Combustion characteristics during cofiring of palm empty fruit bunch, palm frond with bituminous coal

Hariana[1*], Arif Darmawan[1], Hanafi Prida Putra[1], Fairuz Milky Kuswa[1], M. Sholeh[2], Muhammad Aziz[3]

1. The National Research and Innovation Agency (BRIN), Indonesia

2. Group of Research, Innovation & Knowledge Management, PT Indonesia Power.

3. Institute of Industrial Science, The University of Tokyo, Japan

ABSTRACT

Low-rank and medium-rank coal currently dominate Indonesian coal. Unfortunately, while Indonesia produces coal, the country's coal reserves are relatively limited. On the other hand, the use of biomass presents numerous challenges and has low thermal efficiency. Cofiring biomass and coal is thought to be an excellent solution to these issues while also extending the life of power plants. This research aimed to determine the characteristics of coal cofiring with empty fruit bunches and fronds. Coal and biomass fuels were, respectively, mixed with various blend ratios. The LINSEIS thermal analysis equipment is used to investigate combustion characteristics. The test was performed under an inert air atmosphere within atmospheric pressure. Each sample weighed about 5-10 mg, and the temperature was increased to 800℃ with a heating rate of 10℃/min. Some combustion parameters are obtained from thermogravimetry analysis (TGA) and differential scanning calorimetry (DSC) analysis. Results show coal cofiring 75% with 25% biomass (EFB and frond mixture) has the best combustion performance indicated by R_{max} and T_{max} values compared to other coal-biomass mixture combinations. Further investigation will focus on the kinetic aspect of the combustion process, including the impact of cofiring on the tendency to slagging and fouling.

Keywords: cofiring, biomass, empty fruit bunch, TGA-DSC, thermal analysis.

1. INTRODUCTION

Indonesia has the advantage of being a tropical country with many energy variations, such as biomass as an alternative fuel blending in the future [1]. Various types of biomass can be used, ranging from agriculture, forestry, and plantations [2]. In everyday use, these technologies can be used together to complement each other in a single process so that the final product with higher efficiency is produced, as happened in the solid biomass process [3][4].

A possible approach to increasing and accelerating the use of biomass energy is to mix biomass with coal and burn it in power plants designed for coal fuel. In Indonesia, different types of biomass are available for cofiring. One of the readily available sources is palm oil, which is abundant due to Indonesia's annual production of 42 million tons of crude palm oil. It is also estimated that the potential for empty fruit bunches (EFB) is around 42 million tons per year. Indonesia produces the largest palm oil globally, particularly because of the massive expansion of palm plantations and significant global demand [5]. The processing of CPO involved many procedures, which resulted in the production of multiple palm mill wastes [6]. Many methods and researches have been conducted to provide a technical and economical solution to this ever-growing problem, especially for energy uses, such as co-combustion with fossil fuels [7] and thermal treatments.

This study aimed to obtain the characteristics of coal cofiring with empty fruit bunch and the frond, including EFB dan frond mixtures. Understanding co-combustion behavior, including the amount of activation energy

needed for the thermal decomposition process, is required before performing coal-biomass cofiring. TGA-DSC is one of the current analytical methods with relatively easy operation by providing an overview of mass and thermal changes simultaneously during heating. Mass and thermal changes from early ignition to burning out can be studied using the TGA-DSC tool. The resulting data can provide an overview of the stage of spontaneous combustion of coal and forecast the time of occurrence. The data from the TGA–DSC can further be used for the boiler design process. Several researchers have reported cofiring coal & EFB using TGA. Unfortunately, cofiring coal with palm frond and cofiring coal and mixed biomass of EFB and frond in various compositions have never been investigated.

2. EXPERIMENTAL METHODS

2.1 Samples preparation

The coal sample is low-rank coal from South Kalimantan classified as bituminous coal, collected following ASTM coal sampling and then prepared to pass 60 mesh sieves and tested in laboratory according to ASTM standards of coal to obtain the characteristics of coal.

