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Slagging, Fouling, Abrasion, and Corrosion Potential in Cofiring Biomass SRF With Bituminous Coal Blend

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ABSTRACT

Paris Agreement has prompted the world for using clean energy. Biomass Solid Recovered Fuel (SRF) has the potential to substitute fossil fuel for supplying energy. However, several problems such as slagging, fouling, abrasion, and corrosion need to be investigated before applying SRF as fuel. This study was conducted to evaluate slagging, fouling, abrasion, and corrosion potential in blending Indonesian coals with SRF by using an initial prediction calculation based on ash characteristics. Indonesian coals (MRC Coal and LRC Coal) and SRF was blended with various composition. 50% MRC Coal and 50% LRC Coal was blended to obtain A Coal. Then, blending 5%-25% SRF with A Coal was conducted to obtain other coals. Then, the risk level of those potentials was classified based on a certain score. High slagging risk and medium fouling risk were obtained in blending Indonesian coal with 25% SRF. However, the use of 20% SRF in a blend of Indonesian coal and SRF is still safe although it could increase the slagging potential to medium risk. Increased risk of abrasion and corrosion was not found in any composition.

Keywords: Indonesian coal, biomass SRF, slagging, fouling, abrasion, and corrosion

NOMENCLATURE

Abbreviations	
ar	As received
adb	As dry basis
db	Dry basis
atm	Atmospheric
Symbols	
B/A	Base/Acid
kcal	Kilocalorie
kg	Kilogram

1. INTRODUCTION

In Presidential Regulation No. 22 of 2017, Indonesia has committed to increasing the use of new and renewable energy. Besides the international pressure through the Paris Agreement in 2016 regarding the reduction of carbon emission, the potential of biomass in Indonesia that can be used as an alternative fuel is also very abundant. Biomass resources can be found easily in Indonesia such as forest biomass [1].

Biomass can also be obtained from waste [1]. About 38.5 million tons of solid waste is generated in Indonesia with an estimated increase of 2-3% every year. With that amount, Indonesia has the potential to use waste biomass as an alternative fuel [2]. To take advantage of that potential, waste biomass can be used as fuel for co-firing in power plants. In Regulation of the President

Director of PT. PLN No. 001.P/DIR/2020, Indonesian State Electricity Company (PT. PLN) is also conducting trials of co-firing biomass in several of their power plants. Solid Recovered Fuel (SRF), a type of waste that can be used as fuel, comes from household waste and other combustible waste. There is also special treatment in SRF processing to obtain fuel specifications that are following market demand [3].

Besides the potential of waste biomass, some risks may occur due to the use of waste biomass for cofiring such as slagging and fouling. Slagging and fouling are phenomena when the ash from the combustion of fuel melts and sticks to the surface of the boiler [4]. The potential of abrasion and corrosion also needs to be considered because can affect the efficiency and lifetime of the boiler [5–7].

In supporting the Indonesian government to increase the use of new and renewable energy, it is necessary to study the potential of slagging, fouling, abrasion, and corrosion in biomass cofiring. This study aims to evaluate those potentials in Indonesian coals and SRF biomass blends. This evaluation is conducted by using the calculation of the prediction of those potentials based on the ash characteristics of each coal, SRF biomass, and a blend of both.

2. EXPERIMENT

2.1 Materials

Coals (MRC Coal and LRC Coal) and biomass (SRF) from Indonesia were used in this study. SRF was processed from sorted municipal solid waste with a composition of 60% household waste, 20% local market waste, and 20% woodchip from garden waste. Then, SRF was dried by using bacteria additional bio-drying process until the total moisture of SRF was about 20%.

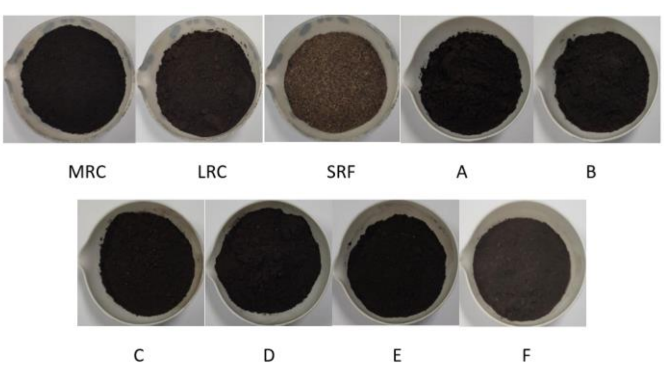

Fig. 1. Coals and biomass blends

Then, those materials were blended to produce multiple blends. 50% of MRC Coal and 50% of LRC Coal were blended to obtain A Coal. Then, blending 95% A Coal with 5% SRF was called B Coal. C Coal was a blend of 90% A Coal and 10% SRF. D Coal was A Coal (85%) and SRF (15%) blend. E Coal was a blend of 80% A Coal and 20% SRF. F Coal was A Coal (75%) and SRF (25%) blend. The result of blending was shown in Fig. 1.

