Simulation of Filter Cake Co-firing Characteristics in Circulating Fluidized Bed Coal Fired Power Plant

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Abstract. A study on co-firing using coal and filter cake biomass was conducted on a circulating fluidized bed boiler power plant varying the co-firing biomass ratio from 0 to 50%. The mixing of coal fuel and filter cake biomass in the model is carried out before entering the mill. After the model iteration shows convergence, the output simulation is validated by comparing the simulation output value with the design and actual parameter values. The evaluation is carried out by comparing the simulation results of baseline conditions with co-firing conditions on the parameters of performance, power output, equipment condition, energy consumption itself, and the impact on emission products. The addition of 1% of the co-firing ratio using rice husks showed a decrease in boiler efficiency (HHV) by 1.3%. Net plant heat rate and SFC increased by 5% and 0.2171%. Furthermore, co-firing using filter cake also reduces SO_2 emission by 1.642 ppmv@6% O_2, dry.

Keywords: *co-firing, CFB, biomass, filter cake, boiler efficiency.*

1 Introduction

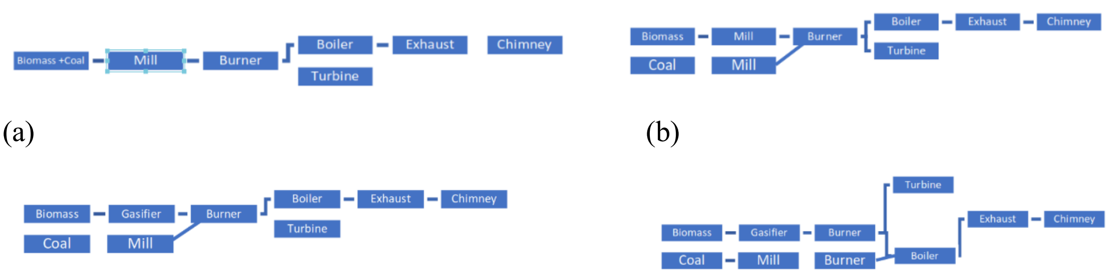
The role of coal in the national energy supply system will be increased, but the use of coal as an energy generator has an obstacle, namely the generation of greenhouse gas (GHG) emissions as the main cause of global warming that is currently being debated. In order to prevent global temperature, rise from exceeding 1.5ºC, Indonesia has increased its greenhouse gas (GHG) emission reduction target to 31.89% by 2030, as stated in the Enhanced Nationally Determined Contribution (ENDC) document of the Republic of Indonesia in 2022. One way to reduce GHG emissions is through coal-biomass co-firing.

Co-firing is the process of burning different fuel materials at the same time. The schematic of co-firing technology is shown in figure 1.

Figure 1. Co-firing technology is divided into three methods, namely direct co-firing as shown in

Figure 1c where one of the fuels undergoes a gasification process first and then mixed with other fuels in the boiler and parallel co-firing as shown in

Figure 1d where each fuel is burned on a different burner and the steam produced from both boilers is combined together for use in further processes [7].



(a) (b)

(c) (d)

Figure 1. Schematic of types of co-firing technology (a) direct co-firing with the same mill (b) direct co-firing with a separate mill (c) indirect co- firing (d) parallel co-firing [6].

Indonesia is estimated to have biomass conversion potential to electrical energy greater than 32 GW with biomass sources including sugarcane, coconut, corn, wood, rice, cassava and municipal waste [5]. Some types of biomasses that have been tested using the direct co-firing method in Indonesia include wood pellets, palm kernel shells and sawdust. One potential biomass that has not been widely utilised is filter cake, a semi-solid waste by-product of the clarification process in the sugar industry. Each tonne of sugarcane processed can produce 30-40 kg of filter cake, which if not managed properly has the potential to cause environmental pollution and iits management is still an obstacle in most sugar factories in Indonesia.

