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Influence of Coal-Solid Recovered Fuel Blended on Slagging, Fouling and Corrosion During Co-Firing in A Drop Tube Furnace#

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ABSTRACT

The problem of urban waste is one of the most complicated problems in Indonesia's big cities. Utilizing municipal waste into co-firing fuel is one way to reduce waste that accumulates and reduce global emissions. Before being used, the urban waste needs to be tested for characteristics to determine its content or its combustion characteristics. This study uses Indonesian low-rank and medium-rank coal and Solid Recovered Fuel (SRF) biomass. This observation aims to decide the effect of coal-SRF blended on slagging and fouling in co-firing using a drop tube furnace (DTF). The results obtained are SRF blending up to 15% there is no slag attached. There is slight slag attached at the blending ratio of 20% and 25%, and there is a corroded part of the plate. It can happen because SRF has a high chlorine content. Overall, it shows that co-firing coal with SRF up to 25% is still safe on slagging and fouling.

Keywords: ash deposit observation, corrosion attack, combustion characteristic, high chlorine content, slagging fouling tendency

NONMENCLATURE

Abbreviations	
ar	As Received
adb	Air Dried Basis
AFT	Ash Fusion Temperature
DTF	Drop Tube Furnace
SRF	Solid Recovered Fuel

1. INTRODUCTION

Economic growth accompanied by increasing public consumptive behaviour causes waste problems in big cities in Indonesia. Garbage build-up in landfills is inevitable. The Indonesian Ministry of Environment and Forestry data shows that the total waste generation reaches 23 million tons/year, with only 62.63% of it being processed. Around 37.37% of waste is not treated [1]. One way to overcome the accumulation of waste is to process waste into green energy, such as converting it into solid recovered fuel (SRF). SRF is a fuel consisting of paper, cardboard, wood, textiles, and plastics with a high calorific value [2].

Indonesian Government is committed to supporting the Paris Agreement by setting a net-zero emission target in 2060. One way to implement it is by starting a co-firing program at existing coal-fired power plants. Co-firing is the burning of two or more fuels in one furnace [3]. SRF, which has a high calorific value, can be used as a co-firing fuel. However, SRF, with its high alkali and chlorine content, has the potential to cause slagging, fouling and corrosion in boilers [4]. One way to determine the combustion characteristics of this co-firing is to use a drop tube furnace (DTF).

Wang et al. (2020) conducted a study using DTF to decide the effect of exhaust gas temperature and oxygen content on slagging and fouling. He found that more fouling occurred by increasing the exhaust gas temperature from 900 ºC to 1200 ºC [5]. Farrow et al. (2020) compared thermogravimetry analysis (TGA) co-firing of sawdust-coal biomass with DTF combustion test, where the maximum heating rate of TGA combustion is higher than DTF [6]. In previous research, Hariana et al. (2021) used DTF to determine the characteristics of the combustion of five coals from various regions in Indonesia [7]. Prismantoko et al. (2021) conducted a coal-sawdust co-firing test using DTF, where the results obtained were that up to 10% of sawdust in coal co-firing were still safe in terms of slagging and fouling [8]. As for SRF, there is still few research that has been done. Wu et al. (2011) found that the 7% SRF co-firing combustion products were rich in Ca, S, and P with ultrafine particle

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sizes [9]. Chae et al. (2018) used TGA analysis to investigated the combustion characteristic of SRF from various source and found that the complete weight loss was achieved in under 500 °C [10].

However, there is very few research on slagging fouling in coal and SRF co-firing. This observe aims to decide the effect of SRF-coal blend on co-firing with various ratios to slagging and fouling tendency. The material used comes from two regions in Indonesia as medium-rank coal and low-rank coal, and one SRF biomass. This research was conducted using DTF equipment to determine the characteristics of combustion, especially slagging and fouling, and the potential for corrosion that occurs.

2. MATERIAL AND METHODS

2.1 Materials and Preparation

One solid biomass recovered fuel (SRF) and two types of coal, Indonesian medium-rank coal (IMR) and Indonesian low-rank coal (ILR), were used in this study. SRF was processed from separated municipal waste consisting of 60% household waste, 20% local municipal waste, and 20% garden waste wood chips. The SRF was then dried using an additional bacterial bio-drying process until the total moisture content of the SRF was approximately 20%. Samples were prepared according to ASTM standards. Both coals were prepared by crushing and sieved to pass 200 mesh (75 µ) per coal. Meanwhile, SRF was ground using a blender to a size of 20 mesh (0.8 mm).

In this study, the two coal samples were blended 50% of IMR : 50% of ILR, then called fuel A. Fuel A was blended with SRF with a composition of 5% (fuel B), 10% (fuel C), 15% (fuel D), 20% (fuel E), and 25% (fuel F), respectively. The results of the laboratory analysis of three single fuels and six mixed fuels can be seen in table 1.

