International Journal of Application on Sciences, Technology and Engineering (IJASTE)
Volume 1, Issue 1, 2023.ISSN:2987-2499

Investigation on Potential of Slagging Fouling and Corrosion in Co-firing Bituminous Coal and Sorghum Waste Pellet

Suyatno[1], Hariana[1, a)], Mochammad Zulfikar Eka Prayoga[1], Agus Sugiyono[1], Ichsan Maulana[2], Ade Sana Ruhiyat[1], and Yudi Hidayat[3]

[1]*The National Research and Innovation Agency, Build. 480, PUSPIPTEK South Tangerang, Banten, 15314, Indonesia.*
[2]*STIE Mahardika, Surabaya, Indonesia*
[3]*PT Indonesia Power*

[a)] *Correspondening author: hariana@brin.go.id*
Submitted: November-December 2022, Revised: January 2023, Accepted: February 23, 2023

Abstract. Indonesia is a country with a very large population. Coal power plant is the largest source of electrical energy in Indonesia to meet the public's electricity supply. The problem currently being faced is that coal power plant produces high levels of CO_2 emissions. Cofiring is a solution to deal with emission problems that occur. The great potential of biomass waste can be used as a coal mixture during combustion. Sorghum is one of the food crops in Indonesia with the utilization of waste that is still not optimal. This study aims to determine the potential of slagging fouling cofiring sorghum biomass with coal from East Kalimantan. The method used is blended with a composition of 5%; 10% and 15%. From the results obtained, the data shows that the potential for slagging from coal and blending is included in the medium category, while for sorghum biomass it is in the low risk potential. The results of the analysis of coal fouling and blending are included in the high risk potential, while the sorghum biomass is in the medium risk.

INTRODUCTION

As an archipelago and agricultural country, the utilization of biomass waste in Indonesia is still not maximized. Currently, the energy sector is still a priority which is supported by fossil fuels [1]. Biomass is a renewable carbon source that can produce renewable chemicals and fuels [2], [3]. Coal is still the main choice for fuel in power plants in Indonesia, but coal has a problem resulting from the greenhouse gas effect. The main problem that arises when generating electricity using coal-fired power plants is the level of emissions produced. Based on data from the IEA in 2019, coal power plant contributed 10% of CO_2 and 75% SO_2 emissions, 70% NOx, and more than 90% of particulate emissions from the total emissions released by power plants [4]. This is contrary to the agreement in the touching Paris Agreement to reduce CO_2 emission levels to below 2% [5]. One that can be a solution to reduce gas emissions is by adding co-firing biomass additives to combustion in power plants [6].

Cofiring is a combustion process of two different types of materials and operated together. Combustion with cofiring provides many advantages in terms of material efficiency and maintenance costs, in addition to reducing CO_2, SOx and NOx emissions from fossil fuels. The use of biomass as co-firing generally causes slagging fouling [7]. Some others have corrosion due to chlorine [8], [9]. However, there are several ways to improve the occurrence of slagging fouling [10]–[13] among others, by pretreatment to improve the quality of raw materials.

This study predicts the potential for slagging fouling, corrosion, co-firing corrosion between coal and sorghum biomass as a research contribution in improving the quality of coal power plant fuel and diversifying new and renewable energy sources. Sorghum biomass is used in the form of pellets obtained from processing tree trunks from agricultural land in the East Java area. The majority of sorghum plants grown are sorghum bicolor (L) Moench which is a type of food plant that is taken from the fruit part, while other parts of the plant have the potential to be developed as co-firing biomass. The co-firing scheme carried out in this study provides coal and sorghum biomass blends with a composition in weight of 5%, 10%, and 15%.

https://doi.org/10.24912/ijaste.v1.i1.197-203

MATERIAL AND METHODS

Sorghum biomass are obtained from agricultural products in the East Java region of Indonesia, while the coal used is East Kalimantan coal, which is a bituminous type. For the preparation of coal, a 200 mesh pass was sifted, as was the sorghum biomass. Coal and sorghum biomass are then blended. Figure 1 below show coal, sorghum biomass, and the result of their blending.

