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Effect of Biomass Composition and Co-pyrolysis Retention Time on Reduction of Non-neutral CO₂ Emission from Combustion of Hybrid Coal in Power Plant

S Handoko, W Wulandari, J Rizkiana, M A Ridha, H A Prasetyo and D Sasongko
Department of Chemical Engineering, Faculty of Industrial Technology, Institut Teknologi Bandung

E-mail: slamethan@gmail.com; sasongko@che.itb.ac.id

Abstract. Indonesia's lignite coal and sawdust production are 131,05 and 11,82 million tonnes, respectively, which are potential to become raw material of hybrid coal through co-pyrolysis. Hybrid coal utilization will reduce non-neutral CO_2 emission, a part of CO_2 emission released from combustion of biomass. The aim of this study is to determine the effects on biomass composition and co-pyrolysis retention time on reduction of non-neutral CO_2 emission from combustion of hybrid coal in power plant. Co-pyrolysis was conducted in a vertical tubular furnace under an inert condition in atmospheric pressure and temperature 300° C. Biomass composition and co-pyrolysis retention time was varied from 20 to 40 %-mass and from 30 to 90 minutes, respectively. Hybrid coal was characterized with proximate, ultimate and calorific value analysis. The result of analysis was used as an input on simulation to determine reduction of non-neutral CO_2 emission on hybrid coal combustion in power plant. An increase in co-pyrolysis retention time (CRT) from 30 to 90 minutes increases the CO_2 emission from 13.25 to 13.30 %-vol. While increase in biomass composition from 20 to 40 %-mass reduce CO_2 emission from 13.18 to 12.81 %-vol. Non-neutral CO_2 emission reduction rises from 24.22 to 26.86 % along with the increased of biomass composition from 20 to 40 %-mass. Average of non-neutral CO_2 emission reduction is about 26.30 % in all variation. CO_2 emission of hybrid coal as fuel for power plant increased along with the increased of co-pyrolysis retention time (CRT), which was about 780-830 kg CO_2/MWh. The highest CO_2 emission was achieved from co-pyrolysis product hybrid coal utilization with 30 %-mass of biomass composition.

1. Introduction

Greenhouse gases emissions contain about 77 % CO_2 which make CO_2 gas as the biggest greenhouse gas in the atmosphere and give big impact in global warming [1]. Since the First Industrial Revolution took place in 1750, the raising demand for electricity due to economic growth has been secured mostly using fossil fuels, such as coal, oil and nuclear power. This adds enormous amounts of greenhouse gases (GHG) such as CO_2 to the atmosphere, which is the most significant driver of climate change [2]. In Indonesia, about 35 % of CO_2 emission in energy sector come from power plant which 67 % of them (0,203 Gt CO_2) is come from coal power plant. Indonesia's lignite coal and saw dust production are 131.05 and 11.82 million tonnes, respectively, which are potential to become raw material of hybrid coal through co-pyrolysis. Hybrid coal utilization will reduce non-neutral CO_2 emission, a part of CO_2 emission released from combustion of biomass. Hybrid coal is coal co-pyrolysis product between coal and biomass. Carbon print estimation used to calculate CO_2 emission reduction from coal and biomass

fuel (hybrid coal) and the result was a reduction of CO_2 emission about 21.2 % compare to pure coal fuel [3]. Different from previous researches [4, 5] which used coal and torrefied biomass on calculation and simulation in power plant, this research use hybrid coal and biomass in calculation and simulation of power plant. Laboratory test and simulation were conducted in this study to determine the effect of %-mass of biomass and co-pyrolysis retention time to the reduction of power plant emission.

2. Material and methods

2.1. Materials
Materials used in this study were Indonesian sub-bituminous coal and mahogany sawdust obtained from a furniture factory in Ciamis, Indonesia.

2.2. Methods

2.2.1. Co-pyrolysis experiment. Co-pyrolysis was conducted in a vertical tubular furnace under an inert condition in atmospheric pressure and temperature 300° C. Both of sawdust and coal were crushed and sieved in order to get smaller particle size, 50-100 mesh for sawdust and 30-100 mesh for coal. Process parameters which were investigated on this experiment were sawdust composition on the mixture and retention time of co-pyrolysis process. Sawdust composition were varied at 20, 30, and 40 %-mass from total mixture of sawdust and coal while co-pyrolysis retention time were varied at 30, 60, and 90 minutes. Hybrid coal characteristics were investigated by the result of proximate analysis, ultimate analysis and calorific value measurement.