2.2 Drop Tube Furnace

Drop tube furnace (DTF) equipment was used in this study to analyze the combustion characteristics of the blended fuel. A laboratory-scale vertical furnace in the form of an alumina ceramic tube with an inner diameter of 72 mm and a length of 1200 mm is heated using a 1 kwth electric heater which is divided into three hot zones to achieve isothermal conditions throughout the

Table 1. Characteristic analysis of single and blended fuels

	IMR	ILR	SRF	A	B	C	D	E	F
				0%	**5%**	**10%**	**15%**	**20%**	**25%**
Ash Content, adb (wt%)	8.31	10.95	28.90	9.44	10.68	11.88	13.05	14.18	15.28
Total Sulpur, adb (wt%)	0.62	0.23	0.47	0.45	0.45	0.45	0.45	0.45	0.45
Chlorine, ppm	110	100	5442	105	298	683	854	875	928
Gross Calorific Value, ar (kcal/kg)	4766	3243	2923	4005	3950	3896	3842	3788	3734
Ash Analysis (wt%)									
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	0.36	0.18	0.21	0.203	0.200	0.197	0.194	0.192
P_2O_5	0.185	0.08	3.24	0.13	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
Ash Fusion Temperature (Reducing, °C)									
Deformation	1360	1280	1110	1340	1330	1310	1240	1260	1190
Spherical	1470	1310	1135	1450	1350	1330	1330	1270	1240
Hemisphere	1500	1320	1140	1460	1380	1340	1340	1320	1280
Flow	1520	1360	1150	1500	1400	1400	1380	1340	1340
Ash Fusion Temperature (Oxidizing, °C)									
Deformation	1380	1340	1115	1360	1360	1340	1340	1280	1220
Spherical	1490	1350	1145	1490	1410	1360	1350	1320	1260
Hemisphere	1520	1360	1155	1510	1420	1400	1360	1340	1320
Flow	1540	1380	1180	1520	1440	1420	1380	1360	1360

furnace. Details of the schematic diagram of DTF can be seen in previous studies [7,8,11]. The furnace is heated up to 1200 °C to simulate actual conditions on a PC boiler at the Coal-Fired Power Plant. Then, 50-100 gr/h of blended fuel is fed into the furnace through a cooling injector probe using a screw feeder driven by a 0.5 hp motor. The airflow rate is controlled using a flowmeter to produce 5% excess oxygen in the flue gas output from the furnace. A detachable 50 mm diameter stainless round plate is placed above the sampling probe to collect the combustion ash deposits. The probe is inserted into the furnace. The probe temperature is adjusted by adjusting the probe position vertically until it is maintained at a temperature of 550 °C (representing the fouling area) and 600 °C (representing the slagging area). The probe temperature is read using a type K thermocouple attached to the surface of the probe plate. The test was carried out for 1 hour, after which the sampling probe was removed and cooled for analysis of the ash deposit.

3. RESULTS AND DISCUSSION

3.1 Characteristic of fuels

Table 1 shows the characteristic analysis of three single fuels and six blended fuels. Based on table 1, single fuels data shows that the gross calorific value of IMR is 4776 kcal/kg (ar) with an ash content of 8.31 wt% (adb), while the calorific value of ILR is 3243 kcal/kg (ar) with an ash content of 10.95 wt% (adb). On the other hand, the calorific value of SRF is 2923 kcal/kg (ar) with an ash content of 28.90 wt% (adb). For blended coal, the six fuels had higher CaO + MgO content than Fe_2O_3, so fuels A to F were included in the lignitic ash type. The larger the SRF blended, the lower ash fusion temperature of fuels, which can potentially cause slagging and fouling. Slagging and fouling can occur if the combustion temperature is higher than the ash fusion temperature (AFT) [12]. Low AFT could decrease fusibility. Low fusibility could increase slagging potential [13]. SRF also has low SiO_2 and high CaO content, which can cause slagging and fouling [13–15]. In addition, it was also found that the chlorine content in SRF was very high at 5442 ppm. High chlorine content can cause corrosion on pipe or boiler walls [16,17].

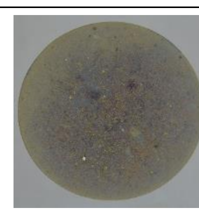
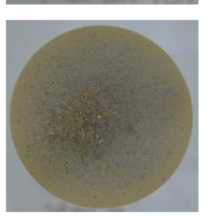
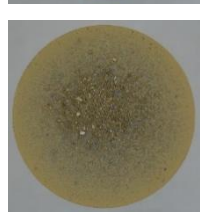
3.2 Influence to slagging and fouling tendency

Ash and slag deposits from the combustion of various fuel blended are shown in table 2. It can be seen that Fuel A ash deposits are light brown in colour, indicating a low amount of ferrous oxide. The more SRF blended in the fuel, the darker the ash deposits formed with a lot of SRF ash attached. Table 3 shows the probes that have collected ash deposits.