FIGURE 1. (a) Coal 100%, (b) Sorghum 100%, (c) Coal 95%+Sorghum 5%, (d) Coal 90%+Sorghum 10%, (e) Coal 85%+Sorghum 15%

After preparing samples from the coal, sorghum biomass and their blending, the next step is to check the laboratory scale analysis to find out the initial predictions. The method used is a blending of East Kalimantan coal and sorghum biomass with a composition in weight % of 95 - 5, 90 - 10, and 85 - 15. **FIGURE 2** is a flow diagram from preparation to material analysis

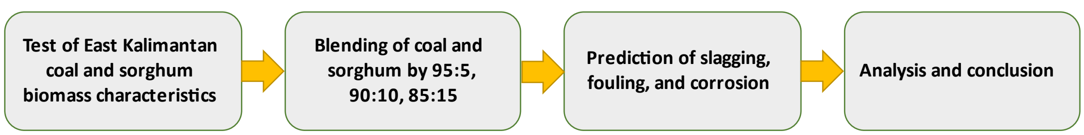

FIGURE 2. Flow Diagram Of Study

For prediction of slagging fouling, general parameters such as slagging index, fouling index, acid-base, alkali, and others are used based on [14]. **TABLE 1.** attached the parameters and risk criteria for potential abrasion, corrosion, and slagging fouling:

TABLE 1. Parameters risk criteria of corrosion, slagging, fouling, and abrasion calculation

No	Indices	Low	Medium	High	Severe	Reference
Slagging Indication						
1	B/A ratio	< 0.4 or > 0.7		0.4 – 0.7		[14]
2	Silica ratio	72 – 80	65 – 72	50 – 65	-	[15]
3	Slagging index	< 0.6	0.6 – 2.0	2.0 – 2.6	> 2.6	[14]
4	Fusibility	> 1343	1232–1343	1149-1232	< 1149	[16]
5	Fe/Ca	< 0.3 or > 3.0		0.3 – 3.0		[17]
6	Fe	3 – 8	8 – 15	15 – 23	> 23	[15]
7	Fe+Ca	< 10 %		> 12%		[18]
8	Si/Al	< 0.7 or > 3.5		0.7 – 3.5		[13]

https://doi.org/10.24912/ijaste.v1.i1.197-203

Fouling Indication						
1	Fouling index	< 0.2	0.2 – 0.5	0.5 – 1.0	> 1.0	[14]
2	Na_2O in ash: $CaO+MgO+Fe_2O_3 < 20\%$	< 1.2		1.2 – 3.0	> 3.0	[14]
	Na_2O in ash: $CaO+MgO+Fe_2O_3 > 20\%$	< 3.0		3.0 – 6.0	> 6.0	[14]
3	Total alkali	< 0.3	0.3 – 0.45	0.45 – 0.6	> 0.6	[15]
Abrasion Index						
1	Abrasion index	< 4.0	4.0 – 8.0	8.0 – 12.0	> 12.0	[15]
Corrosion Indication						
1	Total Chlorine	< 0.3	0.3 – 0.5	> 0.5	-	[15]
2	S/Cl	> 4.0	2.0 – 4.0	< 2.0	-	[19]

After obtaining the value of the parameter, it is then quantified using the value of the risk criteria based on [20], [21] where for a value of 0.0 it is classified as low risk, 0.5 for medium risk and 1.0 for high risk Furthermore, for slagging predictions, the calculation is determined from 8 parameters if as in **Table 1** above, if the results obtained value <3.5 is classified as low risk, for 4-5 medium risk and >5 high risk. As for the prediction of fouling, the values obtained from the 3 parameters in the table above, if the range <1 is low, for the range 1-1.5 it is moderate risk and >2 is high risk. The abrasion parameter is based on the quantification result above. Furthermore, to determine the level of corrosion, it consists of 2 parameters with values, if <1 is included in the low risk, for 1 is included in the moderate risk, and if >1 is in the high risk category. **TABLE 2** below shows the slagging fouling and corrosion scores.

