

Increased Generation Performances by Using Sulfur Dispersant in the Cooling Tower at the Wayang Windu Geothermal Power Plant (A Lesson Learned from Wayang Windu Geothermal Power Plant Operation)

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Keywords

Cooling tower, cooling water quality, sulfur deposits, microbiological growth, chemicals injection

ABSTRACT

Cooling tower performance is the essential instrument to maintain an efficient geothermal Power operation. The historical data from the Wayang Windu Geothermal Power Plant shows that all microbiological cooling water parameters are much lower than the allowable limit; however, it shows that the cooling tower temperature increases about 0.3 °C that equals with 0.3 MWe decrease of the electricity production per year. In the geothermal operation, sulfur sediments is found around water distribution, nozzle and fills etc from the non-condensable H₂S gas that can potentially decrease the cooling water performances. The plant performs mechanical cleaning at least on yearly regular basis that needs at least 1 week shutdown of each single cell of cooling tower (8 cell total for each unit).

The field operation team initiated literature study and developed the prototype scale by installing the bio box. The inside bio box put CT small CT fill, than flowing by condensate injected with some chemicals to make sure the potential control of the sulfur sediment during filling inside the boxes. The sulfur deposit on the box injected with some chemicals had the smaller particulate and was easier to wash off. The trial was continued with actual injection to cool down the system with several dosages of chemicals in 6 months period, and the result showed significant improvement of main cooling water temperature. In 2013 WW operation decided to perform injection control of sulfur treatment in the cooling water system. The following year we found that we need not to clean sulfur sediment in pipeline mechanically anymore, and the approach temperature decreased about 0.23 °C (better performance than the previous condition).

Although it was successfully implemented in WW Geothermal, the treatment could not be implemented directly in other power plants due to the differences of site-specific characteristic of cooling water content. The beginning the process approach by literature study, used the mini scale box than continued by full scale of cooling system. The same process approach potentially conducted in other geothermal plant to minimize the potential risk to the running Plant when applying optimum chemical dosage. In overall the trial is success in controlling sulfur deposit at the main cooling system, at the time operation conducted continuous using sulfur dispersant in the main cooling water system operation.

Background

Wayang Windu power plant operates 2 units' geothermal power plants with total capacity 227 MWe in West Java Indonesia. The Unit-1 has the capacity of 110 MWe operation since 2000 while the 2nd unit introduced in 2009 has the capacity of 117 MWe. Since the initial operation, the main cooling water treatment by adding caustic to maintain PH and bio dispersant injected to maintain microbiological growth in the cooling water system. As the historical data shown that the microbiological growth is always below the operational limit (10,000 *CFU: colony forming unit used to estimate the number of viable bacteria or fungal cells in a sample), the plant average was 1,500 CFU. This condition of cooling tower approach temperature, however, indicates the increase of ± 0.3 °C per year. The cooling water temperature directly

affected to the condenser vacuum that the decrease continues as the increase of cooling water inlet temperature. The Plant capacity shows a decrease about ± 0.3 MWe and this could incur potential opportunity losses of about 1,400 MWh per year.

This condition indicates the need of other management aspect to manage the cooling water system operation going. Based on the inspection in water distribution site of cooling tower indicates that some sediment brown color are based on further analysis sulfur content. The mechanical cleaning is effective to clean out sulfur deposit, but need to shut down each cooling tower fan cells for at least 4 days with estimated opportunity losses of approximately 800 MWh per year with additional losses generation due to the increase of cooling water outlet. This condition prevents sulfur deposits in the cooling water system with optimum cost.

The Overview of Wayang Windu Plant

The company's Geothermal Plant is located about 45 km south of Bandung West Java, the plant is managed under a Joint Operation Contract with PERTAMINA to develop geothermal resources within the 12,960 hectare contract area. The geothermal resources produce some water (two phase) and dry steam. The company operation is under Joint Operation Contract (JOC) with PERTAMINA. The plants began their initial commercial operation in June 2000 with the capacity of 110 MW, and the second commercial operation in March 2009.

This geothermal field was discovered by PERTAMINA in 1985, became Joint operating contract in 1994. The Construction of the first unit was completed in 1999, and this caused the delay in completing the electrical transmission system. The First unit began its commercial operation in June 2000, it was then the largest single casing geothermal turbine in the world. Star Energy acquired a 100% interest in 2004 and continued to develop the field and the second unit began its commercial operation in March 2009. Based on some improvement in main cooling water system, the plant capacity became 117 MWe with the same unit of turbine generator as the previous unit.

