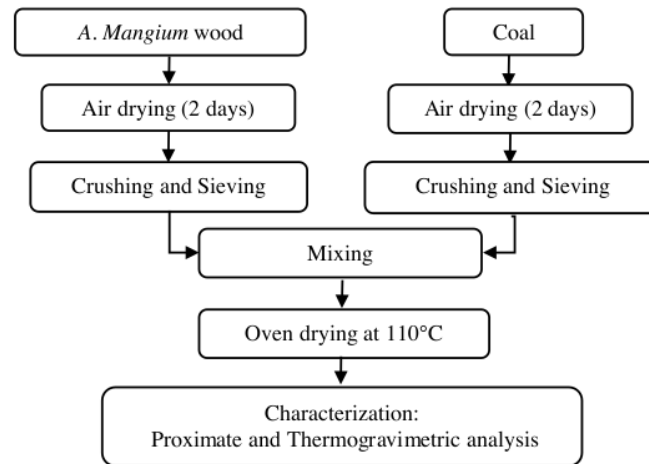
Figure 1 Schematic of methodology

Table 1 Proximate analysis standards

Component	Coal from Tanjung Enim	A. Mangium Wood
Moisture	ASTM D 4442-07 (2007)	ASTM D3173 – 11
Ash	ASTM D 1102-84 (2007)	ASTM D3174 – 11
Volatiles	ASTM D 3175-07 (2007)	ASTM D3175 – 11
Fixed Carbon	ASTM D3172 – 07a (2007)	

Table 2 Proximate analysis of pure fuel

	Coal from Tanjung Enim % adb	A. Mangium Wood % adb
Moisture	18.70	3.87
Ash	5.29	1.02
Volatile Matter	51.78	80.32
Fixed Carbon	42.93	18.66

3. RESULTS AND DISCUSSION

Table 2 shows the results of proximate analysis of the coal and A. Mangium wood sample. Coal comprises higher ash than biomass, but the ash from both samples have much different constituents. Coal is usually considered the main fuel of the combustion system of boilers. Ash of biomass generates major difficulties due to very high levels of alkali metal components, which makes the biomass highly reactive. The combustion process causes slagging, fouling, and corrosion problems when alkali metal components react with sulfur and chlorine. Due to these possible difficulties, some boilers limit the maximum concentration of ash in a biomass. The ash content in A. Mangium wood is relatively lower than other biomass such as palm oil derived biomass (Idris et al., 2010), sea weed, and rice straw biomass (Rizkiana et al., 2014). Biomass also shows a high content of volatile matter compared to coal. This indicates that biomass improved the burnout of the fuel since highly volatile matter may decrease the ignition

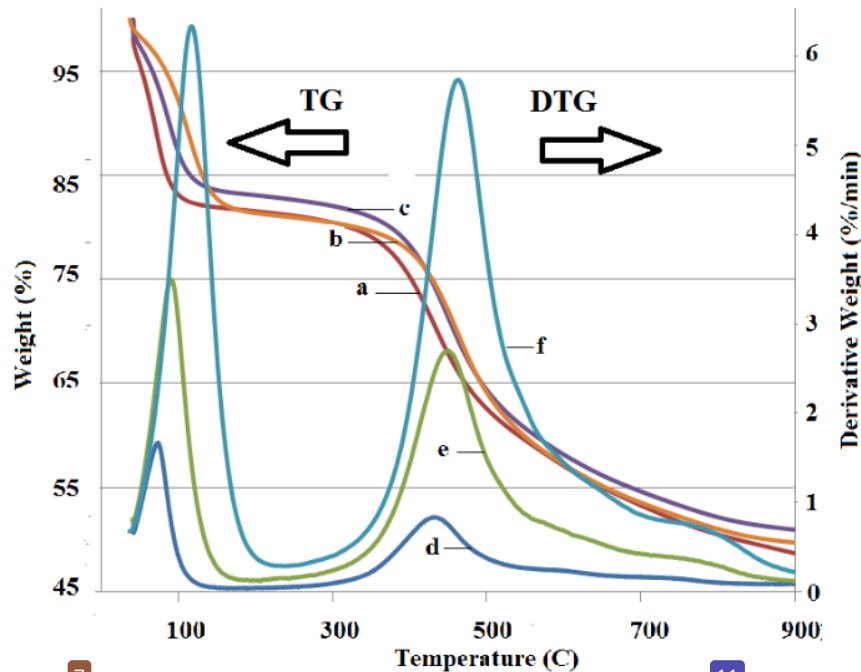temperature of the fuel. However, high volatile matter can also decrease heating value.