2.2.2. Calculation simulation for CO_2 emission in power plant. In this study, CO_2 emission from hybrid coal combustion generated from co-pyrolysis experiment in power plant was estimated by modelling and simulation method. Model as shown in Figure 1 was used. Power plant configuration consist of boiler, steam turbine, condenser and generator. Developed model simulation was established. Simulation calculation was done by using Microsoft excel. The Gibbs minimization method (Pheng-Robinson) was used for all calculation. It is worth noting that ash and N_2 are considered as the inert material and pressure drop and mass transfer limitation are considered to have a minor effect on the process. In addition, an adiabatic condition is assumed in the simulation [6]. The composition and the temperature of flue gas was estimated using the Gibbs free energy minimization method. Given the expected operating temperature is possible to facilitate the reactions to reach the equilibrium [7]. Characterization result of six hybrid coals from co-pyrolysis experiment was used as an input data for the simulation by using 1 kg/s as flow rate base. Several assumptions which used in this simulation were 79 % N_2 and 21 % O_2 air composition, 40 % excess air, 20 bar operational pressure and 400° C temperature. Boiler, steam turbine and generator efficiency were 75 %, 85 % and 90 %, respectively. Simulation was established to model mass balanced, energy balanced and thermodynamics system of power plant.
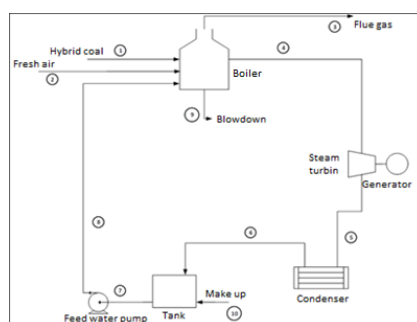

Figure 1. Process diagram of the power plant configuration

3. Result and discussion

3.1. Effect of sawdust %mass

Table 1 shows characterization data of six hybrid coals obtained from co-pyrolysis experiment. Code xxyy means xx%-mass sawdust in the feedstock pyrolized for yy minutes. Data in Table 1 shows that the biggest average calorific value was obtained from co-pyrolysis of 20 %-mass sawdust. It happened because the highest fixed carbon also obtained at 20 %-mass sawdust. This tendency was caused by synergy factor effect between coal and sawdust from co-pyrolysis at 300° C. Temperature range in which the occurrence of significant synergy is 200-500° C which has been previously reported in other study [8]. The presence of indigenous potassium species in raw biomass was a direct consequence of the synergy during co-gasification of coal and biomass [9]. Moreover, the synergy degree greatly depended on the coal and biomass origins [9].

Table 1. Characterization data of hybrid coal

Hybid coal	Proximate analysis (% mass)				Ultimate analysis (% mass)						Calorific value (cal/gr)
	FC	MC	VM	Ash	C	H	O	N	S	Ash	
2030	45.22	4.46	47.69	2.63	63.75	4.89	27.90	0.73	0.10	2.63	5895
2060	47.96	4.52	45.01	2.51	65.24	4.79	26.60	0.77	0.09	2.51	5947
2090	49.92	4.34	43.19	2.55	66.02	4.71	25.86	0.77	0.09	2.55	6025
3030	45.25	2.84	49.77	2.14	65.07	4.96	27.04	0.70	0.09	2.14	5987
3060	49.38	2.99	45.31	2.32	67.14	4.71	24.95	0.79	0.09	2.32	6150
3090	49.75	2.80	44.98	2.47	67.47	4.76	24.44	0.78	0.08	2.47	6224
4030	41.43	4.41	52.28	1.88	61.84	5.08	30.56	0.57	0.07	1.88	5659
4060	46.71	4.51	46.53	2.25	64.36	4.87	27.81	0.64	0.07	2.25	5907
4090	49.36	4.08	44.31	2.25	65.74	4.76	26.53	0.65	0.07	2.25	6031

