



# THE EFFECT OF BLEND RATIO ON THERMAL BEHAVIOR AND ASH COMPOSITIONS OF COAL/BARK CO-COMBUSTION

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## ABSTRACT

The purpose of this work was to study the effect of blend ratio on thermal behavior and ash compositions of coal/bark co-combustion. The study consists of two experiments, thermal behavior analysis and ash composition analysis by using the non-isothermal thermo gravimetric method (TGA) under combustion conditions and X-ray fluorescence (XRF) respectively. The results of the two experiments can show the interaction between coal and bark at three of blending ratio 30:70, 25:75, and 20:80 by weight. Bark shows a good interaction with coal leading to significant reduction in ignition temperature of coal and this effect was more pronounced with higher blending ratio of bark. In addition, it was found that the ash compositions were depended on the blend ratios.

**Keywords:** co-combustion, kinetics analysis.

## 1. INTRODUCTION

Coal is one of the most important fossil fuels in the world and widely used in industry. As per the report of the International Energy Agency (IEA), world energy demand will increase by 1 to 3 times of current used during 25 years from 2010 to 2035. In addition, the IEA's report also shows that the demand of coal is still increasing. Coal combustion generates CO<sub>2</sub> which causes to global warming and makes the average temperature of the world increase.

To minimize the global warming, using of biomass as a fuel has become very important for the production of clean thermal energy by combustion. This is due to it neutral on the issue of the emission of CO<sub>2</sub>, the most important gas causing global warming, so it does not cause global warming.

Although the biomass has many advantages, it also has disadvantage that cannot be avoided. Combustion of biomass can result in ash deposition and high corrosion (Davidsson *et al.* 2008) that effects to the thermal efficiency, and expensive shutdown of boilers. In general, biomass is composed of high alkali (Potassium, K and Calcium, Ca) and Chlorine (Cl) and low sulphur (S) content compare to coal. Alkali from co-combustion with bark can cause low-melting-temperature ash which results in expensive shutdown of boilers. In this study, behavior of co-combustion and ash analysis between local eucalyptus bark and Indonesian coal at various blend ratios will be investigated. The obtained results will be useful information for bark and coal co-combustion.

## 2. EXPERIMENTAL

### a. Experimental setup

The experiments were carried out for co-combustion of two types of fuels: sub-bituminous from Indonesia and eucalyptus bark from KhonKaen, Thailand. There are five samples: Coal, Bark, C30B70, CB25B75, and C20B80. The sample C30B70, CB25B75, and C20B80 corresponds to the ratio of coal/bark 30:70, 25:75,

and 20:80 by weight respectively. Proximate and ultimate analyses of the fuels are shown in Table-1.

**Table-1.** Proximate and ultimate analysis of the fuels.

	Coal	Eucalyptus bark
Proximate analysis		
Moisture <sup>a</sup>	32.05	63.83
Volatile matter <sup>b</sup> (%)	38.47	66.52
Fixed carbon (%)	57.85	16.57
Ash <sup>b</sup> (%)	3.68	16.91
Ultimate analysis <sup>b</sup> (%)		
C	70.21	36.95
H	5.05	4.69
O	19.87	40.25
N	1.08	0.18
S	0.11	0.10
K		0.57
Na		0.04
Cl		0.31
Calorific value <sup>b</sup> , HHV (MJ/kg)	23,027	13,927

<sup>a</sup>as received basis, <sup>b</sup>dry basis

The materials were prepared for thermal analysis by Thermo gravimetric Analysis (TGA) method and Ash analysis by X-ray fluorescence (XRF).

### b. Thermo gravimetric analysis (TGA)

Similar to several researchers (Cheoreon *et al.* 2013), (Gil *et al.* 2010), (Jillian *et al.* 2013), (Kaihua *et al.* 2013), (Marisamy *et al.* 2010), (Munir *et al.* 2009), TGA was used to investigate the thermal behavior of blending fuels. In this work, the experiments were carried out by the simultaneous thermal analyzer, NETZSH model STA 449F3. The maximum weight loss temperature was estimated as the temperature at which a derivative thermogravity (DTG) curve showed the peak value. Burnout temperature was detected based on the mass



stabilization. All of experiments were carried out at atmospheric pressure at a constant rate of heating up 10°C/min from 30°C to 850°C which were oxidized by oxygen and carried out by placing about 200 mg of dried sample on a platinum pan. The TG and DTG curves are show in Figure-1 and Figure-2, respectively.

