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Study of Coal Sawdust Co-Firing with Slagging Fouling Prediction and Observation of Probe from Drop Tube Furnace Combustion Test

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***Abstract*—The use of biomass in co-firing in coal-fired power plants is one step to achieve the renewable energy mix target in Indonesia. Several aspects need considering to implement co-firing, including the slagging fouling aspect. It has the potential to interfere with process performance, reliability, and plant life. In this study, an investigation was carried out on the potential for slagging fouling in co-firing of coal and sawdust 10% (C10) during combustion with a drop tube furnace (DTF). From the ash analysis, coal and C10 let in the lignite ash type. Predictive calculations carry out to complete the DTF test. Even though the prediction of slagging based on the calculation is low to medium and fouling medium to high, the combustion test tends to be low to medium. In the probe's observation on combustion at DTF, ash deposit on coal is less than that of C10. For C10, the probe temperature of 600 °C represents the superheater area (slagging), and the supercritical temperature of 700 °C contains little sticky ash while 550 °C representing the fouling area is relatively clean. The addition of 10% of sawdust to the combustion system increased the risk, but within safe limits.**

Keywords—coal sawdust co-firing, slagging fouling prediction, Drop Tube Furnace (DTF)

I. INTRODUCTION

The use of biomass as a mixture in combustion in a coal-fired power plant is one way to achieve the new and renewable energy mix target set by the Indonesian government of 23% by 2025 [1]. Indonesia, which is located on the equator, has a tremendous biomass potential [2]. Biomass with high potassium content can cause boilers' problems, such as slagging and fouling [3].

Performance, efficiency, and the plant's life are affected by the tendency of slagging fouling [4]. For this reason, before being used as fuel in power plants, it is necessary to calculate the prediction of slagging fouling and laboratory-scale combustion tests. Predictive calculations used in coal-burning can be used to evaluate trends in biomass co-firing [5]. Luan et al. [6] conducted a laboratory-scale test using a drop tube furnace (DTF) on co-firing of coal and biomass of straw and sawdust, which concluded that the addition of biomass for co-firing affects the sintering temperature of the ash.

In this study, an investigation was carried out on the potential for slagging fouling on co-firing of 90% coal and 10% sawdust biomass which was later referred to as C10 by calculating predictions combustion tests on DTF. Ash deposition that occurs during combustion at DTF is observed to validate the initial prediction calculation based on fuel analysis. The comparison of the deposition of ash formed during combustion between coal and C10 is also discussed in this study.

II. EXPERIMENTAL

A. Sample

Coal that has been prepared to pass 200 mesh is used in this study. Also, sawdust that passed 20 mesh was prepared for blending with 10% (C10) coal. The characteristic tests of coal and C10 are shown in Table 1.

TABLE I. FUEL CHARACTERISTIC ANALYSIS

Parameter			Coal	C10
Total Sulfur	%	db	0.63	0.57
Ash Content	%	db	6.78	6.60
AFT Reducing				
Deformation	°C	atm	1140	1110
Spherical	°C	atm	1200	1180
Hemisphere	°C	atm	1220	1220
Flow	°C	atm	1260	1260
AFT Oxidizing				
Deformation	°C	atm	1220	1150
Spherical	°C	atm	1250	1220
Hemisphere	°C	atm	1260	1260
Flow	°C	atm	1280	1300
Ash Analysis				
SiO_2	%	in ash	51.20	50.54

Al_2O_3	%	in ash	14.34	15.63
Fe_2O_3	%	in ash	7.83	8.54

Table 1. *Cont.*

CaO	%	in ash	8.72	8.43
MgO	%	in ash	2.82	2.69
TiO_2	%	in ash	0.48	0.58
Na_2O	%	in ash	3.63	3.31
K_2O	%	in ash	0.83	0.79
Mn_3O_4	%	in ash	0.09	0.10
P_2O_5	%	in ash	0.20	0.30
SO_3	%	in ash	9.62	8.68
			db :	dry basis

Table 1 shows that in general, there is no significant difference between the two samples. Both samples iron and calcium content were low while the sodium content was high, which could potentially cause fouling. The amount of calcium oxide content and magnesium oxide content in both samples was more significant than the iron oxide content so that both samples are included in the type of lignite ash [7].

B. Drop Tube Furnace

Coal and C10 samples were tested for combustion characteristics using a drop tube furnace (DTF), a furnace with a ceramic tube length of 1200 mm and an inner diameter of 72 mm as shown in Figure 1. An electric heater is used to heat the furnace to around 1100 °C indicated for PC Boiler. The dried sample is fed into the furnace using a screw feeder with a flow rate of 50-100 gr / h. The premier air flow rate is 12.5 l / h and the secondary air is 10 l / h. A probe with a diameter of 55 mm connected to a thermocouple is inserted into the furnace. The probe's position is adjusted to a temperature of 550 °C to simulate the wall tube area (fouling potential) and temperatures of 600 °C and 700 °C to simulate the superheater area (slagging potential). After 1 hour, the probe was pulled out and cooled at room temperature, then observed and ash deposits were taken on the probe.