CO_2 emission in %-mass sawdust and CRT variation is shown in Figure 2. CO_2 emission tends to decline with the increasing of %-mass sawdust in most of co-pyrolysis retention time (CRT) variation because fixed carbon content decreasing along with increasing %-mass sawdust as shown in Table 1. Fixed carbon participate in CO_2 compound formation. Therefore decreasing in fixed carbon will decrease CO_2 emission. It is notable that all biomass samples have higher CO_2 emission factors than those of coals burned herein because of their lower heating values [10]. Higher biomass composition resulted higher CO_2 emission. But for 30 %-mass sawdust composition, CO_2 emission is lower compare to 20 % and 40 %-mass sawdust. It happened because 30 %-mass sawdust has higher heating value which caused by synergistic factor that occurred during co-pyrolysis process [11]. Amount of CO_2 emission at 30, 60, and 90 minutes CRT at 20 and 30 %-mass of sawdust variation are similar, 13.2 %-vol. While at 40 %-mass sawdust, CO_2 emission have the same value, 12.81 %-vol, at 60 and 90 minutes CRT.
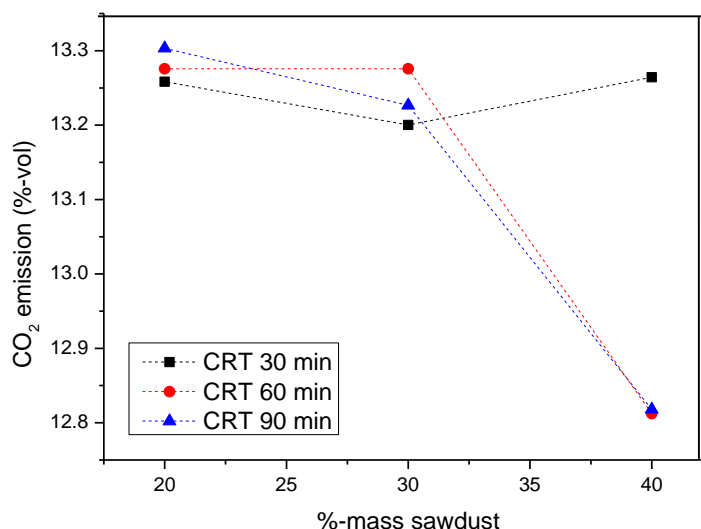
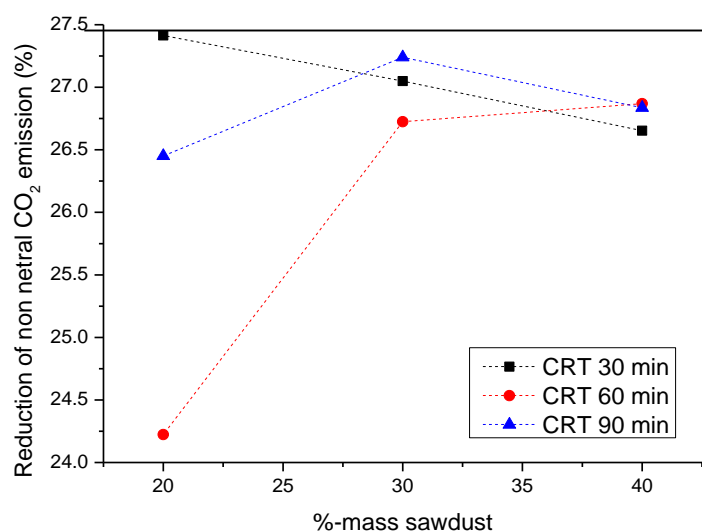**Figure 2.** CO_2 emission as function of %-mass sawdust and CRT

Figure 3. Reduction of non-neutral CO_2 emission as function of %-mass sawdust and CRT

Figure 3 shows effect of %-mass sawdust to non-neutral CO_2 emission reduction. One of the benefits of co-firing biomass is to reduce CO_2 emission because CO_2 from the combustion of biomass fuel source is not assumed to increase the net atmospheric CO_2 levels [9]. Biomass carbon neutrality is a term used to differentiate biomass-derived carbon from fossil-fuel derived carbon with respect to its role in the global carbon cycle. It reflects the fact that biomass-derived carbon is part of a relatively rapid natural cycle that, when in balance, neither adds nor subtracts carbon to/from the atmosphere, whereas fossil fuel-derived carbon is not part of such a rapid cycle [12].