2.2 Equipment

Materials were prepared by using equipment to pulverize, milling, sieve, and blend. Then, all samples were analyzed to find the characteristics. Analysis of coal and biomass blends was conducted by using equipment that complies with the American Society for Testing and Materials (ASTM) as shown in Table 1.

Table 1. ASTM for analysis of coals and biomass blends

Total moisture	ASTM D3302/D3302M-2017
Sample moisture	ASTM D3173-2017
Ash content	ASTM D3174-2012
Volatile matter	ASTM D3175-2017
Fixed carbon	ASTM D3172-2013
Total sulfur	ASTM D4239-2017
Gross Calorific Value	ASTM D5865-2013
Ultimate analysis	ASTM D5373-2016
Oxygen	ASTM D3176-2015
Ash analysis	ASTM D3682-2013 ASTM D5016-2016
Ash Fusion Temperature	ASTM D1857-2017
Total chlorine	ASTM D4208-2019

2.3 Methods

The test results were used to calculate slagging, fouling, abrasion, and corrosion potential. The prediction of those potentials was calculated according to indices in Table 2. After each parameter was calculated, the result of each parameter was classified based on the classification in Table 2. Then, the risk of each parameter was converted into a certain score. If the risk is low, the score is 0.00; if the risk is medium, the score is 0.50; and if the risk is high, the score is 1.00 [8–10].

After the risk of each parameter was converted, the scores of each parameter for each slagging, fouling, abrasion, and corrosion were totaled. Then, the prediction of those potentials was determined based on that score. For slagging prediction, if the score is below or equal to 3.5, the risk is low; if the score is between 4.0 to 5.0, the risk is medium; and if the score is above 5.0, the risk is high. For fouling prediction with 3 parameters, if the score is below 1.0, the risk is low; if the score is between 1.0 to 1.5, the risk is medium; and if the score is above or equal to 2.0, the risk is high. For corrosion, if the score is below 1.0, the risk is low; if the score is equal to 1.0, the risk is medium; and if the score is above 1.0, the risk is high.

Table 2. Slagging, fouling, abrasion, and corrosion parameters

No	Indices		Low	Medium	High	Severe	Reference
Slagging Indication							
1	B/A ratio		< 0.4 or > 0.7		0.4 – 0.7		[11]
2	Silica ratio		72 – 80	65 – 72	50 – 65	-	[10]
3	Slagging index		< 0.6	0.6 – 2.0	2.0 – 2.6	> 2.6	[10]
4	Fusibility		> 1343	1232–1343	1149-1232	< 1149	[10]
5	Fe/Ca		< 0.3 or > 3.0		0.3 – 3.0		[12]
6	Fe		3 – 8	8 – 15	15 – 23	> 23	[13]
7	Fe+Ca		< 10%		> 12%		[9]
8	Si/Al		< 0.7 or > 3.5		0.7 – 3.5		[14]
Fouling Indication							
9	Fouling index		< 0.2	0.2 – 0.5	0.5 – 1.0	> 1.0	[15]
10	Na2O in ash	CaO+MgO+ Fe2O3 < 20%	< 1.2		1.2 – 3.0	> 3.0	[15]
		CaO+MgO+ Fe2O3 > 20%	< 3.0		3.0 – 6.0	> 6.0	
11	Total alkali		< 0.3	0.3 – 0.45	0.45 – 0.6	> 0.6	[13]
Abrasion Indication							
12	Abrasion index		< 4.0	4.0 – 8.0	8.0 – 12.0	> 12.0	[13]
Chlorine Indication							
13	Total chlorine		< 0.3	0.3 – 0.5	> 0.5	-	[13]
14	S/Cl		> 4.0	2.0 – 4.0	< 2.0	-	[16]