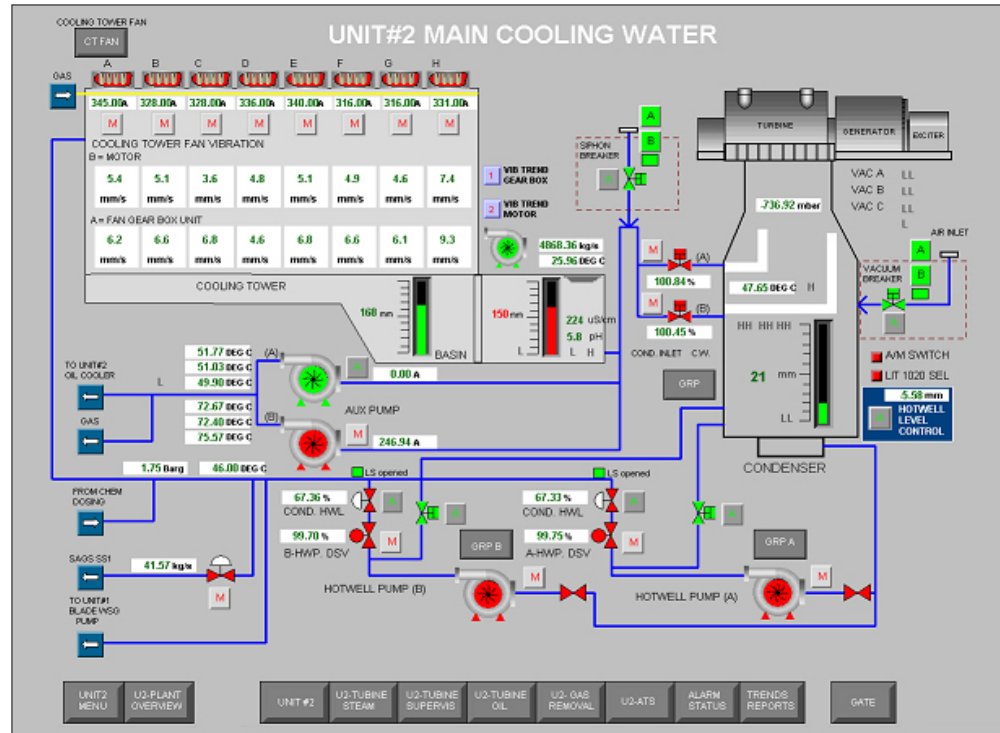


Figure 1. Main Cooling Water Re-circulation (Wayang Windu).

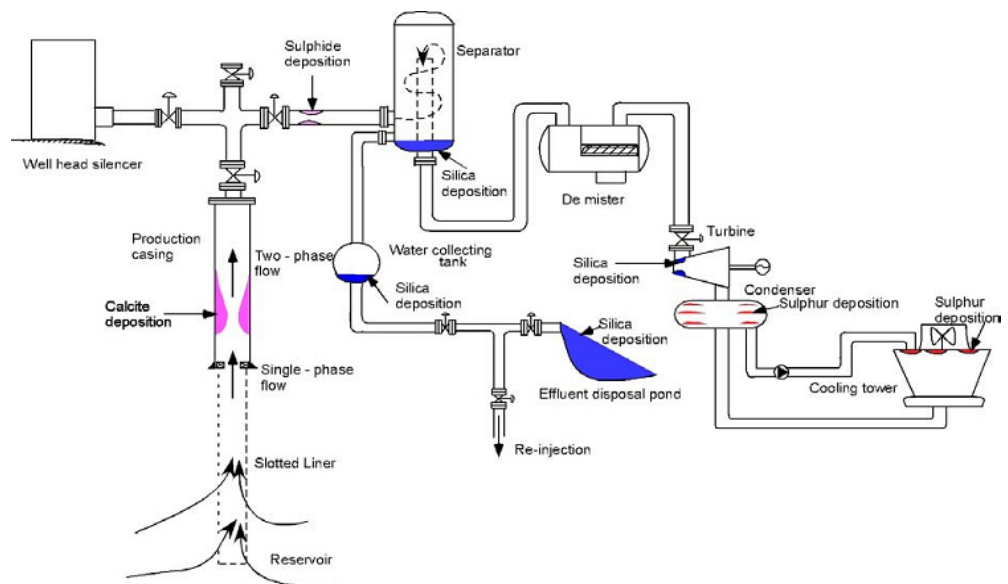


Figure 2. Common Locations of Solid Deposition. (*adopt from Merga Tassew, 2001).