One of the uses of filter cake as fuel, as happened in Situbondo and Bondowoso which obtained it from a number of Sugar Factories, namely in Situbondo are PG Wringin Anom, PG Olean, PG Panji and PG Asembagus and PG Prajekan in Bondowoso (Detik, 2007). Other uses by the community are residents of Sidorejo Village, Madiun Regency. The community has implemented filter cake fuel from sugarcane dregs since the 2010s, as an alternative fuel to replace LPG in daily activities. A number of residents in Sidorejo Village, Wungu District, have started to switch to using filter cake or sugarcane processing waste from sugar factories as an alternative fuel to replace LPG (Trans7, 2023). The utilization of filter cake as renewable energy that can produce benefits is an important part that must be implemented regardless of the high cost of oil, gas or the difficulty of natural gas. Because the utilization of bioenergy is an environmentally friendly solution. This study then focuses on analyzing with a literature review regarding the utilization of filter cake sugarcane waste as renewable energy for fuel. In accordance with several cases found in several regencies in East Java Province and relevant research on the utilization of sugarcane waste, the researcher focuses on the study of the efficiency value of filter cake utilization as fuel within the limits for household activities and small industries.

This study will simulate the co-firing of filter cake and coal with a mixing ratio of

0 - 50% in power plant with CFB boiler type to determine the effect of using filter cake co-firing on the performance and emissions of the power plant.

2. Materials and research methods

2.1 Power plant specifications

The study was conducted on a Circulating Fluidized Bed boiler. The detailed technical specifications of the main equipment at the power plant used as one of the simulation input data are shown in Table 1 below.

Parameter	Unit	Value
	Boiler	
Type		Circulating Fluidized Bed
Capacity	Ton/jam	443
Superheater Steam Pressure	kg/cm2	94,8336
Superheater Steam Temperature	ºC	540
	Furnance	
Furnance Exit gas Temperature (FEGT)	ºC	927
	Turbine	
Manufacture		Mitsubishi Heavy Industries
Type		Tandem Compound Double Exhaust
Capacity	Mw	420000
Speed	Rpm	3000
Turbine Exit Pressure	mmHg	704,4
main steam pressure	kg/cm^2	170

main steam temperature	ºC	538
reheat steam temperature	ºC	538
IP Turbin pressure	kg/cm^2	38,97
IP turbin turbine	ºC	538

2.2 Simulation Parameter

Simulation of characteristics in this study using THERMOFLOW 21 software consisting of STEAM PRO and STEAM MASTER. Thermoflow STEAM PRO can calculate boiler efficiency in both lower heating value (LHV) and higher heating value (HHV) basis. Boiler efficiency is defined as the ratio between the rate of heat transfer in the steam produced by the boiler divided by the rate of energy supplied to the boiler which can be calculated by the equation:

$$\eta = \frac{Total\ heat\ provided\ by\ Boiler}{m_{fuel}\,HV_{adj} + m_{fuel}\,(h_{air} - h_{amb}) + Q_{stmht}}$$

Where:

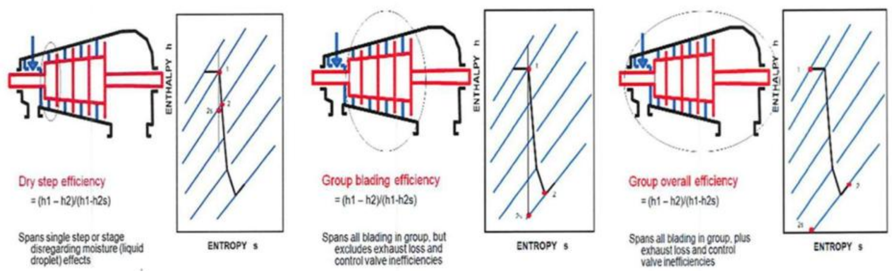
m_{fuel} x HV_{adj} : result of fuel flow rate and heating value at supply temperature. The calorific value can be on an LHV or HHV basis.

m_{fuel} x (h_{air}-h_{amb}) : the energy flow rate of the incoming air in the boiler against the ambient temperature, where hair is the enthalpy at the boiler inlet and hamb is the enthalpy of the ambient air.

Q_{stmht} : the rate of heat energy supplied to the air by the steam air heater (if there is a steam air heater).