TABLE 2. The score of slagging and fouling

Risk	Low	Medium	High
Slagging	≤ 3.5	4 – 5	> 5
Fouling	< 1	1 – 1.5	≥ 2
Abrasion	< 4	4.0 – 8.0	8.0 – 12.0
Corrosion	<1	1	>1

https://doi.org/10.24912/ijaste.v1.i1.197-203

RESULTS AND DISCUSSION

Material Characteristics

Based on Table 3. AFT of coal is quite high, while for sorghum biomass it tends to be low for PC boilers at 1020°C. Based on the observation of the ash composition, it was found that coal has medium SiO_2 while the sorghum biomass tends to be high. Al_2O_3 for coal is quite high at 21.16%, Fe_2O_3 for sorghum biomass is low, while for medium coal. Low CaO and low Na_2O are less than 2% [17]. This composition causes the AFT value of sorghum biomass to be lower than coal [13]. Potassium for coal is low while sorghum biomass is high at 17.35%, this is quite risky for pure sorghum biomass.

TABLE 3. Characteristics and composition of ash sample

Parameter		Coal	Sorghum	Coal and Sorghum Blend With Composition in Weight % of		
				95-5	90-10	85-15
Total Moisture, %	ar	23.13	8.5	22.40	21.67	20.94
Moisture in the sample, %	adb	9.34	7.5	9.25	9.16	9.06
ash content, %	adb	6.88	9.7	7.04	7.20	7.36
Volatile matter, %	adb	39.7	66.6	41.25	42.77	44.27
Fixed carbon by difference, %	adb	44.08	16.2	42.46	40.87	39.30
Total Sulfur, %	adb	0.6	0.1	0.57	0.57	0.51
Gross calori value, kcal/kg	adb	6045	4064	5929	5816	5704
Gross calori value, kcal/kg	ar	5126	4020	5071	5015	4960
Gross calori value, kcal/kg	db	6668	4394	6534	6402	6273
Total Chlorine	ppm	110	1000	161	212	262
Ultimate Analysis						
Carbon, %	adb	66.24	39.5	64.68	63.15	61.65
Hydrogen, %	adb	4.43	4.73	4.45	4.46	4.48
Nitogen, %	adb	1.37	0.72	1.33	1.30	1.26
Oxygen by difference, %	adb	20.48	40.81	21.65	22.81	23.94
AFT Reducing						
Deformation, ºC	atm	1230	1020	1230	1200	1215
Spherical, ºC	atm	1240	1125	1280	1240	1235
Hemisphere, ºC	atm	1300	1160	1320	1250	1260
Flow, ºC	atm	1320	1200	1350	1290	1320
AFT Oxidizing						
Deformation, ºC	atm	1280	1060	1290	1220	1225
Spherical, ºC	atm	1300	1135	1330	1245	1250
Hemisphere, ºC	atm	1360	1165	1350	1255	1295
Flow, ºC	atm	1380	1215	1370	1300	1330
Ash Analysis						
SiO_2, %	% in ash	53.46	61.80	54.12	54.75	55.34
Al_2O_3, %	% in ash	21.16	5.14	19.88	18.68	17.56
Fe_2O_3, %	% in ash	9.66	0.85	8.96	8.30	7.68

https://doi.org/10.24912/ijaste.v1.i1.197-203

CaO, %	% in ash	3.88	7.24	4.15	4.40	4.64
MgO, %	% in ash	3.14	1.16	2.98	2.83	2.69
TiO_2, %	% in ash	0.78	0.20	0.73	0.69	0.65
Na_2O, %	% in ash	1.96	0.01	1.80	1.66	1.52
K_2O, %	% in ash	1.92	17.35	3.15	4.30	5.39
Mn_3O_4, %	% in ash	0.074	0.060	0.073	0.072	0.071
P_2O_5, %	% in ash	0.259	3.550	0.521	0.768	0.999

The calorific value of coal tends to be higher than that of sorghum biomass and blended, where the calorific value of coal is 6668 kcal/kg while that of sorghum biomass and blended is between 4394–6534 kcal/kg. Coal ash content is moderate while sorghum biomass is quite high at 9.7%. The sulfur content of sorghum biomass tends to include low, which is only 0.1%. Based on the chlorine content for sorghum biomass it is quite high at 1000 ppm while East Kalimantan coal is only 110 ppm while the chlorine content for blending ranges from 161–262 ppm.