Table 1. Result of characteristics sample analysis

PARAMETER		COAL	EFB	FRONDS
Moisture, %	ar	43.42	4.94	10.04
Moisture, %	adb	11.78	4.81	5.81
Ash content, %	adb	6.78	3.20	2.09
Volatile matter, %	adb	43.28	74.57	77.81
Fixed carbon, %	adb	38.16	17.42	14.29
Total sulphur, %	adb	0.19	0.08	0.10
GCV, kcal/kg	adb	5476	4174	4126
GCV, kcal/kg	ar	3664	4168	3941
GCV, kcal/kg	db	6207	4385	4381
Ultimate				
Carbon	adb	59.48	45.36	44.37
Hydrogen	adb	4.08	5.59	5.51
Nitrogen	adb	0.75	0.62	0.46
Oxygen	adb	28.72	40.34	41.66

Figure 1 shows the material used for the experimental investigation involving bituminous coal, frond, and EFB. For TG-DSC analysis and blending for cofiring fuel, the coal is prepared to pass 200 mesh sieves.
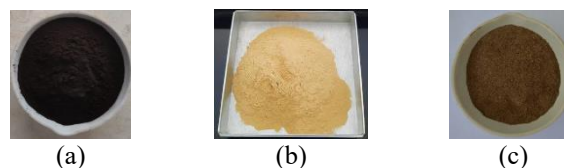

(a)   (b)   (c)
Fig. 1. The material used for combustion analyses including (a) coal, (b) frond, and (c) EFB

EFB and palm fronds samples are collected from the Laboratory of Fuels and Engineering Design, Serpong, dried, and prepared to pass 60 mesh sieves for testing in the laboratory according to ASTM standards of coal and blending for cofiring fuel.

2.2 Laboratory testing equipment

The LINSEIS thermal analysis equipment is used for combustion characteristics, as shown in figure 2. The test was performed under an inert air atmosphere within atmospheric pressure. Each sample weighed about 5-10 mg, and the temperature was increased to 800°C with a heating rate of 10°C/min. Some combustion parameters are obtained from thermogravimetry (TG) and differential scanning calorimetry (DSC) analysis.

First, the furnace is opened, the sample is weighed and put into a crucible, then the furnace is closed. Set the temperature program with the following conditions; Rate: 10°C/min, Temperature: 900°C, Dwell time: 2 min.

Fig. 2. TGA-DSC employed for the analyses

The condition was held for 2 minutes at a temperature of 800°C. After cooling with a flow rate of 10°C/min to a temperature of 50°C, the equipment was turned off. Various parameters of the TGA-DSC profile can be obtained, such as Tig (°C) or initial ignition, Tmax (°C), maximum peak temperature (DSC), Tbo (°C), final combustion temperature at which the heat flow rate is

zero (dDSC), Rmax(mg s^{-1}), maximum weight loss rate over time (dDTG) T$_{max}$, Onset /offset point (time of start and end of the oxidation reaction between carbon and oxygen).

3. RESULT AND DISCUSSION

The combustion characteristics were investigated at the atmospheric condition. The thermal treatment usually causes the sample to degrade in three phases: drying, char formation, and char burning. In phase 1 (< 200°C), some water will be released; decomposition in step 1 is not significant. Phase 2 is the active pyrolysis zone. In contrast, the third phase is the burning of char produced from the pyrolysis process. The mechanism of initial combustion of samples under atmospheric conditions is classified into three types, namely; a) homogeneous ignition, combustion of volatile matter released from the sample, b) heterogeneous ignition, combustion of the sample particle surface, and c) hetero-homogeneous ignition, which is the result of simultaneous combustion of the sample particle surface.

The TGA curve shows the mass loss (weight loss) in two stages, namely dehydration, and combustion. From Table 2, the initial temperature of samples starts to burn (T$_{ig}$) in the range of 229.7°C. Tig also shows the starting point for volatile matter devolatilization to phase 2, namely the active pyrolysis process. This loss of mass takes place slowly, resulting in further combustion, and then an active pyrolysis reaction of the sample begins to occur until it reaches the maximum temperature (T_{max}). Higher Tig lower volatile matter, the higher volatile matter easier to burn [8][9]. Interval temperature ($T_{bo} - T_{ig}$) reflect the length of time burn out [10]. R_{max} higher easier to burn because of high calorific value and less moisture [11].

T_{max} is related to combustion reactivity, defined as the reactivity of fuel to oxidation at low temperatures, which causes self-burning. The lower the T_{max} value, the higher the material's reactivity so that the tendency for self-burning is also higher. Combustion characteristics for pure biomass for EFB and Frond have almost the same T_{ig} values, which are 236.0 and 229.7°C, respectively, and the lowest T_{ig}, while for coal, it is 282.8 (highest T_{ig}). T_{max} for coal, EFB and Frond, respectively, are 334.0°C, 290.0°C, and 331.0°C. As for the burnout temperature, the T_{bo} value is 490.0°C, 518°C, and 530.0°C, respectively. So, it can be seen here that the frond has the farthest temperature range from initial burning to exhaustion, followed by EFB and coal.