3. RESULTS AND DISCUSSION

3.1 Materials Characteristics

All samples were tested to find the characteristics. The result of the test can be seen in Table 3. For comparison between MRC Coal, LRC Coal, and SRF, the ash content in SRF was higher than in other samples with a percentage of 28.9%. Ash content in MRC Coal was 8.31% and LRC Coal was 10.95%. Then, the total sulfur in SRF was 0.47%. It was higher than LRC Coal but lower than MRC Coal. Total sulfur in MRC Coal was 0.62% and LRC Coal was 0.23%. SRF had a calorific value that was lower than MRC Coal and LRC Coal with a value of 2923 kcal/kg. The calorific value in MRC Coal was 4766 kcal/kg and LRC Coal was 3243 kcal/kg. Total chlorine in SRF was 5442 ppm. It was higher than MRC Coal and LRC Coal. Total chlorine in MRC Coal was 110 ppm and LRC Coal was 100 ppm. Then, the ash fusion temperature (AFT) of SRF was lower than MRC Coal and LRC Coal. In ash analysis, SiO_2 and Al_2O_3 in SRF were lower than in other samples with a percentage of 33.12% SiO_2 and 10.80% Al_2O_3. SiO_2 in MRC Coal was 64.34% and LRC Coal was 50.81%. For Al_2O_3, MRC Coal had 22.36% and LRC Coal had 23.13%. SRF and LRC Coal had a similar percentage of Fe_2O_3 with a percentage of 8.89% in SRF and 8.39% in LRC Coal. However, it was still higher than the percentage of Fe_2O_3 in MRC Coal (4.00%). CaO in SRF was higher than in MRC Coal and LRC Coal. CaO in SRF was 20.06%, MRC Coal was 2.30%, and LRC Coal was 9.28%. The percentage of K_2O in SRF ash was also higher than in other samples with a percentage of 3.60%. K_2O in MRC Coal was 0.68% and LRC Coal was 0.94%. For other compounds, the difference was not significant.

Table 3. Coals and biomass blend characteristics

Parameters	Basis	MRC	LRC	SRF	A	B	C	D	E	F
					0% SRF	**5% SRF**	**10% SRF**	**15% SRF**	**20% SRF**	**25% SRF**
Total Moisture (%)	ar	27.24	45.34	14.38	36.29	35.19	34.10	33.00	31.91	30.81
Sample Moisture (%)	adb	6.47	8.86	4.25	7.67	7.49	7.32	7.15	6.98	6.81
Ash Content (%)	adb	8.31	10.95	28.90	9.44	10.68	11.88	13.05	14.18	15.28
Volatile Matter (%)	adb	42.20	42.67	54.19	42.33	43.07	43.78	44.48	45.16	45.82
Fixed Carbon (%)	adb	43.12	37.52	12.66	40.61	38.81	37.06	35.36	33.72	32.12
Total Sulfur (%)	adb	0.62	0.23	0.47	0.45	0.45	0.45	0.45	0.45	0.45
Gross Calorific Value (kcal/kg)	ar	4766	3243	2923	4005	3950	3896	3842	3788	3734
Chlorine (ppm)	-	110	100	5442	105	298	683	854	875	928
Ultimate Analysis (%)										
Carbon	adb	63.64	57.39	33.90	60.82	59.07	57.37	55.73	54.14	52.60
Hydrogen	adb	4.68	4.25	4.25	4.49	4.47	4.45	4.44	4.42	4.41

Nitrogen	adb	0.98	0.86	1.73	0.93	0.98	1.03	1.07	1.12	1.17
Oxygen	adb	21.77	26.32	26.30	23.71	23.86	24.01	24.16	24.30	24.45
Ash Fusion Temperature (Reducing, ℃)										
Deformation	atm	1360	1280	1110	1340	1330	1310	1240	1260	1190
Spherical	atm	1470	1310	1135	1450	1350	1330	1330	1270	1240
Hemisphere	atm	1500	1320	1140	1460	1380	1340	1340	1320	1280
Flow	atm	1520	1360	1150	1500	1400	1400	1380	1340	1340
Ash Fusion Temperature (Oxidizing, ℃)										
Deformation	atm	1380	1340	1115	1360	1360	1340	1340	1280	1220
Spherical	atm	1490	1350	1145	1490	1410	1360	1350	1320	1260
Hemisphere	atm	1520	1360	1155	1510	1420	1400	1360	1340	1320
Flow	atm	1540	1380	1180	1520	1440	1420	1380	1360	1360
Ash Analysis (in ash, %)										
SiO_2		64.34	50.81	33.12	57.52	53.31	50.06	47.47	45.37	43.63
Al_2O_3		22.36	23.13	10.80	22.75	20.68	19.09	17.83	16.80	15.95
Fe_2O_3		4.00	8.39	8.89	6.21	6.67	7.03	7.31	7.55	7.74
CaO		2.30	9.28	20.06	5.82	8.28	10.17	11.68	12.91	13.93
MgO		1.06	1.75	2.28	1.41	1.56	1.67	1.77	1.84	1.90
TiO_2		0.57	0.60	0.67	0.59	0.60	0.61	0.62	0.63	0.63
Na_2O		1.02	0.30	0.42	0.66	0.62	0.58	0.56	0.54	0.52
K_2O		0.68	0.94	3.60	0.81	1.29	1.66	1.96	2.20	2.40
Mn_3O_4		0.059	0.355	0.180	0.208	0.203	0.200	0.197	0.194	0.192
P_2O_5		0.185	0.076	3.240	0.130	0.667	1.081	1.411	1.678	1.901
SO_3		3.12	4.00	1.99	3.56	3.29	3.08	2.92	2.78	2.67

