The experimental study of identification trigger components in ash deposits at the boiler pipe of the electric steam power plant in Nagan Raya, Aceh province

A F Syah¹, A Gani² and Khairil¹,³

¹ Department of Mechanical Engineering, Faculty of Engineering Universitas Syiah Kuala 23374, Aceh, Indonesia
² Department of Chemical Engineering, Faculty of Engineering Universitas Syiah Kuala 23374, Aceh, Indonesia

E-mail: khairil@unsyiah.ac.id

Abstract. Coal energy is used as the greatest main source of power plant in this day and age. The consequence of the coal energy exertion is the ash deposits are cumulated in the used boiler. In this experiment, the fly ash and ash deposit are analyzed by using SEM/EDX (scanning electron microscope/ energy dispersive x-ray) to obtain the tendency of the ash deposits with a base to acid ratio. The sample of ash deposit was selected at three layers of observation to discover the slagging index of the combustion process. The result of the study indicates that the tendency of the ash deposits is 0.959736 and the slagging index on three layers observation are 0.4987, 0.264183, and 0.140248. The result of the slagging index on three layers observation is categorized as low. The trigger compound of cumulation is K₂O which is found more in the ash deposits around the pipe and constitutes in the lowest melting point compounds as compared to the other compounds contained in the slagging ash.

1. Introduction

The cumulation of deposits in the boiler’s pipe is one of the effects of combustion process commonly happened in the high temperature furnace in the boiler. Most of the formed ash deposits is caused by the inorganic materials which fuse in the high temperature furnace and adhere to the boiler wall. Those problems affect the overall work of the boiler. The deposits in the boiler’s pipe forms several linings with various structures and colors. Nevertheless, the exertion of various coal energy causes various deposits effects. The deposits formation occurs in three mechanisms, they are first the particle displacement in the cause of gradient concentration (diffusion), second the displacement of small particles in the cause of temperature (thermophoresis), and third the ash precipitation in the cause of large inertia quantity in the impacted deposits (inertial impact). CaO, Al₂O₃, and SiO₂ are the primary sources of deposits formation in the boiler’s pipe as the initial lining of deposits formation (the trigger). Furthermore, the other metal elements (Mg, Al, and Fe) are bound to form the deposit compounds. On the other hand, the deposits formation occurred in the water wall with a high temperature boiler has the initial lining (the trigger) formed as a thin white layer with 10% of S, Na, Si, and Ca. The condensed CaSO₄ in the combustion process leads to the formation of a strong initial deposits compounds due to the displacement of small particle as the result of the temperature gradient (thermophoresis). Moreover, molten aluminosilicate formed in the farther layer of deposits detains solid particle elements as in CaO, Al₂O₃, etc., to form the outer layer of deposits. [1-4].

In this study, the fly ash and the ash deposits from the combustion process in the boiler of the electric steam power plant in Nagan Raya are observed by Scanning Electron Microscope / Energy Dispersive X-Ray Analysis (SEM/EDX) to discover the trigger compounds of slagging formation in boiler’s pipes.

³ To whom any correspondence should be addressed.
in the furnace. Furthermore, the aim of study is to identify the compounds found in the ash deposits to obtain the tendency of the fly ash and the slagging index of the combustion process in the boiler.

2. Experimental
The samples of ash deposit generated during combustion at Nagan Raya steam power plant under boiler conditions are shown in table 1. Figure 1 shows the condition of the sample ash deposit after it was formed in a furnace at the Nagan Raya steam power plant which operated for 6 months with a loading of around 70 MW. The ash deposits formed and attached on the pipe in the furnace is obtained and observed with SEM/EDX. The observation of the ash deposits consists of three parts and has been decided beforehand (figure 2). The three parts of the ash deposits are the ash attached on the water pipe wall, the middle part ash, and the external part which connects directly to the furnace. The samples are studied on several parts of examination to observe the image in enlargement up to 2000 times using SEM, moreover, the samples as in chemical composition are presented by EDX.

![Figure 1](image1.png)  
**Figure 1.** The ash deposit formed on a pipe in the furnace during the combustion process at the Nagan Raya steam power plant.

![Figure 2](image2.png)  
**Figure 2.** The examples of ash deposit to be observed at 3 scanning points

3. Result and Discussion

3.1. Amount of ash formed
Proximate analysis of coal in the Nagan Raya electric steam power plant (table 1) obtained the weight of ash content in every 1 kg of coal is 8.3194%. the amount of ash produced by normal coal combustion in the furnace is 4,3344 - 4,5007 T/h

| Proximate analysis (%) | Coal consumption (T/h) |
|------------------------|------------------------|
| Total moisture | Volatile content | Ash content | Fixed carbon | Min | Max |
| 35.55 | 43.67 | 8,3194 | 38,67 | 52,1 | 54,1 |

3.2. The tendency of ash deposits
The amount of ash deposits in combustion process is determined by several methods of observation. One of the methods used is observing the chemical compositions of the ash resulted from the combustion process. Equation 1 can be used if the compound content is CaO < 7.5 and Na2O < 2.5. The tendency of the ash deposits can be obtained using the equation 1

\[
R = \frac{Fe_2O_3 + CaO + MgO + K_2O + Na_2O}{SiO_2 + Al_2O_3 + TiO_2}
\]  

(1)
The result of SEM/EDX test for base-acid ratio in the ash resulted from the combustion process is presented in Table 2.

