Performance Analysis of Co-firing Using Palm Kernel Shells in Chain Grate Stoker Coal Fired Power Plant 2 x 7 MW

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Abstract: Co-firing is the efforts to reduce the use of fossil fuel (coal) form steam power plant. Adding biomass as a partial fuel to the boiler to reduce coal consumption thereby reducing carbon dioxide emissions which can have an impact on the greenhouse effect. This co-firing study implemented 5-20% palm kernel shells. The emission has decreased very significantly in the use of biomass by 20%, Carbon dioxide (CO_2) from 7% to 0.9% and carbon monoxide (CO) from 759 Mg/Nm^3 to 105 Mg/Nm^3. Slagging index during is still within safe limits. Fouling index when coal firing and co-firings 5%, 15% and 20% are in the high category, while co-firing is 10% in the severe category. Base to acid ratio during co-firing test 5%, 10% and 15% in the high/severe category, while co-firing is 20% is still within safe limits. The potential for corrosion due to the presence of chlorine is Cl-induced active oxidation minor. The toxic properties samples obtained from various co-firings are still in safe condition and meet quality standards.

INTRODUCTION

The rate of energy consumption is directly proportional to a country's population and economic growth. The increase in energy consumption has an impact on climate change which is a global issue in the world. Climate change has become an important topic of global concern because can affects our societies by destroying natural, economic, and social systems. Gases that contribute to the greenhouse (GHG) effect leading to global warming (climate change) come from many sources. CO_2 makes the largest contribution to global GHG emissions by 65% from the power generation sector (fossil fuel) and industrial processes (IPCC, 2014). Power generation is the largest source of steady carbon dioxide (CO_2) emissions (Khorshidi et al., 2013). Coal is the most widely available and used fuel worldwide (Birol et al., 1999). In Indonesia, the biggest contributor to carbon dioxide (CO_2) emissions is from power plants with 68% followed by the transportation and industrial sectors with 23.7% and 16.1% (DEN, 2022). The coal consumption for power generation in Indonesia reached 112 million tons which influenced by the increase in domestic coal power plant capacity (Neraca energi nasional, 2022). The emission of CO_2 from fossil fuels has become one of the most dangerous and complex problems causing global warming and global climate change (Lin et al., 2019). To prevent climate change globally, countries must reduce their greenhouse gas (GHG) emissions, as regularly warned in the Intergovernmental Panel on Climate Change report (Millot et al., 2020). Energy consumption is the largest source of anthropogenic emissions of carbon dioxide (CO_2) along with other GHGs is suspected to be the main cause of global climate change (Cassarino et al., 2018). Climate change refers to changes in temperature and weather patterns over the long term. Climate change has a negative impact on people's lives. Reducing carbon dioxide (CO_2) emissions has become a very important focus worldwide. Some research has been done to capture the carbon dioxide (CO_2) produced using Carbon Capture and Storage technology to reduce the impact of global warming on coal consumption (Kumar et al., 2020; Wilberforce et al., 2021; Osman et al., 2021; Pudasainee et al., 2020). However, Carbon Capture and Storage technology that mitigate the impact of coal use still required significant investment in equipment systems. Because of the high cost of clean coal technology, some other alternatives must be found to reduce the impact of carbon dioxide (CO_2) emissions.

The energy transition is a pathway toward transformation of replacing fossil fuels with low carbon energy sources from fossil-based to zero-carbon (United Nation, 2021). This energy transition will require the intervention of governments. To achieve efficient carbon reduction in the power generation sector requires policies, regulations, and laws. The Government of Indonesia has adopted the Paris Agreement to the united nation framework convention of climate change to reducing the greenhouse gas (GHG) emission effect by 29% in 2030 as business-as-usual scenario and 41% in 2030 with international supports (UU No. 16, 2016). Moreover, to reduce carbon CO_2 emissions by setting a Net Zero Emission (NZE) target by 2060. The target of the Indonesian Government regarding the plan national policy for clean renewable energy management is 23% in 2025 and 31% in 2050 (Peraturan Presiden No. 22, 2017). This is in line with the Paris Agreement to reduce carbon use from fossil fuels that contribute to carbon dioxide (CO_2) emissions so that global warming can be supervised (Clancy et al., 2018; Murphy et al., 2017). Co-firing technology was an alternative to reduce the environmental impact of existing power plants (Al-naiema et al., 2015; Xu et al., 2020). Biomass co-firing is the process of blending coal and biomass from different feedstocks. Biomass fuel is widely used as renewable energy that does not emit carbon dioxide (CO_2), has been attracting a great deal of attention in recent years (Riaza et al., 2014; Sami et al., 2001; Ashraf et al., 2019; Tillman et al., 2012). The examples of Biomass that can be used in co-firing are wood wastes, short rotation woody crops, agricultural wastes, short rotation herbaceous crops (Demirbas, 2003; Tursi, 2019).