At a temperature of 550 °C, Fuel A, Fuel B, Fuel C and Fuel D were seen to have no slag attached to the probe. Meanwhile, Fuel E and Fuel F have a slight slag on the probe. This is influenced by the blending composition of the biomass in the coal, which causes an increase in alkali content (K and Na) which can lead to ash deposits on the heating metal surface [18]. High alkali content also can reduce AFT value and increase the potential for slagging [13], but this condition can still be removed by using a shoot blower in the CFPP. In addition, the Fuel E and Fuel F probes have eroded areas. This indicates the presence of corrosion on the two probes. Corrosion that occurs is caused by the presence of high chlorine content in Fuel E and Fuel F, which have a higher proportion of SRF in the blended.

On the other hand, at a temperature of 600 °C, which represents the temperature in the boiler superheater area, it is seen that the Fuel A and Fuel B probes look clean. In contrast, the Fuel C to Fuel F probes have a small white slag spots which are still normal and can be removed with a shoot blower. Similar to the probe at 550 °C, the Fuel E and Fuel F probes show that corrosion

Table 2. Probe of blended fuels with dust and slag

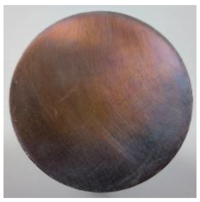
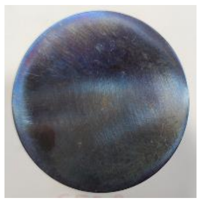
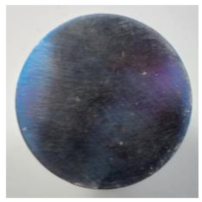
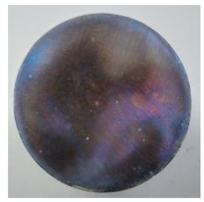
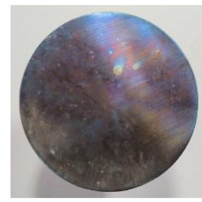
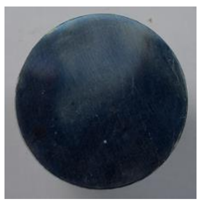
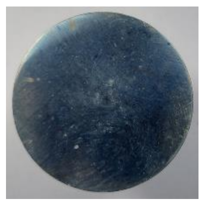
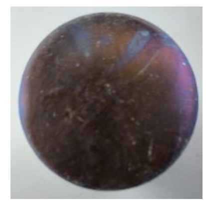
	A	B	C	D	E	F
550						
600						

occurs during combustion. Several factors which could increase the corrosion rate in the combustion of fuel containing Cl are flue gas temperature and steam temperature [19]. Metals containing Cr and Fe at temperature 425°C – 525°C begin to experience grain boundary corrosion attacks and excessive metal temperature can melt ash containing chlorine [20].

4. CONCLUSIONS

This study focuses on the influence of Indonesian coal-SRF blended on slagging and fouling during co-firing in a drop tube furnace. The results confirmed that the overall ash deposit observations were light brown in colour, which indicated the least iron content in the ash. At the temperature probe of 550 °C, Fuel A to Fuel D does not see any sticking slag, while on Fuel E and Fuel F there is a slight slag attached. At the 600 °C temperature probe, there is no visible slag attached to Fuel A and Fuel B. In comparison, Fuel C to Fuel F looks a little slag attached. In general, from the point of view of slagging and fouling, it shows that co-firing coal with SRF up to 25% is still safe. What needs to be considered is the high content of chlorine in SRF, which can cause corrosion. As the results of probe observations, corrosion occurred in Fuel E (20% SRF) and Fuel F (25% SRF) at both probe temperatures. Thus, from the corrosion perspective, it is shown that blending SRF is still safe up to 15%.

Table 3. Probe of blended fuels with dust and slag

	A	B	C	D	E	F
550						
600						

The ash deposit resulting from the burning of the six fuels is weighed to determine the weight of the ash deposit formed. Table 4 shows the weight of the ash deposits of the six mixed fuels at different temperature conditions. According to table 4, fuel with a probe temperature of 600 °C showed more ash deposits formed than the probe with a temperature of 550 °C. Only two fuels showed fewer ash deposits as the probe temperature increased, namely Fuel B and Fuel F. This most likely occurred due to the inhomogeneous size of the SRF in the sample so that the SRF ash produced was of different size.

Table 4. Deposit weight of blended fuels in gram

	A	B	C	D	E	F
550	0.0117	0.0371	0.0282	0.0144	0.0166	0.0454
600	0.0262	0.0115	0.0398	0.0738	0.0170	0.0125

From the results of combustion and visual observations on the six fuels, it shows that the blending of medium rank coal and low-rank coal with SRF of up to 25% is still safe in terms of slagging and fouling. The thing that needs attention is the high chlorine content in SRF, which has the potential to cause corrosion. To find out more about the content formed in the ash from the combustion, it is necessary to test Scanning Electron Microscope (SEM) and X-ray Diffraction (XRD).

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