STEAM PRO will iterate boiler efficiency starting from the maximum input value (100% by default) and decreasing until several conditions are met including: minimum flue gas exit temperature, minimum boiler pinch, minimum steam approach to flame temperature and minimum air preheater pinch. Meanwhile, the

Steam turbine efficiency in STEAM PRO modelling is an isentropic efficiency obtained by comparing the actual steam enthalpy change with the change in the ideal, reversible steam expansion process (constant entropy) under the condition of equal inlet and outlet energy (see Figure 2).



(a) (b) (c)

Figure 2. (a) dry step efficiency (b) group blading efficiency dan (c) group overall efficiency.

The shape of the POWER PLANT model in STEAM PRO and STEAM MASTER consists of main components such as pulverizer / mill, boiler, turbine, condenser, condensate pump, low pressure heater (LPH), deaerator, boiler feed pump (BFP), high pressure heater (HPH), primary air fan, secondary air fan, air heater, electrostatic precipitator, induced draft fan and chimney / stack (see Figure 3). For each component, data on both design and operating parameters such as dimensions, temperature, pressure, flow rate and other input parameters are input.

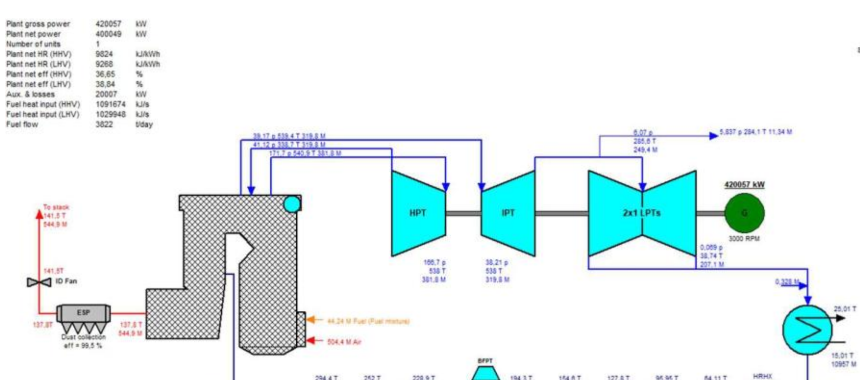


Figure 3. Power plant Modelling Components in THERMOFLOW 21.0 Software

One of the required simulation input data is the fuel composition test results of coal and filter cake. Both samples were tested at an accredited laboratory. Characteristically, filter cake has a lower calorific value and moisture content compared to coal. Meanwhile, the ash and volatile matter content of filter cake is much higher than coal. From the composition of alkali content, SiO_2 and K_2O contained in filter cake have higher values compared to coal (see Table 2).

Name	Coal	Filter Cake
Heating Values		
LHV (at 25C), kJ/kg	23742	14675
HHV (at 25C), kJ/kg	25137	15962
Ultimate Analysis		
Moisture, (wt.%)	23,25	5,33
Ash, (wt.%)	8,22	23,2
Carbon, (wt.%)	63,4	45
Hydrogen, (wt.%)	3,79	5,3
Nitrogen, (wt.%)	1,07	1,04
Chlorine, (wt.%)	0	0
Sulfur, (wt.%)	0,27	0,01
Oxygen, (wt.%)	0	20,12
Total, (wt.%)	100	100
Proximate Analysis		
Moisture, (wt.%)	23,25	5,33
Ash, (wt.%)	8,22	23,2
Volatile Matter, (wt.%)	30	64,28
Fixed Carbon, (wt.%)	38,53	7,19
Total, (wt.%)	100	100
Other Properties		
Specific Heat @ 25C, dry, kJ/kg-C	1,298	1,256
Specific Heat @ 300C, dry, kJ/kg-C	2,093	2,051
Hardgrove Grindability Index (HGI)	57	N/A
Ash Analysis		

