

Analysis of Scale Deposit in the Geothermal Power Plant

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Abstract

Gunung Salak is one of the potential geothermal area in Indonesia. The steam character is categorised as the water – dominated steam with low steam purity. During inspection, deposit was found in several equipment which are turbine, demister, scrubber and separator. Demister is an essential in the geothermal system as it keeps the steam quality above the saturated condition, by removing the water phase from the steam. The deposit was predicted to be form because of scaling problem due to the impurities of the steam. Oxygen is expected to be responsible of the scaling problem. This research is to analyze the effect of oxygen partial pressure to the formation of scaling through thermodynamic approach. The formation of iron oxide scaling is to be focused in this research as it is mostly found in the deposit alongside other compounds. Demister’s deposit was analyzed using ICP, AAS, XRD and SEM – EDX method. The actual composition found in the demister is then compared to the phase stability diagram results using a chemical reaction software. The deposit used is from the demister. The results of this study shows that Fe_2O_3 reaction can occur in demister current operational condition which are 164.3 °C in temperature and oxygen partial pressure, 3.307×10^{-5} bar

Keywords: water steam cycle; deposit ; power plant geothermal; Corrosion; scaling

1. Introduction

One of potential geothermal area in Indonesia, Gunung Salak has contributed to fulfill national electric demand for over the years. During inspection, scaling deposition was found on the turbine’s blade as well as on other surface of essential equipments which are separator, scrubber, demister and strainer [1]. The deposit was analyzed and the composition was determined. Iron oxide was one of the compound mainly found in the deposit of each components alongside others. Iron oxide was not initially assumed to be found in the deposit because the

steam analysis from well showed no presence of iron [?]. However, the deposit’s analysis results showed a presence of iron oxide. This had happened before in 2005 and caused de – rating of turbine. Presence of dissolved oxygen in steam was believed to be responsible of the iron oxide formation. Therefore, a further study on the effect of oxygen partial pressure is carried out in this research through thermodynamic analysis approach. The thermodynamic parameters used in this study are the equipments’ system temperature and pressure. Below is the simplified scheme of the geothermal power plant system analysed in this study is given in Figure 1.

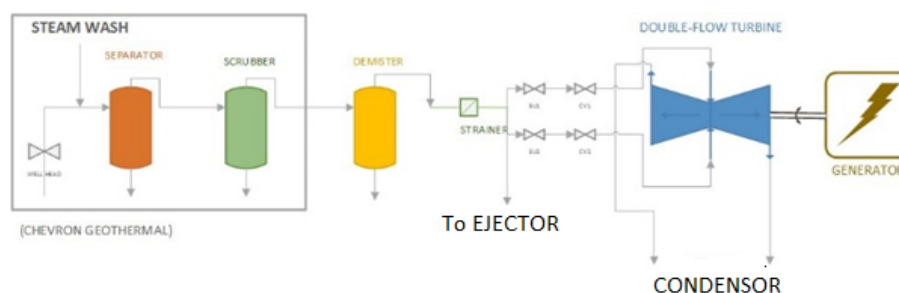


Figure 1. Simplified scheme of a geothermal power plant shows the steam flow path from the well to the turbine to rotate the generator shaft and generate electricity

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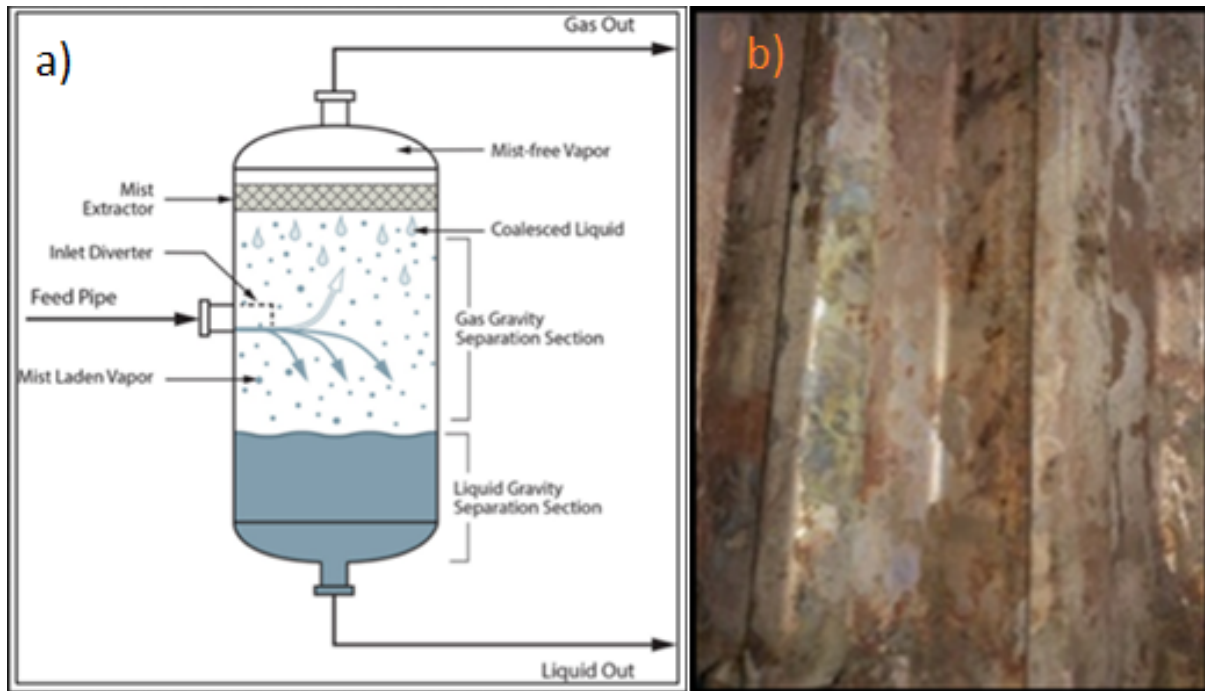