Figure 2 TG curves of coal at heating rate of: (a) 5; (b) 15; and (c) 30°C/min. DTG curves of coal at heating rate of: (d) 5; € 15; and (f) 30°C/min

Generally, coal combustion has two processes: the first is pyrolysis due to thermal stress, and the second is heterogeneous burning of the residual char. Figure 2 depicts TG and DTG curves of pure coal (100:0 sample) pyrolysis at various heating rates. The DTG curves show three zones of thermal degradations, which represent moisture evaporation, and the first and second step of pyrolysis. For low heating rate of 5°C/min, removal of moisture usually occurs below 184°C. The first decomposition or the first step of pyrolysis can be seen from a wide temperature distribution between 184°C and 874°C of thermal evolution profile that represents the release of volatile matter. The second decomposition, or the second step of pyrolysis, can be observed by low decomposition rate and char formation. Total mass loss rate depends on temperature, the larger mass loss occurred in the higher temperature due to the slow pyrolysis process at low temperature.

It can also be seen from Figure 2 that the increase of the heating rate does not change the amount of TEP peak; however, the faster the heating rate, the more reactive the pyrolysis process that occurs. However, as the heating rate increases, the maximum temperature of the first zone pyrolysis of the coal shifted to the upper temperature. This may be due to the higher heating rate, as the faster decomposition rate occurred in a short space of time. This process then leads to a higher temperature since at the higher heating rate, the heat transfer is not effective and efficient as the heating rate is lower. At the level of lower heating rate, heating fuel particles may occur more gradually leading to better heat transfer, it is more effective for the inside and outside of the particles. In other words, when a low heating rate is applied, less heat is required to break down the particles of solid fuels into products.
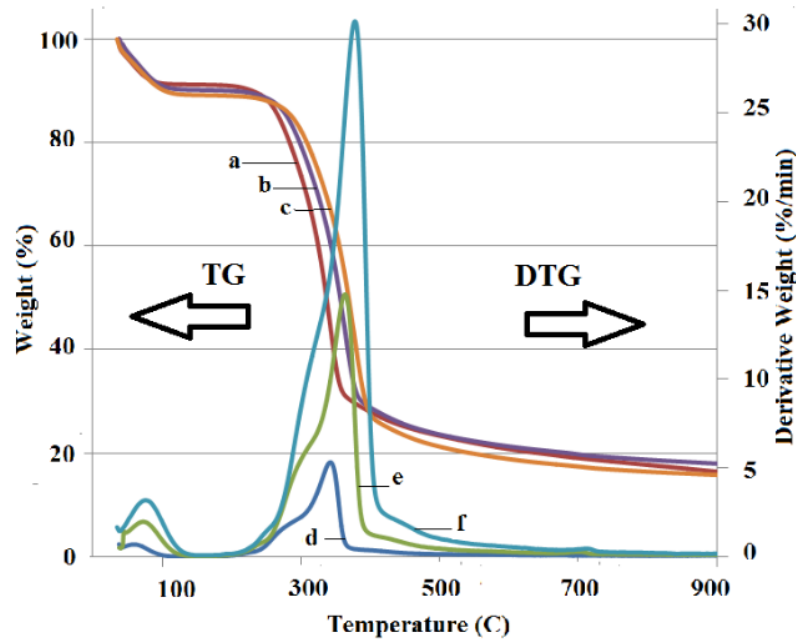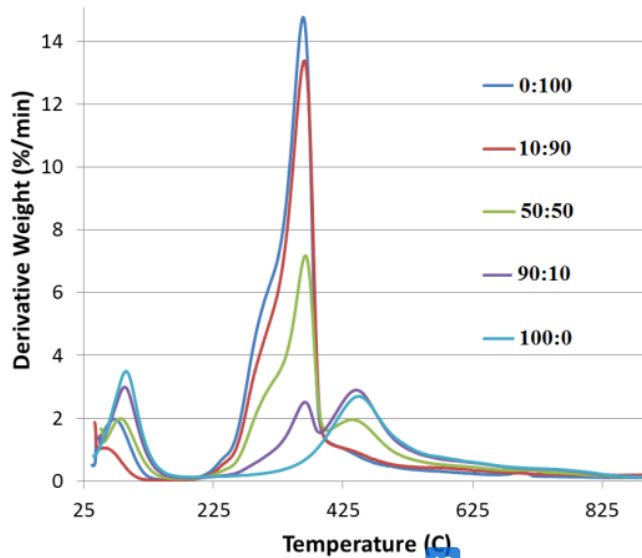
Figure 3 TG curves of *A. Mangium* wood at heating rate of: a. 5; b. 15; and c. 30°C/min. DTG curves of *A. Mangium* wood at heating rates of: d. 5; e. 15; and f. 30°C/min.