For comparison between a blend of MRC Coal, LRC Coal, and SRF, several parameters were affected by a percentage of SRF in a blend linearly. Ash content in A Coal was lower than in others with a percentage of 9.44%. Ash content in other samples was between 10.68-15.28%. The calorific value in A Coal was 4005 kcal/kg. It was higher than other blends. The calorific value in other blends was between 3950-3734 kcal/kg. Then, total chlorine in A Coal was lower than other blends with the amount of 105 ppm. For other blends, total chlorine was between 298-928 ppm. For AFT, the highest AFT was A Coal, while the lowest AFT was F Coal. In ash analysis, SiO_2 in A Coal was also higher than other blends with 57.52%. SiO_2 in other blends was between 53.31-43.63%. For Al_2O_3, A Coal had 22.75%. In other blends, the percentage of Al_2O_3 was between 20.68-15.95%. Fe_2O_3 in A Coal was lower than other blends with a percentage of 6.21%, while Fe_2O_3 in other blends was between 6.67-7.74%. CaO in Coal was also lower than in other blends with a percentage of 5.82%, while CaO in other samples was between 8.28-13.93%. Then, A Coal also had a K_2O that was lower than other blends with a percentage of 0.81%, while K_2O in other blends was between 1.29-2.40%.

3.2 The prediction of slagging, fouling, abrasion, and corrosion

The results of slagging, fouling, abrasion, and corrosion prediction were shown in Table 4. For MRC Coal, there was a low risk for slagging with a score of 2.0. The medium risk was obtained in LRC Coal with a score of 4.0. Meanwhile, high risk with a score of 5.5 was obtained in SRF. SRF had a high slagging risk because SiO_2 in SRF ash was low with a percentage of 33.12%. Low SiO_2 in ash can increase slagging potential [10,11,14]. High slagging risk in SRF was also caused by the percentage of Fe_2O_3 in SRF ash was 8.89%. Slagging potential can be increased if the percentage of Fe_2O_3 in ash is above or equal to 8.00% [13]. Then, slagging risk also was influenced by high CaO in SRF [9]. Moreover, the Fusibility of SRF also was lower than the fusibility of MRC Coal and LRC Coal. Low fusibility could also increase slagging potential. Fusibility was affected by AFT. Low AFT could decrease fusibility [10]. In addition, AFT was affected by compounds in ash. Low Al_2O_3 in SRF ash could decrease AFT [14,17–19]. Moreover, high Fe_2O_3 in SRF ash also could decrease AFT [20]. In a blended sample, A Coal had a low risk with a score of 3. Low risk also was obtained in B Coal with a score of 3 and C Coal with a score of 3.5. Slagging potential started to increase in a blend of 85% A Coal and 15% SRF. The medium risk was obtained in D Coal and E Coal with a score of 4.0. Then, high risk with a score of 6 was obtained in F Coal.

Fouling potential in MRC Coal and LRC Coal was a low risk with a score of 0.0. Meanwhile, the medium risk with a score of 1.5 was obtained in SRF. SRF had a medium fouling risk because SRF ash had a high percentage of K_2O with a percentage of 3.60%. High K_2O in ash also can increase the risk of fouling [13]. Then, low risk with a score of 0.0 was found in all blend samples, except for E Coal and F Coal. E Coal also had a low risk, but the score was 0.5. Meanwhile, the medium risk with a score of 1.0 was obtained in F Coal.