### c. Kinetic analysis

In a heterogeneous solid-state reaction, the initial mass of the sample  $w_o$  is decomposed to instantaneous mass  $w_t$  at time  $t$ , hence the rate change can be written as a function of weight conversion ratio as:

$$\alpha = \frac{w_o - w_t}{w_o - w_\infty} \quad (1)$$

Where  $w_\infty$  is the residue mass at the end of process. The reaction rate may be described by Arrhenius equation:

$$\frac{d\alpha}{dt} = k(T)f(\alpha) \quad (2)$$

$k(T)$  is the rate constant, according to the Arrhenius correlation:

$$k(T) = Ae^{-E/RT} \quad (3)$$

Where  $T$  is the reaction temperature,  $A$  is the pre-exponential Arrhenius factor,  $E$  is the activation energy and  $R$  is the gas constant.

$f(\alpha)$  is the function called the reaction model which describes the dependence of the reaction rate on the extent of reaction. It is defined as:

$$f(\alpha) = (1 - \alpha)^n \quad (4)$$

Where  $n$  is the reaction order. Substitution equations (3) and (4) into equation (2):

$$\frac{d\alpha}{dt} = Ae^{-E/RT} (1 - \alpha)^n \quad (5)$$

For non-isothermal TGA heating rate,  $\beta = dT/dt$ . Equation (5) can be written as:

$$\frac{d\alpha}{dT} = \frac{A}{\beta} (1 - \alpha)^n e^{-E/RT} \quad (6)$$

Equation (6) can be rearranged as:

$$\ln \left[ \frac{\frac{d\alpha}{dT}}{(1 - \alpha)^n} \right] = \ln \frac{A}{\beta} - \frac{E}{RT} \quad (7)$$

According to equation (7), a plot of  $\ln [(d\alpha/dT)/(1-\alpha)^n]$  versus  $1/T$  corresponds to a straight line. For the value of  $n$  which gives regression coefficient close to unity,  $A$  and  $E$  can be determined from the intercept and slope of the line respectively, which can show in Figure-3.

## 3. RESULTS AND DISCUSSIONS

Thermo gravimetric analysis (TGA) and

derivative thermo gravimetric analysis (DTG) were used to investigate combustion behavior of the Coal/Bark blends. The TG and DTG results in Figure-1 and Figure-2, respectively. According to the results, Coal and Bark have difference profiles so they will have difference burning performance. The profiles indicate that the process can be divided into three stages: moisture evaporation, decomposition of volatile organic compound and char combustion.

Based on volatile matter to fixed carbon ratio, the bark is expected to be more reactive than the coal. After initial moisture is removed, three characteristic temperatures are investigated for this study: the first initiation temperature where the weight loss first begins to fall, the second is the peak temperature where the weight loss reaches the maximum, and the third is the burn-out temperature where the weight is constant indicating the completion of combustion.

### a) Bark

The first stage of weight loss of bark starts from 36°C to 127 °C which is an initial moisture loss. It corresponds to about 43% of the total weight. The second stage or combustion stage starts from 127°C up to 487°C, at this stage the decomposition and release of volatile starts approximately at 170°C and there are two peaks of weight loss at the temperature of 306°C and 405°C. One is mainly due to volatile combustion and the other is char combustion. The last stage is the stage of the low reactive components reaction or the burn-out stage which corresponds to temperature of 436 °C. This effect can be clearly seen in the DTG profile for bark in Fig. 2. As it has high volatile content, bark can be classified as a high reactive material.

### b) Indonesian coal

The weight loss reduced from 100 to 70 % (wt %) during the initial moisture loss. After that, the weight is quite constant until the temperature of 240°C and then the rate of weight loss starts to increase again due to pre-combustion. In the case of coal, there is only single peak of weight loss in the combustion stage and higher temperature is required for combustion to start as compared to the bark. The volatile release temperature for coal is around 216°C compared to 170°C for bark. This indicates that coal requires a higher temperature to release its volatile matter, which makes it difficult to initiate combustion, and also the activation energy is higher than bark.