The duration of the combustion process is expressed by $(T_{bo} - T_{ig})$; the largest is coal + 25% frond, coal + biomass 25% (80% EFB and 20% frond), and coal + biomass 25% (60% EFB and 40% frond). The lowest is coal + biomass 25% (20% EFB and 80% frond). These results can be considered for boiler sizing. The lowest R_{max} occurred in a mixture of 80% coal and 20% frond, while the highest Rmax occurred with 75% coal with biomass consisting of 60% EFB and 40% Frond. A high value here indicates that the second cofiring has a slow combustion rate.

From Figure 3, EFB 100% has the lowest Tig while coal has highest Tig. Naturally, composition blended of coal and EFB have value between TGA curve of coal and EFB. But in this study, composition of EFB 15% and 25% outside of the curve caused by high Tmax. From Figure 4, mixture of coal 75% and frond 25% has distinct curve compared to the other mixture between coal and frond. It caused by the high Tmax and high Tbo. While Figure 5 showed similarity curve of blended coal and mixture of biomass that consist of EFB and frond.

Coal cofiring 85% with EFB 15% had the highest tendency to self-combustion, while coal blending 75%, Biomass 25% (EFB 60 : Frond 40) had the lowest, indicated by the T_{max} value. Blending coal 75% and Biomass 25% also has the highest R_{max} of 0.0990 mg/s. High R_{max} indicates the material is easy to burn, or in other words, its combustion efficiency is high. For other examples of coal blending coal and biomass, on the other hand, results in a lower tendency to burn (lowering combustion efficiency).

4. CONCLUSION AND FUTURE WORKS

This paper investigates coal cofiring with biomass waste from palm oil combustion behavior using thermogravimetric and differential scanning calorimetry analysis, providing useful information before being implemented into a real plant. The test was performed under an inert air atmosphere within atmospheric pressure. Each sample weighed about 5-10 mg, and the temperature was increased to 800°C with a heating rate of 10°C /min. Some combustion parameters are obtained from thermogravimetry analysis (TGA) and differential scanning calorimetry (DSC) analysis. Results show coal cofiring 75% with 25% biomass (EFB and frond mixture) has the best combustion performance indicated by R_{max} and T_{max} values compared to other coal-biomass mixture combinations. Because low-rank coal used in this study has high moisture, adding biomass to 25% does not affect combustion characteristics

drastically. However, for high-grade coal, further investigation is required.

- In general, the characteristics of EFB and frond have the same calorific value, including ultimate and approximate analysis
- The combustion characteristics of these two biomasses are also almost the same.
- Data in Table 2 can be used to select the most desired combustion composition
- Further research will be focused on the kinetic aspect of the combustion process by testing it with different rates of temperature increase. The second study investigates the variation of biomass composition in cofiring with a composition of 5%, 10%, 15%, and 20% of the mixture (EFB and frond). To fully characterize the process effectively, the impact of cofiring on the tendency to slagging and fouling the boiler heating surfaces must be determined.