In many countries co-firing using biomass has been widely applied such as Malaysia (Griffin et al., 2014), Vietnam (Amann et al., 2019; Truong et al., 2022), Europe (Al-mansour & Zuwala, 2010), and Same as in North America co-firing of biomass has been successfully implemented generally within 5–10% but has constraints of a sustainable supply of biomass (Agbor et al., 2014). Biomass is a source of new and renewable energy which has abundant potential in Indonesia because Indonesia is an archipelago country. The largest amount of biomass in Indonesia is oil palm. Extensive oil palm plantations in Indonesia reach 16.6 million hectares planted area of estate crops, crude palm oil production 46.2 million tons Kalimantan, Sumatra and Sulawesi producing the most (BPS, 2022). The implementation of palm oil and its derivatives could be a positive fossil fuel alternative (Kaniapan et al., 2021). The potential for biomass in Indonesia is approximately 50 GW (Singh & Setiawan, 2013; Mahidin et al., 2020). Due to the enormous potential of biomass, the government has encouraged the use of new and renewable energy through regulations and laws that have been issued. To expedite national energy plan, PLN as Indonesian electric company own by government has an initiative strategy called green booster which requires all existing power plants owned by PLN to implement co-firing of biomass. Co-firing is one of PLN's breakthroughs without significant investment costs as well as being a waste management solution. PLN's existing power plants have the potential for co-firing biomass of 18,895 MW and will continue in 52 locations with a biomass requirement of 8 million tons/year spread across Indonesia (RUPTL, 2021). This paper aims to analyze and evaluate direct co-firing use palm kernel shell biomass 5-20% on existing power plants stoker boiler 2 x 7 MW, including carbon dioxide (CO_2) emissions reduction, the potential for slagging and fouling, and Analyzing fuel waste (Fly ash and Bottom Ash) from Co-firing.

Co-firing of coal and biomass is often a relatively simple process of mixing the fuels before burning them in a power plant. Co-firing applied was first practiced in Alaska, United States, utilize a combination of coal and wood chips to generate steam in grate-fired boilers (Samson et al., 1991). Co-firing already used in various power plant with various methods which is easy to apply and is a cost-effective technology (Baxter et al., 2005). Various studies on co-firing have shown that the cost of producing electricity using biomass is higher than coal firing, but the use of biomass can greatly reduce the environmental impact of carbon dioxide (CO_2) (Agbor et al., 2016; Basu et al., 2011). Biomass can be used for boiler combustion using three different methods that is Direct Co-firing, Indirect Co-firing, Parallel Co-firing (Dam-johansen et al., 2013).

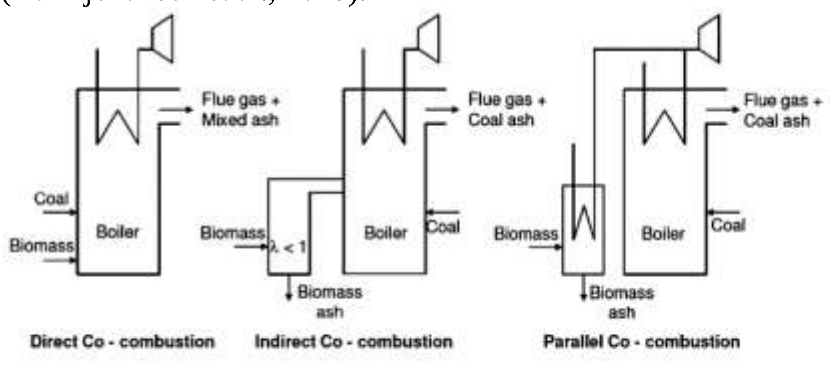

Figure 1. Various co-firing methods (Dam-johansen et al., 2013)

From the three methods above, the easiest, cheapest, and minimal in providing supporting facilities is Direct Co-firing because the mixing is in the coal handling facility which has facilities in every power plant. The stoker-fired furnace is well-thought-of the oldest combustion system for solid fuels (Giaier & Loviska, 1997), however, still used in remote areas in Indonesia.