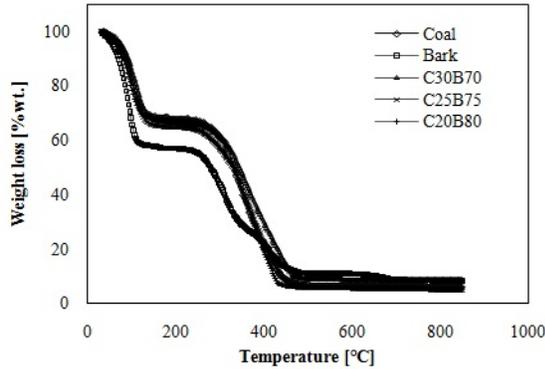


Figure-1. TG curves of coal, bark, C30B70, C25B75, and C20B80.

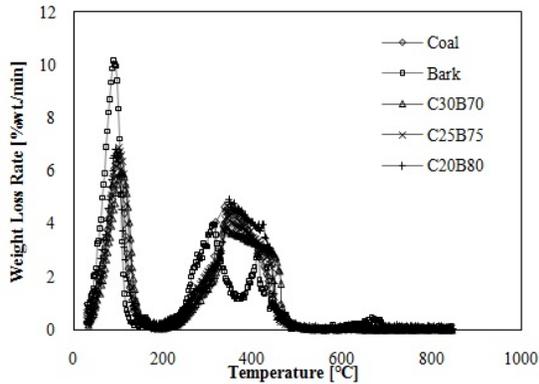


Figure-2. DTG curves of Coal, Bark, C30B70, C25B75, and C20B80.

c) Co-combustion behavior of blend materials

The Coal/Bark blends were prepared in three ratios 30:70 (C30B70), 25:75 (C25B75), and 20:80 (C20B80). The characteristic parameters were given in Table-2 and Table-3. The TG and DTG curves of the blend materials show three regions of weight loss and two peak temperatures same as the coal. The first region is initial moisture loss, the second is volatile combustion, and the last region is burnout.

Table-2. Thermal characteristic parameters of the samples.

Sample	$T_i(^{\circ}\text{C})$	$T_b(^{\circ}\text{C})$	$T_{max}(^{\circ}\text{C})$	$R_{max}(\%wt./min)$
Coal	315.5	381.3	321.4	7.3
C30B70	306.5	448.6	334.1	4.0
C25B75	284.1	433.7	338.9	5.5
C20B80	279.2	440.1	344.2	4.6
Bark	262.4	436.3	316.4/410.9	4.0/2.8

The mainly difference of blend materials compare to coal is the temperature corresponding to maximum rate of weight loss ( $T_{max}$ ) and the ignition temperature ( $T_i$ ). Impact of the high volatile contents in the bark can reduce

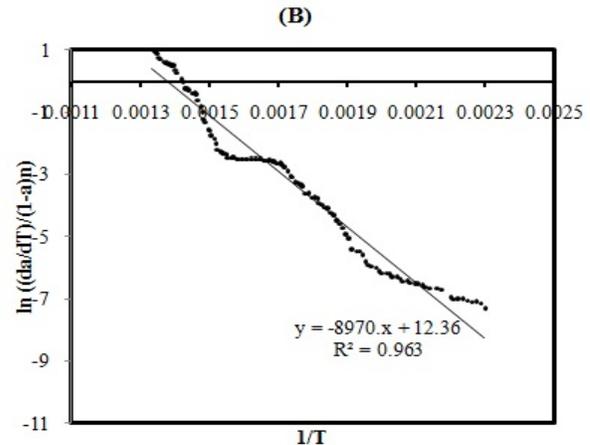
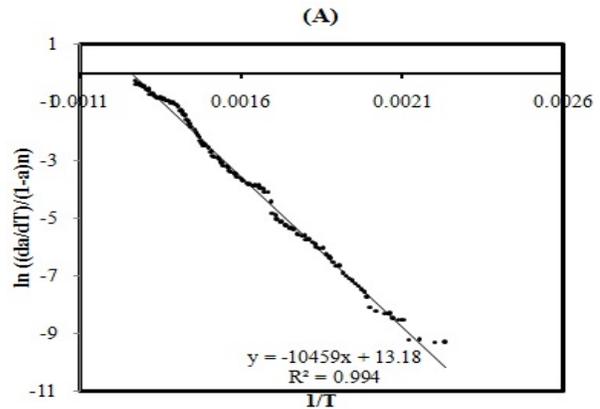
the ignition temperature and the activation energy, but the bark did not show a reduction in the burn out temperature.