Although TGA studies cannot fully predict the burning characteristics in utility operations, they can provide useful inputs for design and operation issues and the selection of an appropriate mixture combination. Such studies also provide sufficient support for the careful selection of mixture-proportion for a specific blend combination. As a result, the findings can promote biomass from palm oil wastes as a carbon-neutral for power generation.
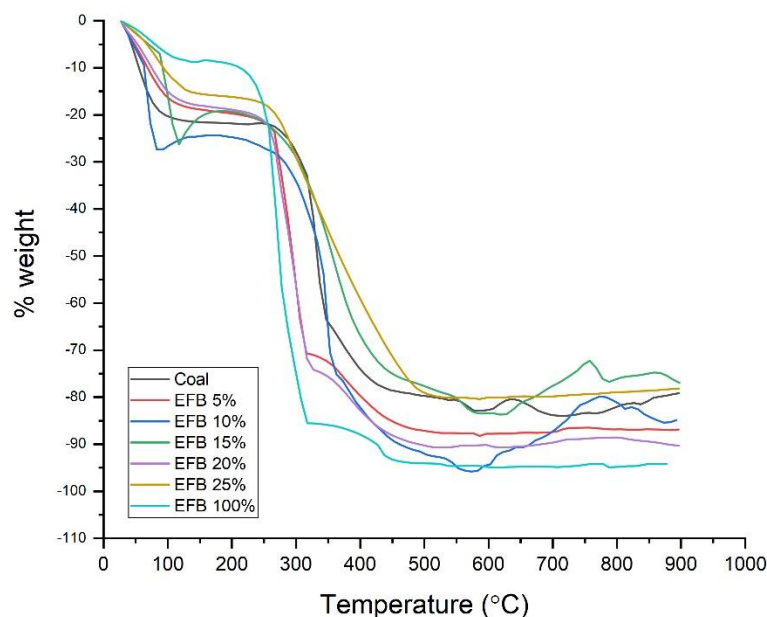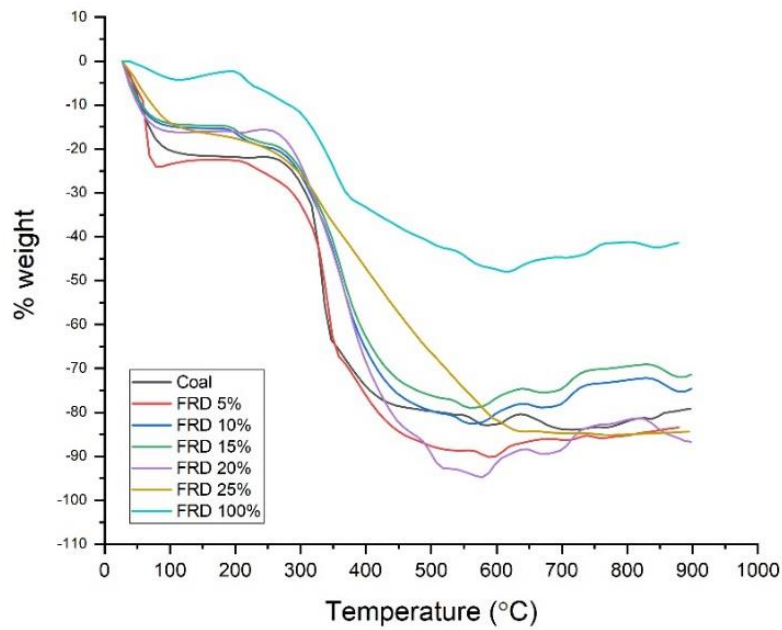

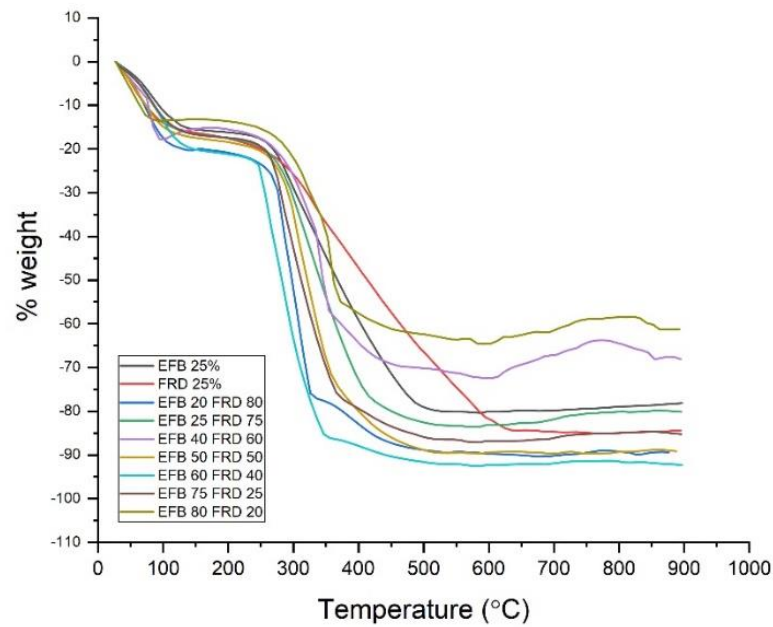Fig. 3. TGA of Coal – EFB

Fig. 4. TGA of Coal – Frond

Fig. 5. TGA of Coal-Biomass 25% (mix of EFB and Frond)

Table 2. Result data of DTG-DSC

Composition	Tig	Tmax	Tbo	R_{max}	Onset point		Offset point		Point of reaction	
	ºC	ºC	ºC	mg/s	ºC	min	ºC	min	ºC	min
Low rank coal 100%	282.80	334.00	490.10	0.0240	311.90	26	347.30	30	321.40	27
EFB 100%	236.00	290.00	518.50	0.0920	254.90	22	321.40	30	269.70	23