Table 2. The value of acid-base compounds in the ash resulted from the combustion process of the electric steam power plant in Nagan Raya region.

| The amount of acidic compounds | The amount of basic compounds |
|-----------------------------|-------------------------------|
| SiO₂ | Al₂O₃ | TiO₂ | Fe₂O₃ | CaO | MgO | K₂O | Na₂O |
| 5.49 | 4.481 | 0.92 | 6.59 | 2.118 | 1.006 | 0.774 | 0.31 |

The ratio accumulation above shows that the base to acid ratio contained in the ash from the combustion process in the boiler of the electric steam power plant in Nagan Raya is 0.95736.

Base-acid ratio directly reacts to the temperature point of the ash fusion. The value escalation in base-acid ratio of the ash deposits decreases the Initial Deformation Temperature (IDT), the Softening Temperature (ST), the Hemispheric Temperature (HT), and the Flow Temperature (FT). In the base-acid ratio ≤ 0.15, the fusion temperature of the ash reaches out 1873 K and decreases gradually along with the escalation of based-acid ratio that is formed in the process. In the base-acid ratio 0.75 – 2, the fusion temperature of the ash deposits reaches out 1473 K which easily causes slagging. In the base-acid ratio > 2, the dependency of the base-acid ratio towards the fusion temperature of the formed ash does not exist [5].

3.3. Slagging index
The slagging index of the cumulation of ash deposits is obtained using equation 2

\[
F_s = \left( \frac{Fe_2O_3 + CaO + MgO + K_2O + Na_2O}{SiO₂ + Al₂O₃ + TiO₂} \right) \times \frac{b}{a} \times S
\] (2)

The value of the compounds can be discovered by observing the samples of ash deposits that are formed in the process. The study is undertaken on three-point samples of ash deposits resulted from the combustion process of the electric steam power plant in Nagan Raya. They are the part around the pipes, the middle part of ash deposits, and the external part of ash deposits.

Figure 3 is the portrait of the ash deposit particles on the part around the pipes and compound compositions found in the observation. The lines in the portrait shows the result of mineral attached on groups of fine ash caused by combustion on fluidized-bed boiler type. The particles do not merge as one because of inadequate temperature level in fluidized-bed combustion type. According to Raask, 1985, the intergranular cracks from the lines are caused by the high level of sulfur in each stem lines. The white dots in the portrait are chars or ashes [6].
Figure 3. The result of SEM/EDX observation of the slagging ash around the pipe. The enlargement image of ash deposits up to 2000 times 30 µm

Figure 4. The result of SEM/EDX observation of the slagging ash around the pipe. The chemical compositions in the observation.

Figure 5 and 6 are the portraits of ash deposits on the middle part of ash and the compound compositions found in the observation. The portraits are similar to figure 3 and 4 because it formed intergranular lines as the result of the high level of sulfur in the lines. Moreover, the bigger formed of the line stems are caused by the increasing amount of silica in the middle part observation compared with the part around the pipe.

Figure 5. The result of SEM/EDX observation of the slagging ash in the middle part. The enlargement image of ash deposits up to 2000 times 30 µm

Figure 6. The result of SEM/EDX observation of the slagging ash in the middle part. The chemical compositions in the observation.

Figure 7 and 8 are the observation of the ash deposits external part of 2000 times enlargement with the size of 30 µm and the compound compositions found in the observation. The distinction for each clot in each particle portrays different characteristic of the formed ash. Moreover, the picture shows that the diameter of the ash particles is differed based on the size; large and small [7].
Figure 7. The result of SEM/EDX observation of slagging ash in the external part. The enlargement image of ash deposits up to 2000 times 30 µm

Using the same equation for each sample, the slagging index is discovered with the value of; the part around the pipe 0.4987, the middle part of ash deposits 0.264183, the external part of ash deposits 0.140284. According to the result of slagging index observation, the researcher concludes that the slagging index of the electric steam power plant in Nagan Raya is classified as low. It is caused by the use of sand containing big amount of silica as the heat transfer media in the boiler of the electric steam power plant in Nagan Raya. The calculation result of the slagging index describes the most accretion of slagging occurs in the part around the pipe due to the bigger amount of sulfur found in it. Furthermore, in that part occurs the large heat transfer that put an impact on the transformation of inorganic components contained in the melted coal because of the high-temperature combustion in the boiler reshaping the deposits caused by the heat transfer.