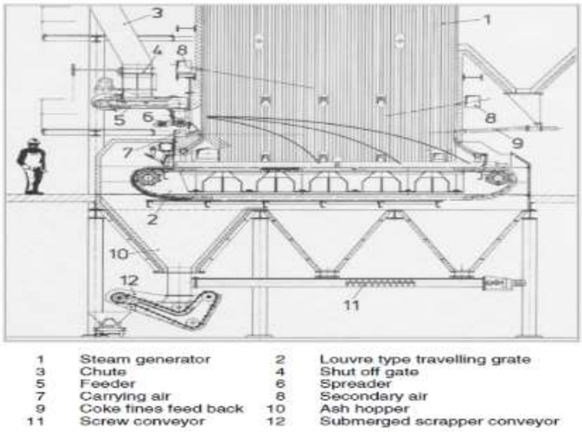

Figure 2. Chain grate stoker with a spreader (*Source*: Alstom Power)

The travelling/chain grate is arranged of many parallel grate bars arrange in rows one behind the other and connected by joints and the primary air which is the combustion air blown into the layer from below. Numerous research of grate stoker boilers has been done in firing and co-firing a wide range of fuels (Li et al., 2009) The type of stoker boiler used in this study is backward moving travelling grate has height of 6947 mm, width of 3930 mm, steam generation capacity of 45 t/h, working steam pressure at 5.5 MPa.

Both coal firing and biomass co-firing in boiler will produce ash. Due to the dissimilar process associated in the deposition of ash on the heated surfaces of boiler pipes, two common types of ash deposition have been defined as slagging and fouling. Ash deposits cause increased thermal resistance and decreased heat absorption, reducing the thermal efficiency of boilers. Ash consists of various kinds of inorganic materials. Several elements found in ash such as SiO_2, CaO, K_2O, P_2O_5, Al_2O_3, MgO, Fe_2O_3, Na_2O, SO_3 and TiO_2 which will be used for analysis. The phenomenon of ash adhering is influenced by the Ash Fusion Temperature (AFT). Ash fusion temperatures (AFT) denote a range of temperatures where ash deposits form on the heat-absorbing surfaces of process equipment (Tambe et al., 2018). Evaluation of this phenomenon can be known by calculating the ratio of certain elements in the ash. To determine the potential for slagging and fouling, fuel analysis is generally carried out in the laboratory. In testing the characteristics of fuel in the laboratory focused on sulfur content, ash fusion temperature, and ash composition analysis. From the results of the characteristic test, predictions of slagging and fouling can be calculated based on the analysis of the ash with the equation as shown below (Magdziarz et al., 2016; Rizvi et al., 2015; Pronobis et al., 2013).

Base to acid ratio:

$$B/A = \frac{Fe2O3 + CaO + MgO + Na2O + K2O}{SiO2 + AlO3 + TiO2}$$

Ash composition is a good indicator of the problem of biomass properties. The potential for ash deposition can be evaluated using the base to acid (B/A) ratio. From the calculation of this formula, there is a standard B/A ratio that can be categorized into 3 levels, namely B/A <0.4 low category, B/A > 0.7 medium category, and B/A between 0.4 – 0.7 high or severe. Slagging characteristics are determined based on the calculation of the ratio of alkaline elements to acidic elements, with sulfur content.

$$Rs = \frac{\mathrm{Fe2O3+\ CaO+\ MgO+\ Na2O+\ K2O}}{\mathrm{SiO2+\ AlO3+\ TiO2}} \text{ x } S$$

From the calculation of this formula, there is a standard value of Rs (Slagging Index) that can be categorized into 4 levels, namely: Rs < 0.6 low category, Rs between 0.6 – 2 medium category Rs between 2.0 – 2.6 high category, Rs > 2.6 severe category. Ash deposits that build up on the convection surfaces of the boiler severely impair heat transfer. Fouling index describes the tendency of coal to cause heating surface fouling.

$$Rf\ (Fouling\ Index) = \frac{\mathrm{B}}{A} \text{ x } (Na2O + K_2O)$$

From the calculation of the formula, there is a standard Rf value that can be categorized into 4 levels, namely: Rf < 0.2 Low category, Rf between 0.2 – 0.5 medium category, Rf between 0.5 – 1.0 high category, Rf. 1.0 severe category.

METHOD

The framework is a conceptual model of the relationship between theory and various factors identified as important issues. The framework of thinking is useful in building a hypothesis so that it can be called the basis for constructing a hypothesis. The characteristics of the fuel used in co-firing can be analyzed through laboratory tests. Laboratory tests required include proximate analysis, ultimate analysis, ash analysis, Ash Fusion Temperature, and chlorine analysis. It is important to carry out laboratory tests on the fuel mixture used in addition to knowing the calorific value, it can be known the substances contained in the fuel and the substances formed in the combustion products so that the potential for slagging and fouling in boiler pipes can be predicted. Comparison of the characteristics between coal and palm shells was carried out by comparing the results of the analysis of ultimate and proximate materials obtained from the report of sampling and analysis of coal, palm shells, and a mixture of coal with a percentage of palm shells of 5%, 10%, 15%, and 20 %. For actual data comparison, the operating parameters were observed under conditions before and after the co-firing test or under unit operating conditions with 100% coal. The operating conditions of the units will be treated the same and use the same type of coal for both the 100% coal operation and the 5%, 10%, 15%, and 20% co-firing operation.

