ATLANTIS PRESS

Advances in Engineering Research, volume 208

Proceedings of the International Conference on Innovation in Science and Technology (ICIST 2020)

XRD Analysis of Slagging and Fouling Characteristics on Co-Firing Lignite and 10% Sawdust Ash from DTF

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***Abstract*—The energy mix in 2024 is targeted to be 23% of total energy availability. At this time, the combination of coal and biomass is a priority to achieve the target. This paper describes coal combustion results and sawdust from the slagging and fouling employing XRD analysis. To guarantee co-firing is a safety obstacle, primarily slagging fouling, it is necessary to apply a combustion test, specifically the Drop Tube Furnace (DTF). The test results are ash that sticks to the probe for lignite coal, and a mixture of coal and sawdust 10% biomass, processed at temperatures of 550º C, 600º C, and 700º C. coal and 10% sawdust XRD analysis shows Quartz above 70 % still dominated XRD results. Some were still above 90%. The conclusion obtained from this XRD test is that there is no increased risk of slagging fouling with 10% biomass.**

Keywords—slagging-fouling, co-firing, biomass, XRD, coal

I. INTRODUCTION

The Indonesian government will increase the energy mix by 23% in 2025 by co-firing the coal-fired power plant. This policy is very beneficial because Indonesia's power plants are still dominated by coal-fired power plant [1]. Indonesian biomass is very profitable from the supply that it is rich in potential biomass resources. However, biomass generally contains potassium that will affect the potential for slagging fouling [2,3], which will affect the efficiency and durability of the coal-fired power plant.

Biomass as a coal blender for solid fuel Co-firing needs to be tested in a laboratory or on a pilot scale to ensure it is safe for power plant. One way of testing is to burn the mass results according to the blending results that need to be done in a Drop Tube Furnace (DTF). DTF is considered very similar to a coal-fired power plant with PC Boiler [4]. The way the DTF works is as stated [5].

This study depicts an investigation of the potential for slagging fouling in co-firing 90% coal and 10% biomass, which is sawdust, referred to as C-10 by combustion test a Drop Tube Furnace (DTF). Ash deposits that occur during the combustion process at DTF are observed by carrying out XRD tests to check the minerals that occur in coal ash and their transformations.

II. EXPERIMENTAL

A. Samples

The experiment is a coal blending product with fuel conditions for PC Boilers. Furthermore, the coal mixed with sawdust biomass with 90% coal and 10% sawdust. After that, the mixing fuel burned in a DTF furnace similar to the coal-fired power plant condition, especially PC Boiler. The results of the ash obtained were investigated on XRD. Coal specifications are described in Table 1.

TABLE I. ASH COMPOSITION

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K2O	Mn_3O4	P_2O_5	SO_3
Coal	51.2	14.34	7.83	8.72	2.82	0.48	3.63	0.83	0.09	0.2	9.62
C-10	50.54	15.63	8.54	8.43	2.69	0.58	3.31	0.79	0.1	0.3	8.68

B. XRD Experiments

This study uses Drop Tube Furnace (DTF) devices among a process temperature of around 1100 °C by probe temperatures of 550 °C, 600 °C, and 700 °C. The combustion process is carried out as closely as possible with a PC Boiler [6]. Furthermore, the dust material is observed using XRD. X-Ray Diffraction (XRD) analysis was performed using the Bragg-Brentano EMPYREAN type diffractometer from PANALYTICAL. The test steps are carried out as follows:

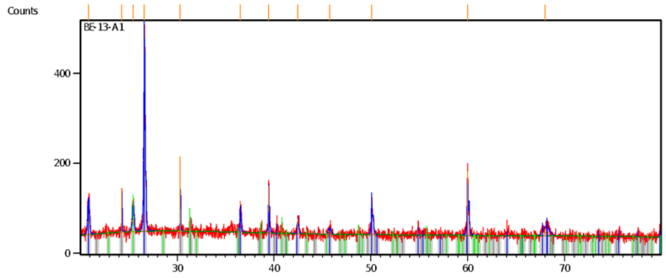
- Powder sample is prepared in a sample holder using the Si substrate (low background),
- The sample holder is clipped to the sample stand,
- The measurement program is set to parameters
  - Measuring angle : 15 - 80 degree,
  - Measurement step : 0.02 degree,
  - Measurement time per step : 1 second,
  - X-ray source : Cu,
  - Source voltage : 40 kV,
  - Source current : 30 mA,

After testing, the sample in the sample holder is returned to its original container. The data obtained were analyzed using the Highscore Plus ver 3.0e application, which is equipped with a crystalographic open database (COD) database, an inorganic crystal structure database (ICSD), and the international center for diffraction data (ICDD). Semi-quantitative data analysis was performed using the RIR method.