Prediction Slagging Fouling

Prediction of slagging fouling is used to determine the criteria of raw materials for coal, sorghum biomass and blending results. From the formula used, the data is attached below:

TABLE 4. Calculation of Slagging Fouling Predictions

Indication		**Coal**	**Sorghum**	**Coal and Sorghum Blend With Composition in Weight % of**		
				95-5	**90-10**	**85-15**
Slagging Indication						
B/A ratio	calc	0.27	0.40	0.28	0.29	0.30
	score	0.00	0.00	0.00	0.00	0.00
Silica ratio	calc	76.22	86.98	77.09	77.90	78.66
	score	0.00	0.00	0.00	0.00	0.00
Slagging Index	calc	0.18	0.04	0.18	0.17	0.17
	score	0.00	0.00	0.00	0.00	0.00
Fussibility	calc	1256	1049	1254	1211	1231
	score	0.50	1.00	0.50	1.00	1.00
Fe_2O_3 / CaO	calc	2.49	0.12	2.16	1.89	1.66
	score	1.00	0.00	1.00	1.00	1.00
Percentage of Fe_2O_3	calc	9.66	0.85	8.96	8.30	7.68
	score	0.50	0.00	0.50	0.50	0.00
Fe_2O_3 + CaO	calc	13.54	8.09	13.11	12.70	12.31
	score	1.00	0.00	1.00	1.00	1.00
SiO_2 / Al_2O_3	calc	2.53	12.02	2.72	2.93	3.15
	score	1.00	0.00	1.00	1.00	1.00
Total Slagging		4.00	1.00	4.00	4.50	4.00
Fouling Indication						
CaO+MgO+Fe_2O_3 … 20	calc	16.68	9.25	16.09	15.53	15.01
	score	<	<	<	<	<
Index Fouling	calc	0.53	0,00	0.51	0.48	0.45
	score	1.00	0.00	1.00	0.50	0.50
Na_2O in ash	calc	1.96	0.01	1.80	1.66	1.52
	score	1.00	0.00	1.00	1.00	1.00

https://doi.org/10.24912/ijaste.v1.i1.197-203

Total alkali	calc	0.22	1.11	0.27	0.32	0.37
	score	0.00	1.00	0.00	0.50	0.50
Total Fouling		2.00	1.00	2.00	2.00	2.00
Abrasion Index	calc	3.07	7.06	3.30	3.52	3.75
	score	0.00	0.50	0.00	0.00	0.00
Corrosion Indication						
Total Chlorine	calc	0.011	0.100	0.016	0.021	0.026
	score	0.00	0.00	0.00	0.00	0.00
S/Cl	calc	49.33	0.90	31.98	23.13	17.77
	score	0.00	1.00	0.00	0.00	0.00
Total Corrosion		0.00	1.00	0.00	0.00	0.00

	LOW		**MEDIUM**		**HIGH**

Based on **TABLE 4**, the analysis results are obtained for the prediction of corrosion, abrasion and slagging fouling. The potential for abrasion and corrosion for coal and blending sorghum biomass is included in the low risk category, while pure sorghum biomass are medium risk. This is due to the high chlorine content in sorghum biomass. Meanwhile, the potential for slagging in coal and blended sorghum biomass is 5%; 10% and 15% are included in the medium category, and sorghum biomass is in a lower category, because the SiO_2 content in sorghum biomass is the highest, resulting in low slagging [22], while coal and high Na_2O blending result in its characteristics in the medium class [14]. The fouling analysis shows that the figures from the calculation of coal and blending of sorghum biomass are classified as high risk characteristics, while sorghum biomass is still in the medium category. This is because the Na_2O content exceeds the 1.2% threshold [14]. East Kalimantan coal has medium grade slagging results and high risk fouling. This coal is included in bituminous ash coal, but has a high Na_2O value. For sorghum biomass, the slagging value is low because it has a high SiO_2 value. As for the results of blending coal and sorghum biomass, the changes are not significant because even though sorghum biomass can add SiO_2 value, high CaO content results in high fouling or high risk.