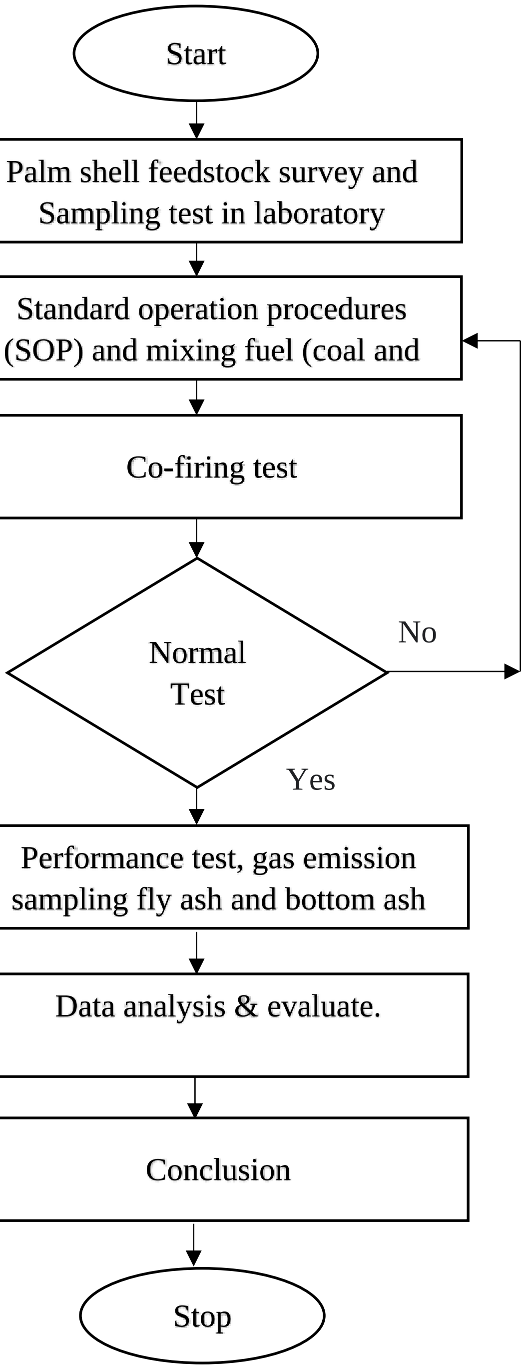

Figure 3. Flowchart of co-firing biomass

RESULTS AND DISCUSSION

Comparison of the characteristics between coal and palm shells was carried out by comparing the results of the ultimate and proximate analysis of fuel obtained from the report of sampling and analysis of coal, palm shells, and a mixture of coal with a percentage of palm shells of 5%, 10%, 15%, and 20% as listed in the table below. It is important to carry out laboratory tests on the fuel mixture used while knowing the heating value, knowing the substances contained in the fuel and the substances formed in the combustion products so that it can predict the potential for slagging and fouling in boiler pipes. In accordance with the results of the proximate analysis of fuel in table 1, the volatile matter content in palm shells is greater than coal, this makes the palm shells burn faster than coal, thereby helping to speed up the overall combustion process in the boiler. Palm shell also has a higher ash content compared to coal so that it can increase the amount of ash formed/produced from the boiler combustion process both for fly ash and bottom ash. Meanwhile, the calorific value of 4083 kCal/kg (ADB) indicates a relatively lower energy content compared to the low rank coal used with a value of 5099 kCal/kg (ADB). As for the mixed coal sample with a percentage of 5%, 10%, 15%, and 20% palm shells, the content of volatile matter and ash content is higher than the coal sample. The high ash content in the mixed sample of coal and palm shells has the potential to increase the ash produced in this combustion.