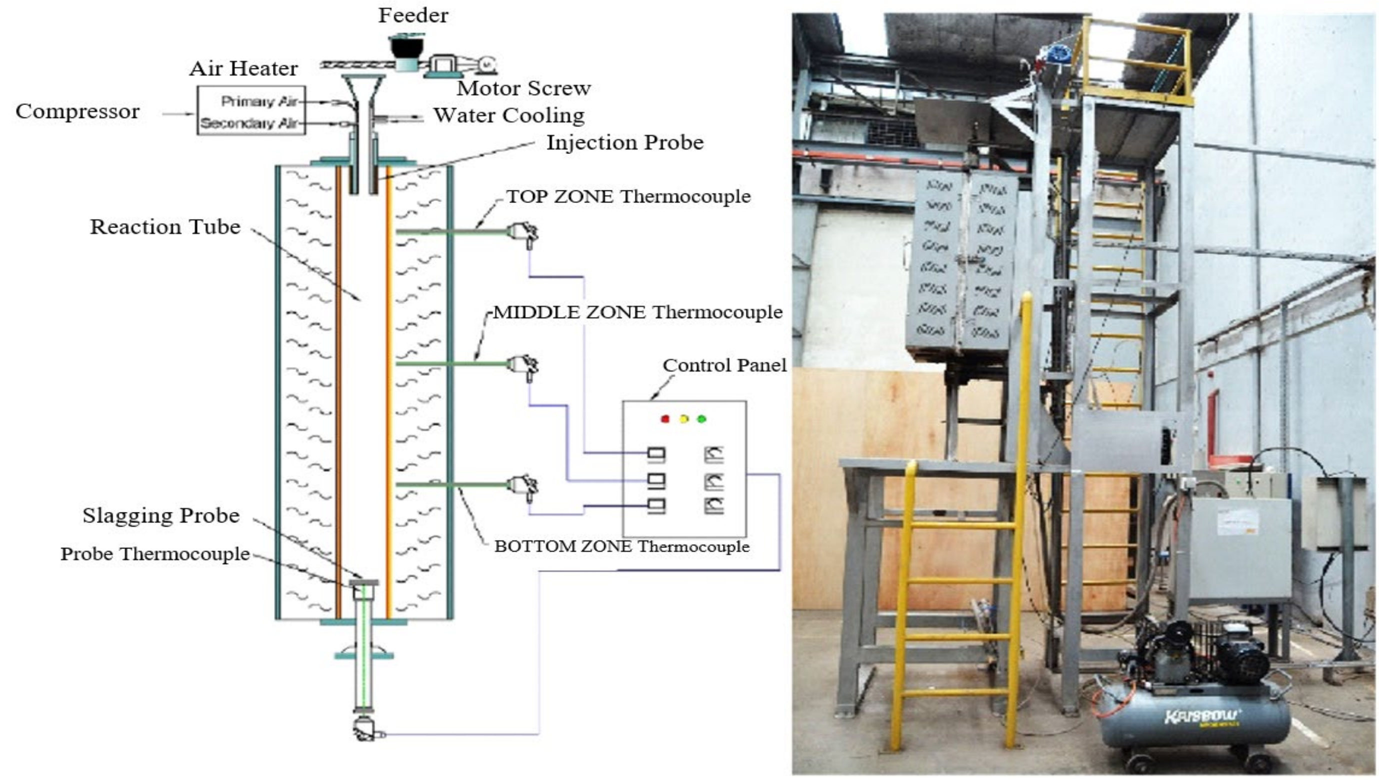

Fig. 1. Schematic of drop tube furnace.

III. Results and Discussion

A. Slagging Fouling Indication

Table 2 shows the tendency of slagging fouling in coal combustion and C10 based on several formulas as follows [8]. Coal which has a fusibility value of 1140 °C has the potential for high slagging and C10, which has a lower fusibility value, namely 1124 °C. Meanwhile, the sodium value in both samples' ashes is very high, which is above 3, which indicates a very high potential for fouling for both samples [7]. The silica/alumina ratio of coal indicates low to medium risk, while C10 is high to severe.

Table 2. Slagging fouling indication.