SiO_2, (wt.%)	18	48,1
Al_2O_3, (wt.%)	19	22,3
Fe_2O_3, (wt.%)	23,5	24,3

CaO, (wt.%)	18,5	1,3
MgO, (wt.%)	7,1	0,6
Na2O, (wt.%)	5	0,3
K2O, (wt.%)	0,5	1,5
TiO2, (wt.%)	0,7	0,7
P2O5, (wt.%)	0,04	0,1
SO3, (wt.%)	7,66	0,8
Other, (wt.%)	0	0
Total, (wt.%)	100	100
Ash Characteristics		
Fouling	Low/Medium	Low/Medium
Initial Deform. Temp., C	1095	1168,3
Softening/Deposition Temp., C	1130	1168,3

2.3. POWER PLANT Co-firing Modelling Method

The study of the impact of co-firing using coal and filter cake biomass was carried out in 11 scenarios by varying the co-firing ratio from 0 to 50%, namely, 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%. The 0% ratio means that the fuel used is full coal or base line condition. The addition of filter cake biomass fuel is shown in the 5% to 50% scenario. The mixing of coal and filter cake biomass fuel in the model is done before entering the pulveriser/mill. There is no addition (modification) of equipment when simulations are carried out on the co-firing model. After the model iteration showed convergence, validation was carried out by checking the simulation output values with design values and actual parameter values. Evaluation is done by comparing the simulation results of baseline conditions with co-firing conditions. Some of the parameters evaluated include boiler efficiency, net plant heat rate, power output, self-use energy and impact on product emissions.

3. Results and Discussion

Table 3. Fuel Composition of Coal and Filter cake Biomass Blends at various %- Co-firing Ratios

Table 3. Fuel Composition of Coal and Filter cake Biomass Blends at various %-Co-firing Ratios

Parameter	SP0	SP5	SP10	SP15	SP20	SP25	SP30	SP35	SP40	SP45	SP50
Heating Values											
LHV (at 25C), kJ/kg	23742	23289	22835	22382	21929	21475	21022	20569	20115	19662	19209
HHV (at 25C), kJ/kg	25137	24678	24220	23761	23302	22843	22385	21926	21467	21008	20550
Ultimate Analysis											
Moisture, (wt.%)	23,25	22,35	21,46	20,56	19,67	18,77	17,87	16,98	16,08	15,19	14,29
Ash, (wt.%)	8,22	8,969	9,718	10,47	11,22	11,96	12,71	13,46	14,21	14,96	15,71
Carbon, (wt.%)	63,4	62,48	61,56	60,64	59,72	58,8	57,88	56,96	56,04	55,12	54,2
Hydrogen, (wt.%)	3,79	3,866	3,941	4,016	4,092	4,168	4,243	4,318	4,394	4,47	4,545
Nitrogen, (wt.%)	1,07	1,068	1,067	1,066	1,064	1,062	1,061	1,06	1,058	1,056	1,055
Chlorine, (wt.%)	0	0	0	0	0	0	0	0	0	0	0
Sulfur, (wt.%)	0,27	0,257	0,244	0,231	0,218	0,205	0,192	0,179	0,166	0,153	0,14
Oxygen, (wt.%)	0	1,006	2,012	3,018	4,024	5,03	6,036	7,042	8,048	9,054	10,06
Total, (wt.%)	100	100	100	100	100	100	100	100	100	100	100
Proximate Analysis											
Moisture, (wt.%)	23,25	22,35	21,46	20,56	19,67	18,77	17,87	16,98	16,08	15,19	14,29
Ash, (wt.%)	8,22	8,969	9,718	10,47	11,22	11,96	12,71	13,46	14,21	14,96	15,71
Volatile Matter, (wt.%)	30	31,71	33,43	35,14	36,86	38,57	40,28	42	43,71	45,43	47,14
Fixed Carbon, (wt.%)	38,53	36,96	35,4	33,83	32,26	30,7	29,13	27,56	25,99	24,43	22,86
Total, (wt.%)	100	100	100	100	100	100	100	100	100	100	100
Other Properties											
Specific Heat @ 25C, dry, kJ/kg-C	1,298	1,295	1,293	1,29	1,288	1,286	1,283	1,281	1,279	1,277	1,275
Specific Heat @ 300C, dry, kJ/kg-C	2,093	2,091	2,088	2,086	2,083	2,081	2,079	2,077	2,074	2,072	2,07
Hardgrove Grindability Index (HGI)	57	57,45	57,9	58,35	58,8	59,25	59,7	60,15	60,6	61,05	61,5
Ash Analysis											