Figure 3 shows that in 30 min and 60 min CRT, the increase of 20 % to 40 %-mass sawdust has reduced the reduction of non-neutral CO_2 emission because the increase in %-mass sawdust will increase donor C element from biomass in combustion process of power plant [9]. While in 90 min CRT, the increase of %-mass sawdust from 20-30 % has increased the reduction of non-neutral CO_2 emission but the increase of %-mass sawdust from 30-40 % has reduced the reduction of non-neutral CO_2 emission. It caused by synergy factor occured at combustion temperature between C element from coal and sawdust. Non-neutral CO_2 emission reduction which was obtained from calculation was lied between 24.22 % and 27.42 %. Average value of non-neutral CO_2 emission reduction is about 26.30 % in all variation.

Figure 4 shows the effect of sawdust %-mass to output power. At every CRT variation, the increase of sawdust from 20 to 30 % cause the reduction of output power. But the increase of sawdust %-masss from 30 to 40 % make output power rises. From ultimate analysis result, C element increased at sawdust 20-30 %-mass and decease at synergy factor between coal and biomass at 30 %-mass sawdust therefore the highest output power was obtained [11]. The thermal decomposition of the hybrid coal and the formation of volatiles are influenced by the thermal interaction between the components at a mass load of straw up to 30 %-mass, thus enhancing the release of the volatiles and improving the combustion conditions with the positive effect on the main combustion characteristics (heat output from the device and product composition). At higher straw mass loads, the thermal decomposition of the mixture and the formation of volatiles predominately are influenced by the linier decrease of the mixture HHV, hydrogen and carbon content with the correlating liniar decrease of the biomass weight loss rate, volume fractios of volatiles at the cinbustor inlet determining thus negative effect of straw combustion characteristics [13]. Output power calculated from nine hybrid coals was lied at 2870 and 3225 MW. The biggest power was gained at 30 %-mass sawdust in 60 minutes CRT.
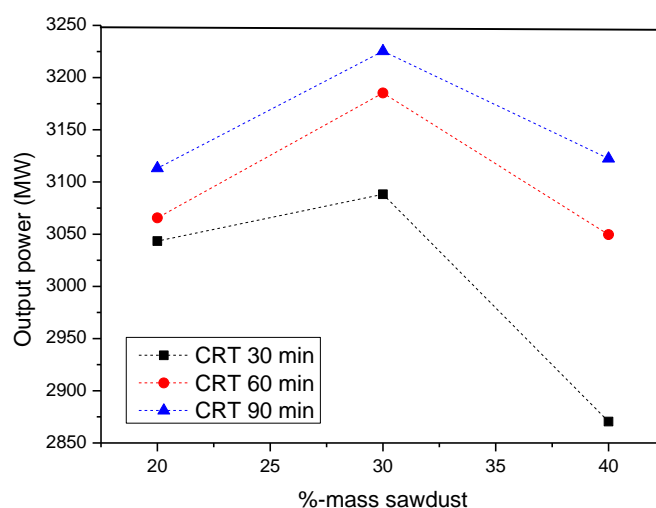

Figure 4. Output power generated as function of %-mass sawdust and CRT

Figure 4 shows that in 30 min, 60 min and 90 min retention time, the increased of sawdust %-mass from 20-30 % has increased tonnes CO_2/MW but the increased of sawdust %-mass from 30-40 % has reduced tonnes CO_2/MW. It happened because the measurements of the elemental composition and heating values of the mixtures have shown that an increase of the biomass load results in linear decrease of the

carbon and hydrogen content in the mixture with the correlating decrease of the heating value of the mixture [13].