Coal 95%, EFB 5%	261.40	293.40	582.10	0.0360	259.60	22	317.60	29	273.00	24
Coal 90%, EFB 10%	278.30	349.10	542.30	0.0130	324.90	27	364.40	31	338.70	29
Coal 85%, EFB 15%	286.00	398.00	647.00	0.0046	175.10	12	458.50	38	199.90	14
Coal 80%, EFB 20%	256.70	292.80	588.20	0.0420	255.20	22	324.20	30	269.70	23
Coal 75%, EFB 25%	257.80	378.10	579.70	0.0180	250.30	21	501.50	47	274.70	23
Frond 100%	229.70	331.00	530.00	0.0035	240.20	20	491.00	46	314.70	28
Coal 95%, Frond 5%	268.70	342.40	564.70	0.0147	317.10	27	359.30	31	331.80	28
Coal 90%, Frond 10%	277.00	362.50	548.70	0.0049	283.40	25	437.20	41	348.80	32
Coal 85%, Frond 15%	287.20	374.00	645.20	0.0046	225.50	17	464.30	41	275.00	21
Coal 80%, Frond 20%	284.80	370.50	558.50	0.0032	244.00	21	451.40	42	308.60	28
Coal 75%, Frond 25%	258.60	511.30	659.80	0.0087	392.90	35	639.30	60	494.70	46
Coal 75%, Biomass 25% (EFB 80:Frond20)	272.90	358.40	673.50	0.0127	324.70	27	379.90	33	346.10	29
Coal 75%, Biomass 25% (EFB 60:Frond40)	245.90	277.20	643.60	0.0990	240.30	20	355.20	34	256.40	23
Coal 75%, Biomass 25% (EFB 40:Frond60)	272.60	319.00	596.10	0.0159	319.00	25	361.70	30	332.90	27
Coal 75%, Biomass 25% (EFB 20:Frond80)	260.60	306.10	524.40	0.0440	259.30	22	336.50	31	279.50	24
Coal 75%, Biomass 25% (EFB 25:Frond75)	266.10	348.10	595.70	0.0210	265.20	23	435.30	41	303.00	27
Coal 75%, Biomass 25% (EFB 50:Frond50)	273.70	319.40	636.30	0.0250	270.80	23	381.80	35	300.60	26
Coal 75%, Biomass 25% (EFB 75:Frond25)	259.60	299.80	560.30	0.0380	265.50	23	310.60	28	277.40	24

REFERENCE

[1]   Renewable Energy Agency I. Renewable Energy Prospects: Indonesia 2017.

[2]   Long H, Li X, Wang H, Jia J. Biomass resources and their bioenergy potential estimation: A review. Renew Sustain Energy Rev 2013;26:344–52. doi:10.1016/J.RSER.2013.05.035.

[3]   Szemmelveisz K, Szucs I, Palotás ÁB, Winkler L, Eddings EG. Examination of the combustion conditions of herbaceous biomass. Fuel Process Technol 2009;90:839–47. doi:10.1016/J.FUPROC.2009.03.001.

[4]   Yin C, Rosendahl LA, Kær SK. Grate-firing of biomass for heat and power production. Prog Energy Combust Sci 2008;34:725–54. doi:10.1016/J.PECS.2008.05.002.

[5]   UNDP. Indonesia Palm Oil 2018:1–33.

[6]   Ng WPQ, Lam HL, Ng FY, Kamal M, Lim JHE. Waste-to-wealth: Green potential from palm biomass in Malaysia. J Clean Prod 2012;34:57–65. doi:10.1016/j.jclepro.2012.04.004.

[7]   Darmawan A, Budianto D, Aziz M, Tokimatsu K. Retrofitting existing coal power plants through cofiring with hydrothermally treated empty fruit bunch and a novel integrated system. Appl Energy 2017;204:1138–47. doi:10.1016/j.apenergy.2017.03.122.

[8]   Umar D, Suganal S, Monika I, Hudaya GK, Diniyati D. THE INFLUENCE OF STEAM DRYING PROCESS ON COMBUSTION BEHAVIOR OF INDONESIAN LOW-RANK COALS, 2020.

[9]   Wagoner CL, Winegartner EC. Further Development of the Burning Profile. J Eng Power 1973;95:119–23. doi:10.1115/1.3445697.

[10] Marinov SP, Gonsalvesh L, Stefanova M, Yperman J, Carleer R, Reggers G, et al. Combustion behaviour of some biodesulphurized coals assessed by TGA/DTA. Thermochim Acta 2010;497:46–51. doi:10.1016/j.tca.2009.08.012.

[11] Song H, Liu G, Zhang J, Wu J. Pyrolysis characteristics and kinetics of low rank coals by TG-FTIR method. Fuel Process Technol 2017;156:454–60. doi:10.1016/J.FUPROC.2016.10.008.