TG and DTG curves of *A. Mangium* wood (0:100 sample) pyrolysis at various heating rates can be seen at Figure 3. In general, in terms of the effect of the heating rate increase to number peak of TEP and total mass loss, a trend of TG and DTG curves that take place in coal also can be seen in biomass. Similar to the coal TGA curve, three zones are also exhibited in the TGA curve of biomass where the first zone attributed to remove moisture content. However, in the first decomposition zone (first step of the pyrolysis), the peak TEP occurs at a lower temperature than the peak of coal. For a low heating rate of 5°C/min, the temperature of the first pyrolysis step occurs between 284°C and 394°C, where at this the temperature range that decomposition cellulose and hemicellulose of wood occurred. The Second pyrolysis step is attributed to the decomposition of lignin content.

The DTG curve of biomass displays a wide-ranging profile with a shoulder; this typical trend is often found on various biomass solids. TEP of DTG is in accordance with the constant slope of the TG curve. Peak height of the TEP of DTG also characterize the reactivity of the sample, the peak height of which is directly related to the reactivity. Figures 2 and 3 also depict at the same heating rate, reactivity of biomass is greater than coal, and the temperature of TEP maximum biomass is lower than the TEP maximum coal. This indicates that the biomass is more reactive than coal, and the biomass temperature reactivity occurs at temperatures much lower than coal. This result agrees with the results shown from proximate analysis, where the content of biomass volatile matter is greater than coal due to the fact that the presence of high volatile matter on the biomass can increases the burn-out of the biomass.

Figure 4 DTG curves of coal, *A. Mangium* wood and it blends at a heating rate of 15°C/min

Figure 4 shows the DTG curves of coal and *A. Mangium* wood as they blend at a heating rate of 15°C/min. Similar to pure fuel, blended fuel also consists of three zones: moisture evaporation, and the first and second step of pyrolysis. The first step of pyrolysis between 184°C and 874°C can be seen as a single peak for each pure fuel; however, fuel blends such as 10:90 and 50:50 show two distinct peaks (except for 1:90 fuel, which only shows one primary peak). Likewise, a broader TEP in blended fuel could be connected to the decomposition process of hemicellulose, cellulose and lignin content of biomass. It was found that the reactivity of the fuel increased with the increasing proportion of the *A. Mangium* wood in the fuel. This result is in good agreement with previous reported research (Tchapda & Pisupati, 2014).

Table 3 Reactivity and peak temperatures of maximum fuel achieved during the pyrolysis at various heating rates

Fuel	Heating rate (°C/min)	Reactivity		Temperature Evolution Profile T_{max} (°C)	
		Peak 1	Peak 2	T_{max} 1	T_{max} 2
100:0	5		0.82		431.62
	15		2.70		434.45
	30		5.63		445.76
90:10	5	1.48	0.82	345.63	432.12
	15	2.37	2.88	359.14	441.08
	30	4.58	4.65	376.54	454.87
50:50	5	2.41	1.06	346.67	430.14
	15	6.92	2.94	362.17	433.77
	30	9.18	5.17	378.72	445.43
10:90	5	4.84		341.49	
	15	12.7		359.03	
	30	24.4		376.64	
0:100	5	5.30		340.63	
	15	14.32		359.81	
	30	29.49		373.63	

The detail of both reactivity and maximum peak temperatures achieved during the pyrolysis of fuel at various heating rates is presented in Table 3. The effect of single fuel on the reactivity can be seen clearly where biomass is more reactive than coal in all heating rate schema. However the blending fuel shows less reactivity when biomass proportion is reduced because the volatility content in the fuel is also reduced. Evidently, in all fuel blending ratios, the reactivity and maximum temperatures increase with the increasing heating rates. Maximum devolatilization takes place in the maximum temperatures, where it increases with increasing heating rates. This leads to the conclusion that the reactivity of devolatilization, also increased while heating rates are increased. Therefore, heating rates and temperatures play an important role in the pyrolysis process.

4. CONCLUSION

A. Mangium biomass is a potential energy resource that is abundant in South Sumatra, Indonesia; however, studies on pyrolysis of coal and *A. Mangium* biomass blending characteristics are scarce. In this work, the pyrolysis of coal, *A. Mangium* wood, and their respective blend samples were investigated using proximate and Thermogravimetric (TG–DTG) at various heating rates. The following conclusions were derived from the research conducted: (1) Ash content of *A. Mangium* wood is relatively lower compared to coal and other biomass that could reduce the negative effects when used as fuel in boiler systems; (2) Biomass of *A. Mangium* wood also shows a high content of volatile matter compared to coal, which indicates biomass may improve burnout of the fuel; (3) The reactivity of the fuel increased with the increase in the proportion of the *A. Mangium* wood in the fuel. The reactivity and maximum temperatures peak of pyrolysis increases with increasing heating rates.

The information obtained from these results will provide a useful platform for further study.

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