At 30 %-mass sawdust, heating value rises so that CO_2 emission obtained per output power generated is the smallest among the three sawdust composition. It is caused by synergy effect of coal and sawdust during co-pyrolysis process at temperature 300° C [11]. Average amount of tonnes CO_2/MW as model prediction result is 0,798 kg CO_2/MW. This number is less than tonnes CO_2/MW obtained from 100 % coal. Typically, a subcritical coal-fired utility plant produces 900 kg CO_2/MWh, and 750 kg CO_2/MWh for a supercritical plant [4]. Other study shows number of 846 kg CO_2/MWh could be recaptured when 100 % fuel switched from coal to torrefied biomass [5].
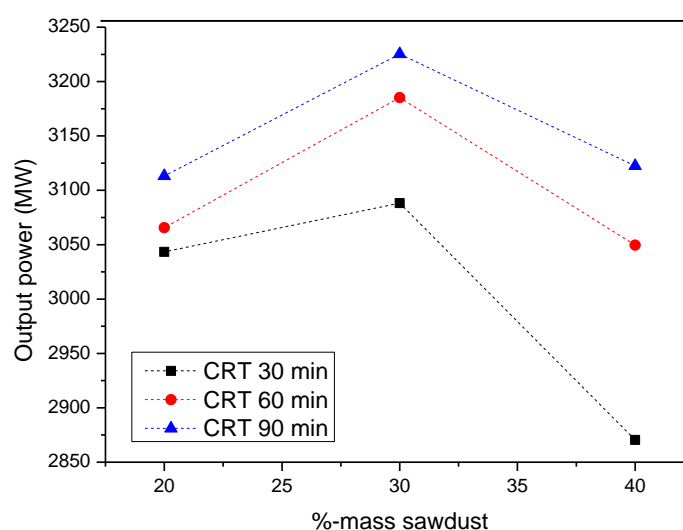

Figure 5. Amount of CO_2 generated per 1 MW power as function of %-mass sawdust and CRT

3.2. Effect of co-pyrolysis retention time (CRT)

For CRT 60 and 90 minutes, CO_2 emission generated from hybrid coal combustion tend to have the same trend. For every sawdust %-mass, 90 minutes CRT generated the smallest CO_2 emission. It happened because long CRT cause more H and O element released so that O/C and O/H ratio at hybrid coal become smaller which affect in increase in calorific value. For non-neutral CO_2 emission, the same trend also happen in every sawdust % mass. Only at CRT 30 minutes and 20 %-mass sawdust the trend is different. It is because CRT not have reached the maximum time to accommodate the release process of moisture content and volatile matter from coal and sawdust feed. Output power from power plant with hybrid coal fuel, CRT 90 minutes generated the biggest power because of it highest calorific value as a result of maximum co-pyrolysis process. CRT 30 minutes generated different trend in number of CO_2/MW because co-pyrolysis time was not sufficient to accommodate the release process of moisture content and volatile matter. Hybrid coal derived from co-pyrolysis with 90 minutes retention time and 30%-mass biomass composition reaches the highest output power and gives the lowest CO_2 emission. Summary of the result is shown in Table 2.

Table 2. Summary result

Hybrid coal	Reduction of non neutral CO_2 emission (%)	Output power (MW)	Tonnes CO_2/MWh
2030	27.41	3043.4	788.8
2060	24.22	3065.7	800.4
2090	26.45	3113.1	797.9
3030	27.05	3088.2	789.5
3060	26.72	3185.3	791.2
3090	27.24	3225.3	786.5
4030	26.65	2870.5	835.5
4060	26.87	3049.6	791.6
4090	26.84	3122.4	789.8

4. Conclusion

An increase in co-pyrolysis retention time from 30 to 90 minutes has increased the CO_2 emission from 13.25 to 13.30 %-vol. While increased in biomass composition from 20 to 40 %-mass has reduced CO_2 emission from 13.18 to 12.81 %-vol. Non-neutral CO_2 emission reduction has risen from 24.22 to 26.86 % along with the increased of biomass composition from 20 to 40 %-mass. Average of non-neutral CO_2 emission reduction was about 26.30 % in all variation. CO_2 emission of hybrid coal as fuel for power plant increased along with co-pyrolysis retention time about 780-830 kg CO_2/MWh. Hybrid coal derived from co-pyrolysis with 90 minutes retention time and 30%-mass biomass composition reaches the highest output power and gives the lowest CO_2 emission.

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