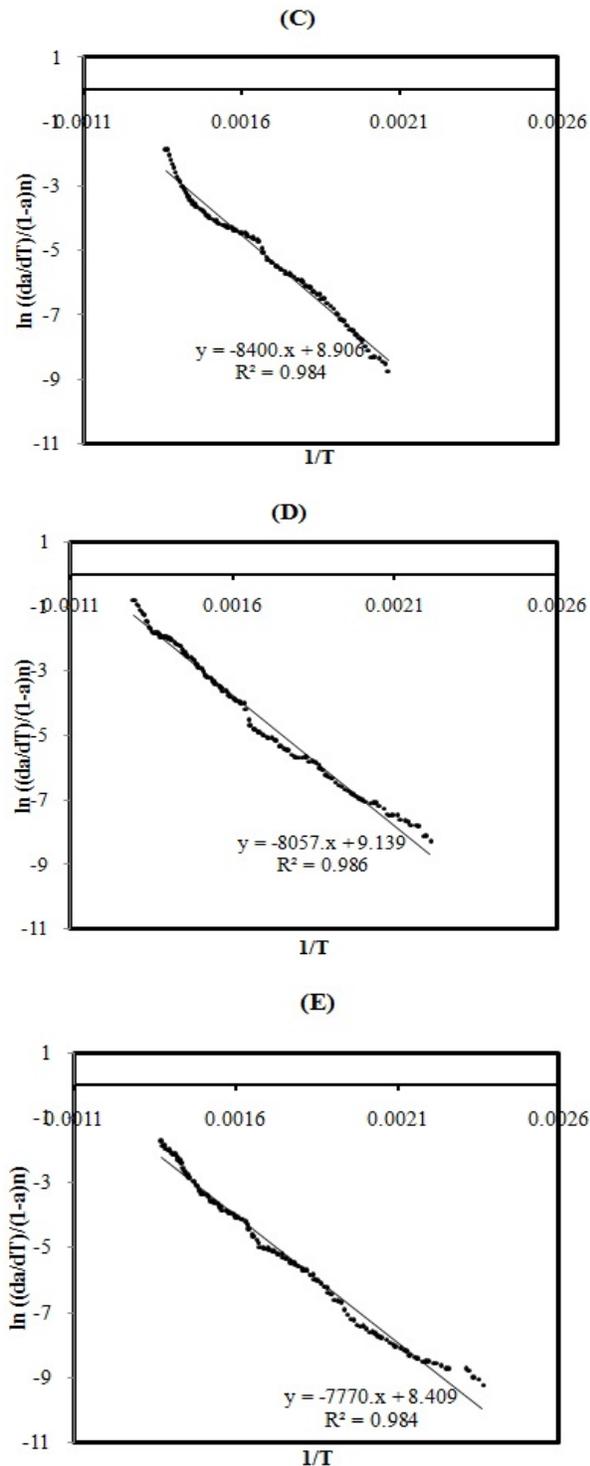
Table-3. Thermal kinetic results of the samples.

Sample	E (kJ/mol)	n	A ( $s^{-1}$ )	$R^2$
Coal	87.58	1.70	6,074,728	0.9948
C30B70	69.84	1.20	73,826	0.9847
C25B75	65.95	1.80	73,781	0.9861
C20B80	64.61	1.42	44,887	0.9843
Bark	59.36	2.60	57,940	0.9635

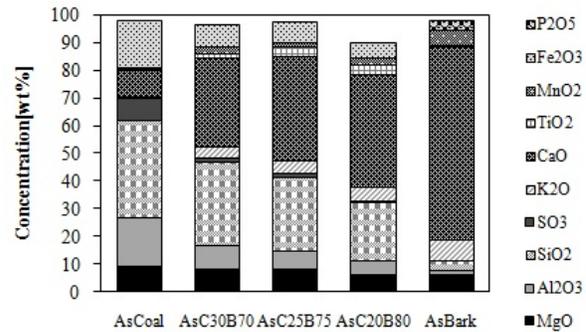
d) Ash analysis

Although the results from TGA can show that the bark can improve devolatilization of coal and also the activation energy was reduced when the ratio of bark increases. Another important thing except thermal behavior is the ash composition of blending. The combustion of biomass (for this study is bark) may cause operational problems such as agglomeration of the bed material and deposits on super heater tubes (Davidsson *et al.* 2008). The result from XRF is necessary to know the ash composition of any blends to avoid the problems as mentioned.