Index	Coal		C10	
	Values	*Risk*	*Values*	*Risk*
Slagging Indication				
B/A Ratio [7]	0.36	low	0.36	low
Silica Ratio, S_R [9]	72.55	low	71.99	low
Slagging Index, Rs [7]	0.23	low	0.20	low
Fusibility, T_{AFI} [7]	1140	severe	1124	severe
Iron/Calcium [10]	0.90	high to severe	1.01	high to severe
Iron Content [9]	7.83	low to medium	8.54	low to medium
Iron + Calcium [11]	16.55	high to severe	16.98	high to severe
Silica/Alumina [12]	3.57	low to medium	3.23	high to severe
Fouling Indication				
Fouling Index, Rf [7]	1.31	severe	1.18	severe
Na_2O in Ash [7]	3.63	severe	3.31	severe
Alkali in Coal [13]	0.28	low	0.25	low

B. *Probe Observation*

The combustion probe on the DTF was observed visually to determine the ash deposits formed. Figure 2 shows the deposition of ash during coal burning and C10 at probe temperatures of 550 °C, 600 °C, and 700 °C. These observations were also compared with the Jones index to determine the risk level of slagging fouling [14].

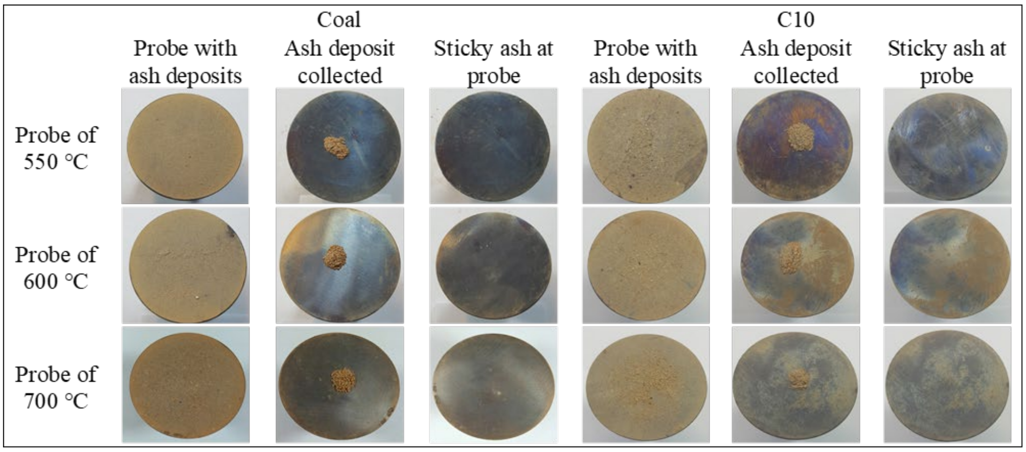

Fig. 2. Ash deposition at temperature 550 °C, 600 °C, and 700 °C.

At a probe temperature of 550 °C, which indicates the fouling area, the coal ash deposits formed during combustion are visually bright and smooth. After the ash has been collected, the probe looks clean, and no ash is stuck, and mostly is dust. Meanwhile, the C10 ash deposit appears bright in colour and contains coarse ash. After the ash has been collected, it is seen to be mostly dust with a small amount of ash adhering to the probe surface.

At a probe temperature of 600 °C, the slagging area, the coal ash deposits formed visually appear bright and smooth. After the ash has been collected, the probe looks relatively clean with a little bit of ash adhering to it. Meanwhile, the C10 ash deposit appears bright in colour and a little rough. After the ash has been collected, a considerable amount of ash is visible on the probe's surface.

At a probe temperature of 700 °C, the coal ash deposits formed during combustion appear visually darker and smoother. After the ash has been collected, the probe shows a small amount of ash adhering to it. Meanwhile, the C10 ash deposit appears bright in colour and contains coarse ash. After the ashes have been collected, that can see a little bit of ash stuck to them.

Based on probe observations and compared with the index Jones [14], it can be stated that the results of coal combustion have a low-risk level at probe temperatures of 550 °C, 600 °C, and 700 °C. At the same time, the results of combustion of C-10 have a low to medium risk.

IV. Conclusions

The results of the investigation carried out on the ash analysis, and the DTF test can be concluded as follows:

- From the ash analysis, both coal and C10 samples are classified as lignite ash. With prediction calculations, the tendency for slagging fouling to occur in both samples is moderate. There is not much difference between coal and C10, which is only in the silica/alumina ratio.

- On probe observations, coal-burning results do not contain firm, sticky ash that cannot be taken.
- In the C10 combustion result, and there is a small and thin amount of sticky material on the temperature probe 600 °C and 700 °C while the 550 °C probe is relatively clean.
- From the three things mentioned above and paying attention to the Jones Index, it can be stated that the addition of 10% of sawdust biomass is still safe based on the DTF test, however further testing is needed, namely SEM and XRD to determine the characteristics of the ash deposit formed.

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