Table 1. Fuel proximate analysis

Parameter		Basis	Result						Unit
			5% BM	10% BM	15% BM	20% BM	100% BM	100% Coal	
Total Moisture		(ARB)	36.6	34.6	36.8	39.2	22.8	36.9	Pct
Inherent Moisture		(ADB)	13.6	19.2	22.8	21.0	9.7	21.0	Pct
Ash Content		(ADB)	4.7	4.8	3.7	4.4	9.6	3.6	Pct
Volatile Matter		(ADB)	40.7	41.5	39.2	39.3	63.4	38.1	Pct
Total Sulphur		(ADB)	0.58	0.4	0.4	0.6	0.1	0.5	Pct
Fixed Carbon		(ADB)	40.9	34.6	34.3	35.3	17.3	37.3	By Difference
Gross Caloric Value		(ARB)	4043	4,103	3,973	3,831	3,491	4,073	Kcal/Kg
Gross Caloric Value		(ADB)	5508	5,071	4,854	4,976	4,083	5,099	Kcal/Kg
Gross Caloric Value		(DAF)	6747	6,670	6,607	6,670	5,059	6,763	Kcal/Kg
Hardgrave Grindability Index			50	55.0	57.0	51.0	16.0	53.0	
Relative Density			1.41	1.4	1.3	1.4	1.3	1.3	Gram/ml
Chlorine		(ADB)	0.01	0.0	0.0	0.0	0.0	0.0	Pct
Size	+ 11.2 mm		22.7	36.0	39.3	36.3	10.0	39.6	Pct
	+ 4.75 mm		19.9	26.8	25.3	27.0	85.0	24.9	Pct
	+ 2.00 mm		18.2	13.8	13.5	13.8	4.0	12.9	Pct
	+ 1.00 mm		39.2	23.4	21.9	22.9	1.0	22.6	Pct

Table 2. Ultimate analysis, AFT, full analysis of fuel

Parameter			Basis	Result						Unit
				5% BM	10% BM	15% BM	20% BM	100% BM	100% Coal	
AFT	Reducing	Deformation		1,170	1,180	1,160	1,130	1,100	1,130	°C
		Spherical		1,190	1,210	1,180	1,150	1,170	1,150	°C
		Hemispherical		1,210	1,240	1,200	1,180	1,290	1,170	°C
		Flow		1,230	1,260	1,220	1,200	1,380	1,190	°C

	Oxidizing	Deformation		1,260	1,280	1,200	1,190	1,190	1,190	°C
		Spherical		1,280	1,300	1,220	1,220	1,240	1,200	°C
		Hemispherical		1,300	1,320	1,240	1,250	1,360	1,230	°C
		Flow		1,320	1,340	1,260	1,280	1,410	1,270	°C
Ultimate Analysis	Carbon		ADB	58.84	53.66	51.83	52.92	45.03	54.32	Pct
	Hydrogen		ADB	4.19	4.11	3.87	3.94	4.80	3.91	Pct
	Nitrogen		ADB	1.05	1.01	0.99	0.95	0.52	1.09	Pct
	Oxygen		ADB	17.04	16.86	16.43	16.15	30.26	15.62	Pct
Full analysis		SiO_2	DB	43.83	45.32	40.89	50.80	61.87	43.07	Pct
		Al_2O_3	DB	17.22	9.41	19.80	16.21	9.09	22.66	Pct
		Fe_2O_3	DB	16.14	12.35	17.47	15.28	15.99	15.77	Pct
		CaO	DB	7.67	12.44	10.21	3.89	5.13	4.48	Pct
		MgO	DB	1.31	2.85	2.44	0.77	2.96	0.32	Pct
		Na_2O	DB	1.54	1.56	0.60	1.55	0.35	1.42	Pct
		K_2O	DB	0.63	0.50	0.94	0.65	1.36	0.42	Pct
		MnO_2	DB	0.16	0.15	0.20	0.13	0.23	0.20	Pct
		TiO_2	DB	0.71	0.86	0.75	0.70	0.52	0.90	Pct
		P_2O_5	DB	0.26	0.20	0.24	0.22	0.21	0.24	Pct
		SO_3	DB	9.95	13.82	5.95	9.30	1.48	9.95	Pct
		Undetermined	DB	0.58	0.54	0.51	0.50	0.81	0.57	Pct

The operating conditions of the units tested will be treated the same and use the same type of coal for both the 100% coal operation test and the 5%, 10%, 15% and 20% co-firing operation test. Operational data collection for 5%, 10%, 15% and 20% co-firing testing of palm shells was carried out at 2 x 7 MW power plants. Furthermore, data collection was carried out for coal firing operations of 100% coal for 64.5 hours each with loading according to system requirements. Analysis is carried out on operating parameter data with a net load setting of +/- 7 MW. Comparison of coal firing and co-firing test operations can be seen as follows:

A. Load

The data collection on coal firing and co-firing tests was carried out at a net load setting of ± 7 MW, where the other parameter settings followed the setting at the 7 MW load. Analysis of operating parameters was taken from 5 test data in the net load range with a comparison of load and fuel consumption.