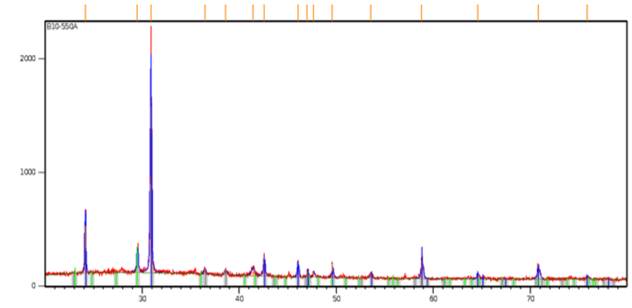
III. Results and Discussion

Testing using XRD (X-Ray Diffraction) is intended to determine the transformation of elements/minerals in the combustion process from low to high temperatures and decreases again with various possible forms. The following is the XRD ratio between C-10 and Coal (Figures 1-3):

A. Probe 550°C



Position [°2Thea] (Copper (Cu))
(a)



Position [°2Thea] (Cobalt (Co))
(b)

Fig. 1. XRD of ash on the 550 °C probe **a**) Coal and **b**) C10.

Table 2 shows the 550 °C probe, which is dominated by low quartz with 70% and is generally considered harmless. This probe is dominated by silicon oxide (SiO2), where this element has harmless properties from its contribution to slagging and fouling and even has a positive effect. This element is stable up to a temperature of about 570 °C, where it is transformed into High quartz. At a temperature of 876°C, it transforms into Tridymite, and at a temperature of 1400°C, it transforms into Cristobalite. Elemental quartz is stable at temperatures of 1530°C. Problems arise if other elements melt first and bind SiO2 and then heat continuously. That is the vigilance that may be, but the focus is on other elements [7,8].

TABLE II. DATA AND PHASE COAL AND C-10 IN PROBE 550 °C

Data and Phase Analysis Coal 550 °C					
Compound Name	***Chemical Formula***	***Score***	***Scale Factor***	***Crystal System***	***SemiQuant [%]***
Quartz low	O2 Sil	70	0.975	Hexagonal	70
Anhydrite	Ca l O4 S1	15	0.163	Orthorhombic	20
Dipotassium Carbonate - Alpha	Cl K2 O2	12	0.098	Hexagonal	10
Data and Phase Analysis C-10 Probe 550 °C					
Compound Name	***Chemical Formula***	***Score***	***Scale Factor***	***Crystal System***	***SemiQuant [%]***
Quartz low	O2 Sil	63	0.64	Hexagonal	90
Iron(III) Phosphate(V) – Beta	Fe1 O4 P1	24	0.096	Hexagonal	7
Potassium Cobalt Oxide	K Co O2	16	0.028	Tetragonal	3

The second element is 20% Anhydrous, $CaSO_4$, which may occur in the reaction between CaO and SO_2 or the presence of the elemental form of $CaSO_4$. The reaction process occurs at temperatures between 800 - 1000 °C in the gas phase. At temperatures of 1000-1200°C and above, SO_4 releases can react with other elements such as Si or Al to form Ca_2AlSiO_7, for example [9]. Other minerals are Di Potassium Cabonat Alpha with an amount of 10%; This mineral is quite vulnerable because it has melted at a temperature of around 900 °C.

Observation of C-10 with Quartz Low with 90% means that the portion increases compared to coal without biomass, which means that the amount of Si_2O_2 increases. Another mineral in this probe is Iron Phosphate Betha 7%, which means that F_2O_3 needs attention because at around 590°C it has begun to transform [7]. Several other references say it is around 800°C. The elements that enter into one family are FeO, FeS, Fe_2O_3, Fe_2 $(SO_4)_3$, which may occur or be formed. Fe_2O_3 will completely melt at temperatures around 1500°C. Another mineral detected in this probe in small amounts is potassium Cobalt Oxide, which is 3%. Given that the amount of SiO_2 is still high, the addition of this biomass is considered safe.

B. *Probe 600°C*

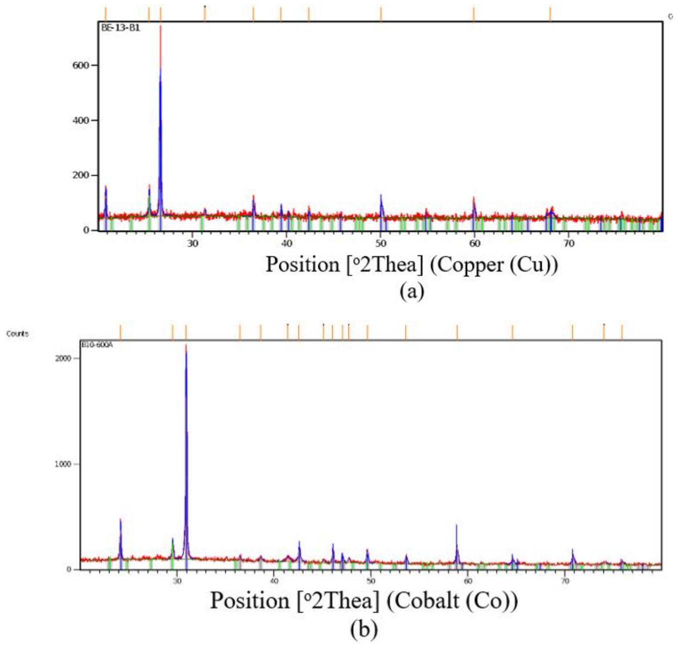


Fig. 2. XRD of ash on the 600 °C probe **a)** Coal and **b**) C10.