SiO2, (wt.%)	18	21,89	25,19	28,01	30,45	32,59	34,48	36,15	37,65	39	40,23
Al2O3, (wt.%)	19	19,43	19,79	20,1	20,37	20,6	20,81	20,99	21,15	21,3	21,44
Fe2O3, (wt.%)	23,5	23,6	23,69	23,77	23,83	23,89	23,94	23,98	24,02	24,06	24,09
CaO, (wt.%)	18,5	16,28	14,39	12,78	11,38	10,16	9,084	8,126	7,269	6,498	5,8
MgO, (wt.%)	7,1	6,259	5,548	4,939	4,411	3,949	3,542	3,18	2,856	2,564	2,301
Na2O, (wt.%)	5	4,392	3,878	3,437	3,056	2,722	2,427	2,165	1,931	1,72	1,53
K2O, (wt.%)	0,5	0,6293	0,7387	0,8325	0,9137	0,9847	1,047	1,103	1,153	1,198	1,238
TiO2, (wt.%)	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
P2O5, (wt.%)	0,04	0,0478	0,0543	0,0599	0,0648	0,0691	0,0728	0,0762	0,0792	0,0819	0,0843
SO3, (wt.%)	7,66	6,773	6,022	5,379	4,822	4,335	3,905	3,522	3,181	2,873	2,595
Other, (wt.%)	0	0	0	0	0	0	0	0	0	0	0
Total, (wt.%)	100	100	100	100	100	100	100	100	100	100	100
Ash Characteristics											
Fouling	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium
Initial Deform. Temp., C	1095	1104,5	1112,5	1119,4	1125,3	1130,5	1135,1	1139,2	1142,9	1146,2	1149,1
Softening/Deposition Temp., C	1130	1135	1139,2	1142,7	1145,9	1148,6	1151	1153,1	1155	1156,7	1158,3

Homogeneous fuel mixing plays an important role in combustion quality. In addition to the difference in characteristics between coal and filter cake, it is necessary to pay attention to the co-firing ratio % so that the power plant remains safe when operating implementation using co-firing mode. The increase in co-firing ratio shows an increase in ash content, potentially increasing the ash product produced (see Table 3). Meanwhile, the chlorine content also increases, causing an increase in the potential for corrosion in the conventive region. The increase in alkali content of the fuel will also result in increased fouling. It should also be noted that the decrease in Initial Deformation Temperature (IDT) is proportional to the increase in co-firing ratio. When the IDT value is close to or lower than the Furnace Exit Gas Temperature (FEGT) value, the combustion ash will begin to melt on the surface of the boiler pipe so that it will have an impact on reducing heat transfer and hot spots in certain areas.

In terms of plant performance, every additional 1% co-firing ratio using filter cake biomass shows a decrease in HHV boiler efficiency by 1.3% (Figure 4.a.). While for the addition of 1% co-firing ratio using filter cake biomass shows an increase in the plant net heat rate (HHV) (kJ/kWh) by 5% (figure 4.b.). For the addition of 1% co-firing ratio using filter cake biomass shows an increase in fuel consumption (SFC) in kg/s by 0.2171% (figure 4.c.).