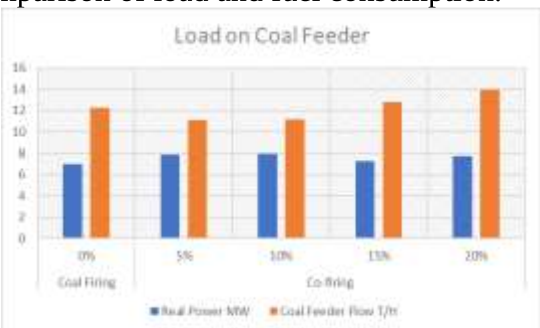

Figure 4. Load on coal feeder

Based on the graph in figure. 4, the testing load on co-firing is greater than coal firing with co-firing fuel consumption of 5% and 10% lower than coal firing. The production of electricity generated is very fluctuating due to following the needs of the grid system.

B. Furnace pressure dan furnace temperature

Based on the load test data generated in the coal firing and co-firing tests above, a comparison of the operating parameters of the furnace pressure and furnace temperature was obtained.

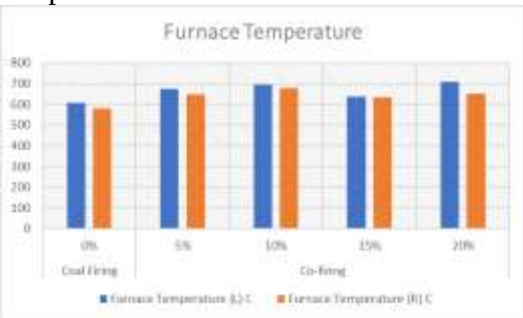

Figure 5. Furnace Temperature

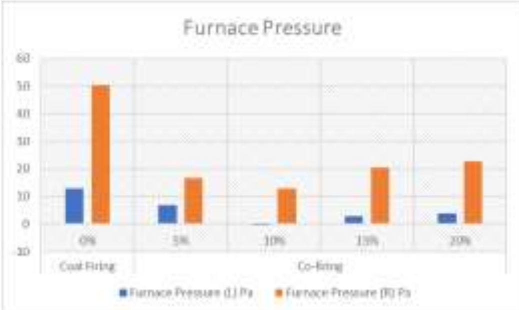

Figure 6. Furnace Pressure

From figure 5 and figure 6 it can be analyzed that the trend of furnace temperature during co-firing operation is higher than coal firing, while the trend of furnace pressure during co-firing operation is lower than coal firing test. The furnace during the second testing process looks unstable and very fluctuating. Unbalanced distribution of pressure in the furnace can be caused by an uneven distribution of mass flow. The average value of the trend of furnace temperature and furnace pressure of coal firing and co-firing figure 5 and figure 6 where there is a very significant measurement difference at each point from the right (right) and left (left). This could indicate non-uniformity of combustion in the left and right side of the furnace, or it could also be a less representative measurement. Besides that, the average pressure of the two tests is positive which can cause the flow of flue gas to slow down so that it can disrupt combustion. Therefore, it is necessary to control so that the combustion chamber pressure is negative by adjusting the opening of the IDF damper.

C. Steam Quality

The parameters needed to determine steam quality are main steam pressure, main steam flow and main steam temperature, the following comparisons with the average can be seen below.

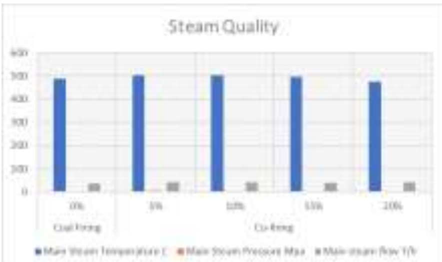

Figure. 7. Steam quality

From the three parameters, the main steam temperature, main steam flow and main steam pressure increased during co-firing. The parameter values fluctuate greatly due to load fluctuations according to grid requirements. The increase in the parameters of main steam temperature, main steam flow and main steam pressure during co-firing was caused by the higher volatile matter content of palm shells compared to coal, which increased the radiation of combustion and accelerated combustion in the furnace.