Figure 2. (a) Demister used in the geothermal system, which is used to separate water from the steam; (b) Surface condition on demister

The steam flows from the well to the separator for separating solid particles from the steam. Before that, the steam was washed using condensate water injected into the system. After going through separator steam flows to the scrubber for again the separation of solid particles from the steam. After that it goes to the demister to separate the water phase from the gas phase of the steam. Next it goes to its last solid separation defense, the strainer. Hence, steam that enters turbine is in a high purify and quality of steam (slightly above saturated condition). The presence of dissolved oxygen is believed to not only come from the well, but also from the water used in the steam wash system. Demister as mentioned before is essential to separate the water phase from the steam to keep it in a saturated phase when it enters the turbine. Figure 2 shows how demister works. When entering through the feed pipe (inlet) the steam uses its centrifugal force and gravity to separate the water phase that is more denser than its gas phase. Then the steam will flow through the vane separator as shown in Figure 2b. Gas with lesser density than water can flow easily follows the vane profile. Meanwhile, water with greater density than gas cannot follow the vane profile and stuck at the intersections. It will then drops down due to gravity. The presence of deposit can reduce the centrifugal force of the steam and change the surface of the vane, causes it to lose the profile needed to separate water from the steam.

N. Mundhek in his research stated that scaling can be caused by the redox reaction between elements in the working fluid without interacting with base metal of the equipment, or redox reaction between elements in the

working fluid and the base metal of the equipment, which is also known as corrosion [3, 4]. Both scaling and corruptions formed deposits that will be deposited on the surface of the equipment. Nucleation can happen both inside the bulk fluid and on the surface of base material, called homogenous and heterogenous nucleation respectively[3]. Nucleation inside the bulk fluid will produce deposit as the product of the redox reaction and deposited on the equipment's surface as it is saturated [2, 5]. Both of the nucleation process is affected by its saturation and thermodynamic condition.

In further discussion, this research will focus on the effect of oxygen partial pressure to formation of iron oxide scaling through thermodynamic approach. Therefore, it is assumed that the oxygen fraction through out the whole system is equal. The temperature is also assumed constant through out the system.

2. Experimental Procedures

During thermodynamic calculation, the compounds assumed to be found in the deposit was pre-assumed by referring to the compound mainly found in the deposit previously. Those are iron oxides. Other compounds were also found in the deposits but this study will focus on the formation of iron oxides. The data used in the simulation are concentration of the involved elements and pressure of the equipments. Demister deposit is analysed using ICP – OES, SEM – EDX and XRD. As a comparison result to ICP – OES, AAS is also used. ICP – OES is used to determine the composition and concentration of the elements found in the deposit. A standard solution of the elements that

are observed, is needed to compare it for analysis. The elements that are observed using this method are iron (Fe) and chromium (Cr). This is determined by previous inspection report that shows the presence of Fe in the deposit[1] and assumption of the possibilities that Fe is from the corrosion of the demister material. SEM analysis is used to determine the morphology of the deposit, while EDX is used to determine the composition of each area of morphology, if different morphology is found, as well as the composition of the whole area. The advantage from this method is that any elements presence will be shown in the analysis result, without having to compare it to its standard element. While the XRD method is used to determine the compound that are found in the deposit.