**Figure-3.** Curves of fitting of kinetic model for: (A) Coal, (B) Bark, (C) C30B70, (D) C25B75, and (E) C20B80.



**Figure-4.** Ash composition of coal (AsCoal), bark (AsBark), C30B70 (C30B70), C25B75 (AsC25B75), and C20B80 (AsC20B80).

After complete combustion process from TGA analysis, ashes of all samples were investigated by Energy Dispersive X-ray Fluorescence analyzer which is illustrated in Figure-4. The element of ash composition is expressed in oxide form. The coal in this study consists of high silica content in the form of quartz ( $\text{SiO}_2$ ) compare to the bark, this element can result in low-melting-temperature ash when reacts with alkali from bark. Furthermore, the bark contents of high Ca (in the presence of CaO). Higher ratio of the bark can cause low-melting-calcium-based silicates results in bed agglomeration in CFB boilers (Elisabet *et al.* 2005).

Ca and K concentration in ash increased with an increasing of the bark ratio. This may result in low-melting-temperature ash as mentioned. On the other hand, low-melting-temperature ash can also form with silica from coal. In order to avoid the problem from interaction between alkali (Ca and K) from the bark and silica from the coal, some countermeasures should be concerned such as minimize the bark ratio, change the type of coal (low silica content) or type of biomass before co-combustion.

#### 4. CONCLUSIONS

As the result of TGA and kinetic analysis, the bark blending improves the devolatilization and ignition characteristics of the coal due to the high volatile contents in the bark. The ignition temperature and the activation energy of coal were reduced as the percent of the bark ratio increases. Although the coal/bark blend enhances the combustion rate of the coal, they did not show a reduction in the burn out temperature, this is the effect from char combustion of bark.

The results from XRF can show the ash composition of individual fuels (coal and bark) and their blends. The co-combustion of the coal/bark may cause low melting temperature ash and results in expensive shutdown of boilers.

Moreover, the results of this study can be applied for another fuels to know the interaction between two (or more than two) species of fuels which is the future works of this study, and it will be useful for large scale or commercial scale boilers to avoid expensive shutdown.

**REFERENCES**

- [1] Cheoreon M., Yonmo S., Seongyool A., Taekyung K., Gyungmin C. and Duckjool K. 2013. Effect of blending ratio on combustion performance in blends of biomass and coals of different ranks. *Experimental Thermal and Fluid Science*, Vol. 47, pp.232--240.
- [2] Davidssona K.O., Amanda L.-E., Steenarib B.-M., Elleda A.-L., Eskilssonc D. and Lecknera B. 2008. Countermeasures against alkali-related problems during combustion of biomass in a circulating fluidized bed boiler. *Chemical Engineering Science* Vol. 63, pp. 5314-5329.
- [3] Elisabet B., Marcus H. and Anders N. 2005. Mechanisms of Bed Agglomeration during Fluidized-Bed Combustion of Biomass Fuels. *Energy & Fuels* Vol. 19, pp. 825-832.
- [4] Gil M.V., Casal D., Pevida C., Pis J.J. and Rubiera F. 2010. Thermal behaviour and kinetics of coal/biomass blends during co-combustion. *Bioresource Technology* Vol. 101, pp.5601-5608.
- [5] Jillian L. G. and Chao L. 2013. Impact of blend ratio on the co-firing of a commercial torrefied biomass and coal via analysis of oxidation kinetics. *Bioresource Technology*, Vol. 149, pp.208-215.
- [6] Kaihua Z., Kai Z., Yan C. and Wei-ping P. 2013. Co-combustion characteristics and blending optimization of tobacco stem and high-sulfur bituminous coal based on thermogravimetric and mass spectrometry analysis. *Bioresource Technology*, Vol. 131, pp.325-332.
- [7] Marisamy M., Tomoaki N. and Kunio Y. 2010. A comparison of co-combustion characteristics of coal with wood and hydrothermally treated municipal solid waste. *Bioresource Technology*, Vol. 101, pp. 2477-2482.
- [8] Munir S., Daood S.S., Nimmo W., Cunliffe A.M. and Gibbs B.M. 2009. Thermal analysis and devolatilization kinetics of cotton stalk, sugar cane bagasse and shea meal under nitrogen and air atmospheres. *Bioresource Technology*, Vol. 100, pp.1413-1418.