3.4. The cause of the ash formation

From the three points observation of the ash deposits found in the boiler of the electric steam power plant in Nagan Raya, the trigger components causing the ash deposits can be discovered by observing the part around the pipe as presented in Table 3.

Table 3. The chemical compositions of ash deposits around the pipe

| Chemical components | SiO₂ | Al₂O₃ | TiO₂ | Fe₂O₃ | CaO | MgO | Na₂O | K₂O | P₂O₅ | MnO |
|---------------------|------|-------|------|-------|-----|-----|------|-----|------|-----|
| Wt (%)              | 8.723| 16.912| 0    | 14.782| 6.732| 0.29| 1.211| 3.119| 0.868| 0   |

The ash deposits are formed from the compounds that are not burned-out by the used fuel. In this case, the compounds undergo the transformation to gas phase because the temperature in the boiler gets up to 1300K, particularly in case of the low melting point compound. In line with the transfer of heat in the boiler’s pipes, the compounds experiences temperature digression that causes the compounds transformed into fluid. The temperature digression is caused by heat absorption of fluids in the internal part of boiler’s pipe with lower temperature than the compounds undergoing heating process. The process causes the compounds caused to clot into solid. The lowest melting point compound is the initial trigger of ash transformation in the boiler’s pipe. Diphosphorus pentaoxide (P₂O₅) is the compound with the lowest temperature that is 613K, however, it has the least composition and cannot be found in all scanning. As a result, kalium oxide (K₂O) is the lowest melting point compound of 7 compounds obtained in the ash deposits around the pipe with the temperature of 1010 K (Lide, 2009), followed by
iron (III) oxide (Fe$_2$O$_3$) and natrium oxide (Na$_2$O). The kalium oxide (K$_2$O) bonds with the other compounds to form the ash deposits along the path of the heat transfer pipe.

4. Conclusion
The tendency of ash deposits process occurred in the boiler’s pipe of the electric steam power plant in Nagan Raya is analyzed by observing the ash resulted from the combustion-output indicates that the base-acid ratio value ($R^b_a$) is 0.959736. It includes in high ratio level which alleviates the Initial Deformation Temperature (IDT), Softening Temperature (ST), the Hemispheric Temperature (HT), and the Flow Temperature (FT) in the ash deposits escalating the probability of the cumulation of ash deposits in the furnace. The Value of Slagging Index of the ash deposits observed in three points observation which is around the pipe, the middle part, and the external part respectively are 0.4987, 0.264183, 0.140248. It includes in the group of low slagging index. The most dominant compound found in the ash deposits in the boiler’s pipe of the electric steam power plant in Nagan Raya are sulfur and silica, furthermore, the compositions containing in the ash deposits are SiO$_2$, Al$_2$O$_3$, CaO, MgO, K$_2$O, Na$_2$O, P$_2$O$_5$, TiO$_2$, and MnO. Kalium oxide (K$_2$O) is the initial trigger of ash transformation in the boiler’s pipe because of that compound is the lowest melting point compound of 7 compounds obtained in the ash deposits around the pipe with the temperature of 1010 K.

Acknowledgements
The author would like to greatly appreciate for research permission from PT. PLN (Persero) Unit Pelaksana Pembangkitan Nagan Raya with contract number No. 093/MUM.01.01/UPKNGR/2018

Reference
[1] Naruse I, Nakayama K and Khairil 2000 Ash Deposition Characteristics in Pulverized Coal Reaction Under High Temperature Conditions J Chem Eng Japan 33 (3)
[2] Wei B, Tan H and Wang Y 2017 Investigation of Characteristics and Formation Mechanisms of Deposits on Different Positions in Full-Scale Boiler Burning High Alkali Coal Appl Therm Eng 119 449-458.
[3] Xianpeng Z, Dunxi Y and Fangqi Liu 2018 Scavenging of Refractory Elements (Ca, Mg, Fe) by Kaolin During Low Rank Coal Combustion Fuel 223 198-210.
[4] Zhou H, Zhou B and Li L 2013 Experimental Measurement of the Effective Thermal Conductivity of Ash for High Sodium Coal (Zhun Dong Coal) in a 300 KW Test Furnace Energ fuels 27 7008-7022.
[5] Marek P 2002 Evaluation of the influence of biomass co-combustion on boiler furnace slagging by means of fusibility correlations Biomass Bioenerg 28 375-383.
[6] Raask E 1985 Mineral Impurities in Coal Combustion. Behavior, Problem and Remedial Measures (London: Hemisphere Publishing Coorporation).
[7] Khairil 2013 Teknik Pembakaran (Bahan Bakar Padat) (Banda Aceh: Syiah Kuala University Press)