These deposit analysis result is then compared to the thermodynamic analysis using a chemical reaction software. Using this software, a phase stability will be obtained from the simulation. From the diagram, the stable phase that is formed in demister's operational condition is

determined, by calculating its oxygen partial pressure and match it to the diagram from the simulation. The input data needed to simulate this diagram are the elements and temperature of the system. The elements are O_2 , $H_2O(g)$ and Fe. The temperature is $164.3\text{ }^\circ\text{C}$. The diagram formed will be the $Fe-O_2-H_2O(g)$ diagram in a $164.3\text{ }^\circ\text{C}$ system.

3. Results and Discussion

ICP – OES shows that 919890 ppm of Fe and 71907 ppm of Cr is presence in the deposit. Meanwhile AAS shows that 2114 ppm of Fe and 45.23 ppm of Cr is presence in the deposit. Both results shows the presence of Fe and Cr but with different concentration. This is can be caused by the concentration analysis error that used the elements standard solution as a comparison. The EDX result of the overall area shows 20.56 wt.% Fe, 74.16 wt.% O, 3.86 wt.%C, 0.12 wt.%Cr and 1.3%S. While XRD shows that the deposit is made up of 49% $Fe_{2.9}O_4$ and 51% Fe_2O_3 .

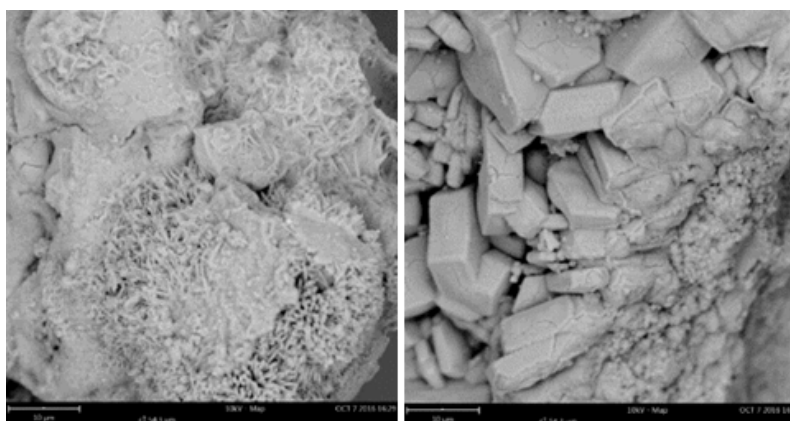


Figure 3. SEM results shows different morpolgy in the deposit (a) a rectangular form (magnification 5000x) and (b) fibric form (magnification 5000x) is visible

Table 1. Results of analysis on deposits using various methods

No	Method	Element/Compound	Concentrations	Units
i.	ICP - OES	Fe	919890	ppm
		Cr	71907	
ii.	SEM - EDX	O	74.16	%
		Fe	20.56	
		C	3.86	
		S	1.3	
		Cr	0.12	
iii.	AAS	Fe	2114	ppm
		Cr	45.23	
iv.	XRD	Iron oxide $Fe_{2.9}O_4$	49	%
		Iron oxide Fe_2O_3	51	

Figure 3 shows the different morphology found on the deposit. There is an evidence of chromium (Cr) and carbon (C) presence in the area with rectangular form. Meanwhile sulfide (S) is presence in the fibric area. As for Fe and O is presence in the overall area.

The output of simulation is the phase stability diagram of Fe–O₂–H₂O. The formation of Fe₂O₃ has a reaction equation: $2\text{Fe} + 1.5\text{O}_2(\text{g}) \longrightarrow \text{Fe}_2\text{O}_3$ and equilibrium when $\Delta G_0 = -168.069$ kcal/mol. The $\log p\text{O}_2(\text{g})$ is -42. It is equal to 10⁻⁴² bar of oxygen partial pressure. Meanwhile, formation of Fe₃O₄ has a reaction equation of $3\text{Fe} + 2\text{O}_2(\text{g}) \longrightarrow \text{Fe}_3\text{O}_4$ and equilibrium when $\Delta G_0 = -230.628$ kcal/mol. The $\log p\text{O}_2(\text{g})$ is -57.616. It is equal to 10^{-57.616} bar of oxygen partial pressure. The calculation of oxygen partial pressure is determined to predict the reaction of oxides formation that took place in the system.