For abrasion potential, the medium risk with a score of 0.5 was found in MRC Coal. Then, LRC Coal had a low risk with a score of 0.0. Meanwhile, SRF had a high risk with a score of 1.0. Abrasion potential in MRC Coal was a medium risk because MRC Coal had a high SiO_2 in ash with a percentage of 64.34% and high total sulfur with a percentage of 0.62%. High SiO_2 in ash and total sulfur can increase the risk of abrasion [13]. High abrasion risk in SRF was obtained because total ash content in SRF was high [13] with a percentage of 28.9%. Moreover, SRF ash had a low Al_2O_3 with a percentage of 10.80%. Abrasion potential can be increased if Al_2O_3 in ash is low [13]. Then, blending A Coal with SRF did not increase abrasion potential. In all blend samples, the medium risk was obtained with a score of 0.5.

Corrosion potential in MRC Coal and LRC Coal was a low risk with a score of 0.0. Meanwhile, SRF had a high risk with a score of 2.0. SRF had a high risk because total chlorine in SRF was high [13,16] with the amount of 5442 ppm. However, increased corrosion potential was not obtained in any blend sample. Low risk was found with a score of 0.0 in all blend samples.

Table 4. The prediction of slagging, fouling, abrasion, and corrosion

Parameter			MRC	LRC	SRF	A	B	C	D	E	F
						0% SRF	5% SRF	10% SRF	15% SRF	20% SRF	25% SRF
Slagging Prediction	B/A ratio	Calc	0.10	0.28	0.79	0.18	0.25	0.30	0.35	0.40	0.44
		Score	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
	Silica ratio	Calc	89.74	72.35	51.47	81.06	76.35	72.61	69.57	67.05	64.93
		Score	0.00	0.00	1.00	0.00	0.00	0.00	0.50	0.50	1.00
	Slagging index	Calc	0.07	0.07	0.39	0.09	0.12	0.15	0.17	0.19	0.21
		Score	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fusibility	Calc	1392	1296	1119	1374	1348	1328	1264	1276	1216
		Score	0.00	0.50	1.00	0.00	0.00	0.50	0.50	0.50	1.00
	Fe2O3 / CaO	Calc	1.74	0.90	0.44	1.07	0.81	0.69	0.63	0.58	0.56
		Score	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Fe2O3 percentage	Calc	4.00	8.39	8.89	6.21	6.67	7.03	7.31	7.55	7.74
		Score	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
	Fe2O3 + CaO	Calc	6.30	17.67	28.95	12.03	14.95	17.21	19.00	20.45	21.66
		Score	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	SiO2 / Al2O3	Calc	2.88	2.20	3.07	2.53	2.58	2.62	2.66	2.70	2.74
		Score	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Total slagging		2.0	4.0	5.5	3.0	3.0	3.5	4.0	4.0	6.0
Fouling Prediction	Fouling index	Calc	0.11	0.08	0.33	0.12	0.15	0.18	0.20	0.21	0.23
		Score	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.50	0.50
	Na2O in ash	Calc	1.02	0.30	0.42	0.66	0.62	0.58	0.56	0.54	0.52
		Score	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total alkali	Calc	0.12	0.10	0.81	0.11	0.16	0.20	0.24	0.28	0.32
		Score	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.50
	Total fouling		0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.5	1.0
Abrasion Prediction	Abrasion index	Calc	4.43	3.91	10.78	4.20	4.61	5.02	5.41	5.80	6.17
		Score	0.50	0.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50
	Total abrasion		0.5	0.0	1.0	0.5	0.5	0.5	0.5	0.5	0.5
Corrosion Prediction	Total chlorine	Calc	0.01	0.01	0.54	0.01	0.03	0.07	0.09	0.09	0.09
		Score	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
	S/Cl	Calc	50.97	20.80	0.78	38.54	13.67	5.98	4.79	4.69	4.43
		Score	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total corrosion		0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0

= High = Medium =Low

4. CONCLUSIONS

Slagging, fouling, abrasion, and corrosion potential in Indonesian coals and biomass blends were evaluated in this study. Ash characteristic was used to predict those potentials. Blending A Coal with 10% SRF did not increase any potential. However, blending A Coal with SRF could increase the risk of slagging to medium risk if the percentage of SRF was above or equal to 15%. Moreover, the potential of slagging could increase to high risk if the percentage of SRF in a blend was 25%. Blending with 25% SRF could also increase the potential of fouling to medium risk. For abrasion and corrosion, blending A Coal with SRF did not increase those potentials. Relatively, the use of SRF with a percentage of up to 20% in a blend is still acceptable although slagging potential could increase to medium risk. However, blending with 25% SRF is too risky because it could increase slagging potential to high risk and fouling potential to medium risk. For further analysis, testing using a drop tube furnace is needed to find ash characteristics from the combustion test.

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