D. Emission

Many literatures conclude that co-firing biomass is a renewable energy source that has the potential to benefit from reducing pollutant production and being CO_2 neutral. Excessive CO_2 emissions can cause the Green House Gas (GHG) effect. The following are the results of measuring CO_2 and CO emissions:

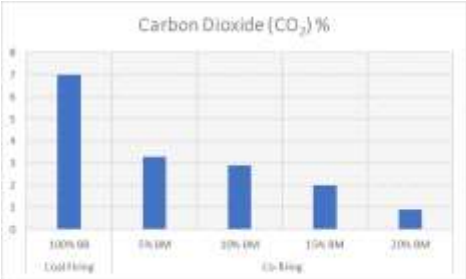

Figure 8. Carbon dioxide (CO_2)

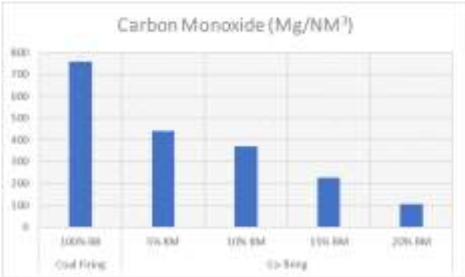

Figure 9. Carbon monoxide (CO)

From the chart above the use of palm kernel shell biomass reduces greenhouse emissions significantly. the more biomass used, the lower the emission value.

E. Potential for corrosion, slagging, and fouling

Potential resistance to heat transfer in boiler pipes needs to be known to maintain boiler efficiency by calculating slagging, fouling and 2S/CI index for both tests whose values can be seen in the table below:

Table 3. Slagging and fouling index

Parameter	Coal Firing	Co-firing			
	100%	5%	10%	15%	20%
Base to acid ratio	0.34	0.44	0.53	0.52	0.33
Slagging Index	0.15	0.26	0.19	0.2	0.21
Fouling Index	0.62	0.96	1.10	0.79	0.72
Ratio 2S/Cl	101.72	128.26	79.61	84.03	70.76

Based on the calculation results above according to the literature review, the following results are obtained: The base to acid ratio during the co-firing test of 5%, 10% and 15% of palm shells is in the high/severe category, Slagging index during coal firing and co-firing is still within safe limits, Fouling index during coal firing and co-firing of 5%, 15% and 20% of palm shells is in the high category, while co-firing is 10% of palm shells is in the severe category, and based on data on sulfur and chlorine in the fuel, the 2S/Cl ratio during coal firing and co-firing is >8 so that the potential for corrosion due to the presence of chlorine is Cl-induced active oxidation minor.

F. Co-firing fly ash and bottom ash quality test

During the co-firing implementation, fly ash and bottom ash were also tested in laboratory. The results are obtained as follows:

Table 4. Bottom Ash Toxicity Characteristic Leaching Procedures

Test Parameters	5% BIO	10% BIO	15% BIO	20% BIO	100% COAL	Standards *) A	Standards *) B	Unit
Sb (Antimoni)	<0.0206	<0.0206	<0.0206	<0.0206	<0.0206	6	1	mg/L
As (Arsen)	<0.0107	<0.0107	<0.0107	<0.0107	<0.0107	3	0.5	mg/L
Ba (Barium)	<0.0072	<0.0072	<0.0072	<0.0072	<0.0072	210	35	mg/L
Be (Berilium)	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	4	0.5	mg/L
B (Boron)	0.11	0.36	0.19	0.07	0.21	150	25	mg/L
Cd (Kadmium)	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	0.9	0.15	mg/L
Cr6+ (Krom Valensi Enam)	<0.030	<0.030	<0.030	0.067	0.08	15	2.5	mg/L
Cu (Tembaga)	<0.0148	<0.0148	<0.0148	<0.0148	<0.0148	60	10	mg/L
Pb (Timbal)	<0.0081	<0.0081	<0.0081	<0.0081	<0.0081	3	0.5	mg/L
Hg (Raksa)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	0.3	0.05	mg/L
Mo (Molibdenum)	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	21	3.5	mg/L
Ni (Nickel)	<0.0022	0.03	<0.0022	<0.0022	0.02	21	3.5	mg/L
Se (Selenium)	<0.0083	0.02	<0.0083	<0.0083	0.03	3	0.5	mg/L
Ag (Perak)	<0.0120	<0.0120	<0.0120	<0.0120	<0.0120	40	5	mg/L
Tributyltin oxide *)	<0.001	<0.001	<0.001	<0.001	<0.001	0.4	0.05	mg/L
Zn (Seng)	<0.0163	<0.0163	<0.0163	<0.0163	<0.0163	300	50	mg/L
ANION:								
Chloride	1.41	41.72	32.34	68.91	2.88	75000	12500	mg/L
Cyanide (total) *)	0.008	<0.005	<0.005	<0.009	<0.005	21	3.5	mg/L
Fluoride	<0.009	0.1	<0.009	<0.07	<0.009	450	75	mg/L
iodide *)	2.64	3.54	3.6	1.6	1.86	40	5	mg/L