It is seen that the partial pressure of oxygen in demister operational condition is 3.31×10^{-5} bar, with a 5.325×10^{-6} fraction of oxygen. This results in $\log p\text{O}_2(\text{g}) = -4.48$. Meanwhile, Fe₂O₃ is equilibrium when the partial oxygen is 10⁻⁴² bar. So, in a 6.21 bar system, the oxygen fraction to result in the equilibrium of Fe₂O₃ is 1.61×10^{-43} . For the equilibrium of Fe₃O₄, the oxygen partial pressure 10^{-57.616} bar. This shows that Fe₃O₄ is formed with a smaller amount of oxygen than the formation of Fe₂O₃. Thus, with the given operational condition, the phase that is likely to form is Fe₂O₃ rather than Fe₃O₄.

Deposit analysis using various methods is shown in Table 1. XRD analysis shows that the iron oxides found in the deposit are Fe₂O₃ and Fe₂O. The difference between these results happen because thermodynamic analysis uses a split second approach. Meanwhile, this demister operates 24 hours non – stop for 2 years. Thus, it is a continuous system. According to an experiment conducted by Xiaozhe Zhang in 2016, Fe₂O₃ may experience reduction of oxygen and form Fe₃O₄ respective to time[3]. The time constant of transformation depends on the temperature and pressure of the working system[3]. This possibly what causes the transformation of Fe₂O₃ to Fe₃O₄. To determine whether the oxidation process is only between the elements inside the fluid or a possible interaction with the equipment's base metal, a stoichiometric calculation is used from the reaction $2\text{Fe} + 1.5\text{O}_2(\text{g}) \longrightarrow \text{Fe}_2\text{O}_3$

From a stoichiometric calculation, Fe concentration in the steam, 0.105 ppm is only enough to form 0.0525 ppm of Fe₂O₃. While there is 51% Fe₂O₃ which is equal to 510000 ppm. Thus, oxidation of demister's base material does occur in the system. It has dark reddish brown colour. This colour is identified as the colour of Fe₂O₃. It is important to differentiate the difference between Fe₂O₃ and Fe₂O₃ · H₂O since there are still water phase present in the demister. This is to determine the reaction that occurs to the demister base material, whether it is caused by wet or dry steam. Since the colour is identified as the colour of Fe₂O₃, the analysis approach to study this reaction is

using the Ellingham Diagram.

So, we got that formation of FeO and Fe₃O₄ need much less oxygen than the formation of Fe₂O₃. Remember that the operational oxygen partial pressure is 3.31×10^{-5} bar from the oxygen fraction 5.325×10^{-6} . Thus we got that with the operational oxygen partial pressure, the oxide that likely to form is Fe₂O₃. This shows that oxidation of demister base material could occur and form Fe₂O₃. Besides the iron oxide formation, evidence of Cr in the deposit shows that chromium oxides also form on the surface of the base material. Chromium can cause reduction reaction to Fe₂O₃. It will form chromium oxide, Cr₂O₃ and reduces Fe₂O₃ to Fe. But there are still iron oxides found in the deposit. This concluded that iron oxidation still occurs regardless of the chromium oxide formation to protect the base material. This could happen because of the diffusion of oxygen to the base material through initial deposit possibly from scaling.

4. Conclusion

From the data and samples analysis, it can be concluded that the demister operational temperature of 164.3 °C and oxygen partial pressure 3.307×10^{-5} bar, can cause the reaction to form Fe₂O₃. This can be confirmed by Ellingham diagram calculation of iron oxide formation could occur to the iron of the demister base material. The sample analysis using various methods was used to analyze the sample of deposit validate the findings of iron oxides chromium oxide in the deposits which suggest that deposit is originated from the corrosion of the part not only resulted of deposition on carryover minerals in the steam.

References

- [1] R. Adiprana and E. Y. Izzuddin. Gunung salak geothermal power plant experience of scaling/deposit: analysis, root cause and prevention. In *Proceedings World Geothermal Congress*, pages 25–29, 2010.
- [2] J. MacAdam and P. Jarvis. Water-formed scales and deposits. In *Mineral Scales and Deposits*, pages 3–23. Elsevier, 2015.
- [3] N. Mundhenk, P. Huttenloch, B. Sanjuan, T. Kohl, H. Steger, and R. Zorn. Corrosion and scaling as inter-related phenomena in an operating geothermal power plant. *Corrosion Science*, 70:17–28, may 2013.
- [4] S. Soylemezoglu and R. Harper. Oxygen ingress into geothermal steam and its effect on corrosion of low carbon steel at broadlands, new zealand. *Geothermics*, 11(1):31–42, jan 1982.
- [5] X. Zhang, S. Yang, Z. Yang, and X. Xu. Kinetics and intermediate phases in epitaxial growth of fe₃o₄ films from deposition and thermal reduction. *Journal of Applied Physics*, 120(8):085313, aug 2016.