The 600°C Probe coal is dominated by low Quartz, where 89% coal and 94% C10 are considered harmless due to the increasing proportion of Quartz (see Table 3). Another mineral is $FePO_4$, 25% for coal and 5% for C10, which is good advice as this base metal decreases. Minerals in minimal amounts of Potassium Cobalt Oxide in minimal amounts of 1% can be ignored in this case. As a result, probe 600 shows no manifest increased risk of adding a 10% Biomass.

TABLE III. DATA AND PHASE COAL AND C-10 IN PROBE 600 °C

Data and Phase Analysis Coal 600 °C					
Compound Name	***Chemical Formula***	***Score***	***Scale Factor***	***Crystal System***	***SemiQuant [%]***
Quartz	O2 Sil	75	0.72	Hexagonal	89
Iron(III) Phosphate(V) – Alpha	Fe1 O4 P1	25	0.103	Hexagonal	11
Data and Phase Analysis C-10 Probe 600 °C					
Compound Name	***Chemical Formula***	***Score***	***Scale Factor***	***Crystal System***	***SemiQuant [%]***
Quartz low	O2 Sil	63	0.915	Hexagonal	94
Iron(III) Phosphate(V) – Beta	Fe1 O4 P1	17	0.078	Hexagonal	5
Potassium Cobalt Oxide	K Co O2	16	0.022	Tetragonal	1

C. *Probe 700 °C*

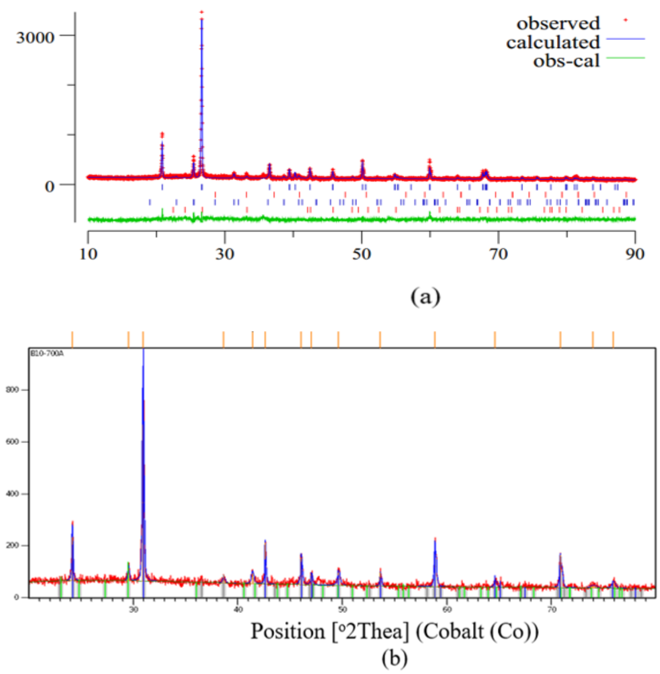


Fig. 3. XRD of ash on the 700 °C probe a) Coal and b) C10.

Probe 700 °C coal is dominated by low quartz where 86.47% coal and 94% C10 are considered harmless because the quantity of quartz is still high (see Table 4). Another mineral is Anhydrite for coal 12.1% for C10 is not detected. However, iron phosphate was detected in C10 by 4%, which was not detected in coal. Iron is a small amount compared to the base SiO_2. In C10 co-firing, there is a small amount of 2% Cobalt Potassium. These observations show that the 700 probe does not appear to have a high risk considering that SIO_2 is still high even though other minerals have more potential than Anhydrite.

TABLE IV. DATA AND PHASE COAL AND C10 IN PROBE 700 °C

Data and Phase Analysis Coal 700 °C					
Compound Name	***Chemical Formula***	***Score***	***Scale Factor***	***Crystal System***	***SemiQuant [%]***
Quartz low	O2 Sil	88.3	0.96	Hexagonal	86.47
Anhydrite	Ca l O4 S1	11.04	0.17	Orthorhombic	12.1
Data and Phase Analysis C-10 Probe 700 °C					
Compound Name	***Chemical Formula***	***Score***	***Scale Factor***	***Crystal System***	***SemiQuant [%]***
Quartz low	O2 Sil	73	1..02	Hexagonal	94
Iron(III) Phosphate(V) – Beta	Fe1 O4 P1	17	0.077	Hexagonal	4
Potassium Cobalt Oxide	K Co O2	9	0.032	Tetragonal	2

IV. CONCLUSION

Comparison results of X-Ray Diffraction (XRD) analysis of combustion ash using Drop Tube Furnace (DTF) in three measuring zones of 550 ºC, 600 ºC, and 700 ºC for coal and C10 (90% coal and 10% sawdust) that there is no increased risk of slagging fouling with 10% biomass. For further research, it will increase the sawdust percentage and a combination of other types of biomass.

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