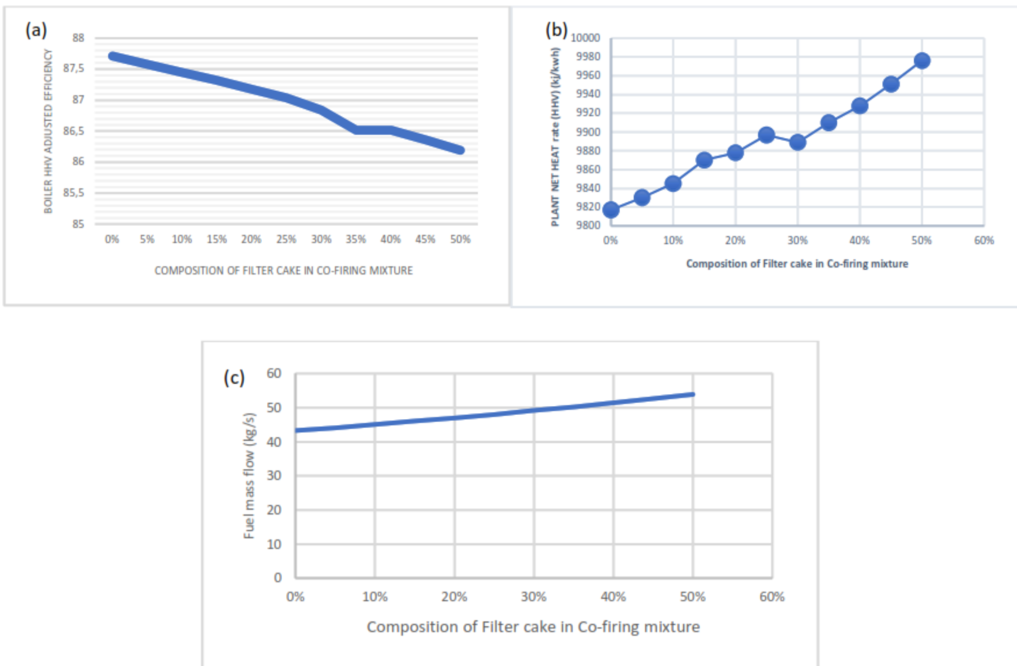


Figure 4. Impact of increasing % co-firing ratio on (a) Boiler HHV Adjusted Efficiency, (b) Plant NET Heat Rate, (c) Fuel Mass Flow

In terms of emissions, the simulation results show that increasing the co- firing ratio using sugarcane filter cake can reduce the resulting SO_2 emissions as shown in Figure 5. Where every 1% increase ratio filter cake in co-firing, can reduce SO_2 emissions by 1,642 ppmv@6% O_2, dry. This is because the sulfur content of filter cake biomass tends to be lower than the sulfur content of coal.

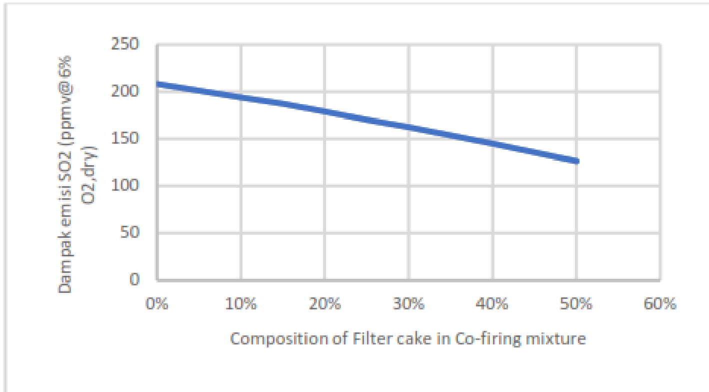


Figure 5. Impact of increasing % co-firing ratio on SO_2 emission

4. Conclussion

Biomass co-firing in Indonesian power plants is a programmed launched by PT PLN to support the government's New Renewable Energy (EBT) acceleration programmed. In the implementation of co-firing, there are stages that need to be passed including the simulation stage to evaluate the impact and identify risk mitigation strategies before conducting on-site testing. In its development, various biomasses have been One of them is filter cake biomass which has a large potential availability, especially in Java. Characteristically, filter cake has higher ash, volatile matter, chlorine and alkali SiO_2 and K_2O contents compared to coal so that it is necessary to mitigate the risk of potential slagging & fouling and corrosion due to chlorine. The simulation results also show that the increasing percentage of co-firing ratio using filter cake biomass contributes to a decrease in the performance of the plant as well as a decrease in the output power (deaerating) of the plant. In terms of emissions, the positive impact of co-firing using filter cake is that SO_2 has decreased. However, the high ash content in filter cake has an impact on increasing the particulate flow rate in the flue gas, thus increasing the ESP work. It is necessary to conduct further studies to obtain a limit to the percentage of co-firing ratio using filter cake that has the smallest possible negative impact so that there is no disruption of reliability on the components of the power plant.

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