Nitrate *)	19.41	21.2	19.43	23.3	20.92	15000	2500	mg/L
Nitrite *)	0.01	<0.003	<0.003	0.01	0.08	900	150	mg/L

Table 5. Fly Ash Toxicity Characteristic Leaching Procedures

Test Parameters	5% BIO	10% BIO	15% BIO	20% BIO	100% COAL	Standard *) A	B	Satuan
Sb (Antimoni)	<0.0206	<0.0206	0.03	0.02	<0.0206	6	1	mg/L
As (Arsen)	<0.0107	<0.0107	<0.0107	<0.0107	<0.0107	3	0.5	mg/L
Ba (Barium)	<0.0072	<0.0072	<0.0072	<0.0072	<0.0072	210	35	mg/L
Be (Berilium)	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	4	0.5	mg/L
B (Boron)	0.2	0.17	0.07	0.01	0.02	150	25	mg/L
Cd (Kadmium)	<0.0006	<0.0006	<0.0006	<10.0006	<0.0006	0.9	0.15	mg/L
Cr6+ (Krom Valensi Enam)	0.056	0.058	0.061	<0.030	0.058	15	2.5	mg/L
Cu (Tembaga)	<0.0148	<0.0148	<0.0148	<0.0148	<0.0148	60	10	mg/L
Pb (Timbal)	0.01	-0.0081	0.01	0.01	<0.0081	3	0.5	mg/L
Hg (Raksa)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	0.3	0.05	mg/L
Mo (Molibdenum)	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	21	3.5	mg/L
Ni (Nikel)	0.03	<0.0022	0.01	<0.0022	<<0.0022	21	3.5	mg/L
Se (Selenium)	0.02	<0.0083	0.02	<0.0083	<0.0083	3	0.5	mg/L
Ag (Perak)	<0.0120	<0.0120	<0.0120	<0.0120	<0.0120	40	5	mg/L
Tributyltin oxide *)	<0.001	<0.001	<0.001	<0.001	<0.001	0.4	0.05	mg/L
Zn (Seng)	<0.0163	<0.0163	<0.0163	<0.0163	<0.0163	300	50	mg/L
ANION:								
Chloride	64.45	45.7	82.27	18.98	75	75000	12500	mg/L
Cyanide (total) *)	<0.005	0.009	<0.005	0.011	<0.005	21	3.5	mg/L
Fluoride	<0.009	0.09	<0.009	<0.009	<0.009	450	75	mg/L
iodide *)	1.74	3.53	2.63	2.54	1.5	40	5	mg/L
Nitrate *)	19.73	22.19	19.15	23.93	19.8	15000	2500	mg/L
nitrite *)	<0.003	<0.003	<0.003	0.01	0.01	900	150	mg/L

From the table test data above, both fly ash and bottom ash are still in accordance with quality standards and are not dangerous.

CONCLUSION

Comparison of Load and Coal feeder can be seen in the co-firing test which is lower than coal firing. Coal firing 12.23 t/h and Co-firing 11.18 t/h when 5% mixing. Based on the operating parameter data, it shows that the trend of the furnace temperature during co-firing operation is higher than the coal firing test, the trend furnace pressure during co-firing operation is lower than the coal firing test, Co-firing furnace temperature 608.09^{0}C and Co-firing 706.96^{0}C for furnace pressure coal firing 13.06 Pa and Co-firing 3.83 Pa. The increase in main steam pressure and main steam temperature during co-firing can be caused by the higher volatile matter content of palm shells compared to coal, thereby increasing the radiant energy of combustion, and accelerating combustion in the furnace. Value of coal firing main steam temperature, main steam pressure and main steam flow respectively 489.33^{0}C, 4.03 MPa, 36.67 t/h for Co firing 504.32^{0}C, 4.12 MPa, 41.02 t/h. Slagging index during coal firing and co-firing is still within safe limits, Fouling index during coal firing and co-firing of 5%, 15% and 20% of palm shells is in the high category, while co-firing is 10% of palm shells is in the severe category. The 2S/Cl ratio during coal firing and co-firing is >8 so that the potential for corrosion due to the presence of chlorine is Cl-induced active oxidation minor, and both fly ash and bottom ash are still in accordance with quality standards and are not dangerous.

SUGGESTION

Co-firing is a strategic program to increase the new renewable energy mix by 23% in 2025 and is the right step towards carbon neutral in 2060 and Indonesia is a country that is abundant in biomass. Apart from contributing to increasing the contribution of renewable energy to the national energy mix, Co-firing is also having a positive impact on the development of the people's economy (circular economy) so increasing the percentage of co-firing by 100% is the right way.

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