CONCLUSION

Based on the results above, it can be concluded as follows:

1. Initial prediction of corrosion and abrasion indications for East Kalimantan coal and blending of 5%, 10% and 15% sorghum biomass are included in the low risk category, while pure sorghum biomass is medium risk.
2. The potential for slagging from East Kalimantan coal and blending results of 5%, 10%, 15% is included in the medium risk category, while for pure sorghum biomass, it is low risk.
3. The potential for fouling from East Kalimantan coal and blending results of 5%, 10%, 15% is included in the high risk category, while for pure sorghum biomass it is medium risk.
4. From the results above, it can be concluded that the cofiring of East Kalimantan coal with sorghum biomass need to be chek more detail in combustion furnace. Combustion Furnace/Drop Tube Furnace is a tool used to test coal combustion with similar conditions in a steam power plant boiler. By testing trough drop tube furnace, it is possible to know in more detail the more accurate result of the slaaging fouling.

REFERENCES

1. Dirjen Ketenagalistrikan, *Statistik Ketenagalistrikan* pp. 1689–1699, (2022)
2. C. Zhao, Q. Shao, and S. P. S. Chundawat, Bioresour. Technol., vol. **298**, p. 122446, (2020)
3. G. Kumar *et al.*, Fuel, vol. **251**, no. February, pp. 352–367, (2019)

https://doi.org/10.24912/ijaste.v1.i1.197-203

4. B. Priyavrat, S. Mandvi, and I. Shruti, *Indonesia's Coal Power Emission Norms: Lesson From India and China*, New Delhi, (2017)

5. BAPPENAS, *Low Carbon Development Initiative*, Jakarta, (2019)

6. PP No 22 tahun 2017, *Rencana Umum Energi Nasional*, Jakarta, (2017)

7. H. Liu *et al.*, Energy and Fuels, vol. **34**, no. 12, pp. 15448–15487, (2020)

8. Okoro et al, Energy and Fuels, vol. **32**, no. 7, pp. 7991–7999, (2018)

9. S. Yu *et al.*, Fuel Process. Technol., vol. **198**, no. September 2019, p. 106234, (2020)

10. K. Cen, X. Zhuang, Z. Gan, Z. Ma, M. Li, and D. Chen, Energy Reports, vol. **7**, pp. 732–739, (2021)

11. W. Ma, T. Wenga, F. J. Frandsen, B. Yan, and G. Chen, Prog. Energy Combust. Sci., vol. **76**, p. 100789, (2020)

12. Karnowo, Z. F. Zahara, S. Kudo, K. Norinaga, and J. I. Hayashi, Energy and Fuels, vol. **28**, no. 10, pp. 6459–6466, (2014)

13. T. Yan, Fuel, vol. **193**, pp. 275–283, (2017)

14. J. B. Kitto and S. C. Stultz, *Steam: Its Generation and Use 41st Edition*. (The Babcock & Wilcox Company,United States of America, 2005), pp. 460-487

15. E. Raask, *Mineral impurities in coal combustion: behavior, problems, and remedial measures*. (Hemisphere Publishing Corporation,New York, 1985), pp. 161-165

16. C. Yin, Z. Luo, M. Ni, and K. Cen, Fuel, vol. **77**, no. 15, pp. 1777–1782, (1998)

17. R. W. Bryers, Prog. Energy Combust. Sci., vol. **22**, no. 1, pp. 29–120, (1996)

18. P. P. Płaza, Cardiff Sch. Eng., p. 227, (2013)

19. J. L. et al. Míguez, Renew. Sustain. Energy Rev., vol. **2021**

20. H. P. Hariana, Putra and F. M. Kuswa, no. December, (2020)

21. Hariana *et al.*, IOP Conf. Ser. Earth Environ. Sci., vol. **882**, no. 1, (2021)

22. S. Hui, Y. Lv, Y. Niu, H. Kan, D. Wang, and P. Li, Fuel, vol. **258**, no. August, p. 116137, (2019)

https://doi.org/10.24912/ijaste.v1.i1.197-203