The Plant Cooling Water System

The cooling water system consists of direct contact condenser, 8 cells of cooling tower, 2 hot well pump for circulation water. The auxiliary cooling water supplied generator and oil cooler and gas removal system.

The steam exhaust from the steam turbine dropped to direct contact condenser in the bottom of the turbine. In the condenser non-condensable gases (NCG) and the water are separated by the density where the NCG is sucked by the steam ejector and the water dropped in the bottom site and is pumped by 2 hot well pumps to cooling tower. The excess water is injected to condensate injection wells while some of them are circulated for cooling system. In reference to Tasew, 2001, the potential solid deposit in geothermal will be in several areas such as: Distribution Line of Spray System and Spray Nozzle, cooling tower fill, tooling water basin, condenser (bottom), Low velocity coolers (ie. lube oil cooler). Area of high sulfur deposits in our plant is in the hot circulating cooling water side such as condenser, hot well pump line to cool down the tower, water spray line in cooling tower etc, while in cold temperature side such as from the cooling line to condenser, fill, etc as inspected during plant outage. Main challenges are how to minimize sulfur deposit without shutting down the plant to maximize potential heat transfer. We consider improving the cooling system area where it potentially can perform while the power plant is in on condition. For investigation purpose, we consider 3 main equipment performances in main cooling water system as follows:

- 1. Steam Ejector Performance:** Considering the ejector performance curve of the condenser vacuum will have small impact of the overall performances in the main cooling water system performances. The steam ejector performances depend on main condenser vacuum as suction pressure of condenser. Several tests have been conducted to maintain inter and after condenser pressure in the gas removal system through decrease and or increase of cooling water in the after / inter condenser vessel. Increasing pressure will impact gas flowing from the gas removal system higher since some material from FRP has, however, limitation of temperature and it can't maintain operational temperature higher than existing operational temperature. With NCG content design flow 2% that is equivalent with flow of 9.5 kg/s, the operational pressure is 100 mbara. If there is no load condition, the ejector pressure will be 10 mbara, the no load condition will only be if there is no NCG in the steam. This condition is impossible in real process operation since there is at least small amount of the NCG in the steam produced from the wells. In that case, we ignore the potential improving performance in the steam ejector process to optimize main cooling water performances.

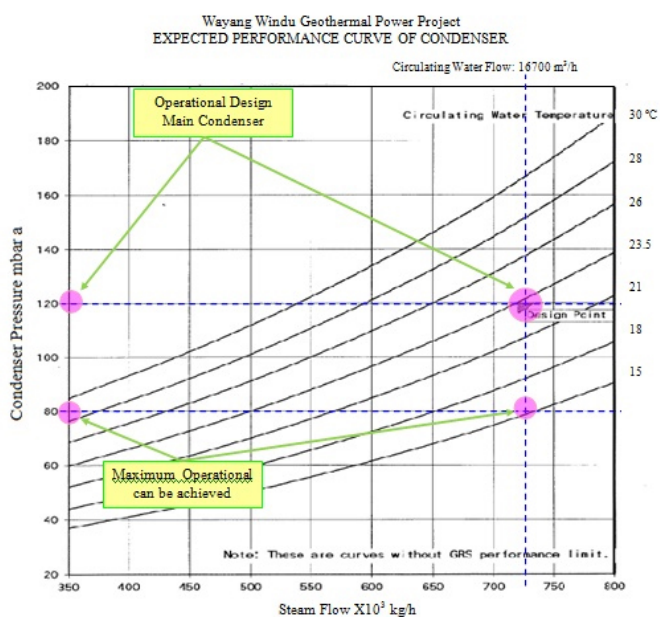


Figure 3. Condenser Performance Curve.

- 2. Main Condenser Performance:** The condenser performance depends on the circulating water quantity and temperature, the water inlet comes from cooling tower while the steam condensing temperature from turbine and it will relatively be constant. The steam flow and re-circulation only function on temperature inlet condenser. Decreasing inlet temperature will increase the condenser vacuum and opposite process. The plant cooling water temperature inlet condenser is designed is 23.5 °C with pressure condenser be 120 mbara. Some sediments inside condenser, combined with increasing of cooling water inlet potentially affect condenser performances.

To perform mechanical cleaning in main condenser, the power plant must be shut down at least 3 days, with estimated generation losses over 16,000 MWh. Operation ignore the potential improving performance to shutdown plant to cleaned main condenser to optimize main cooling water performances, the potential generation lost too high.

- 3. Cooling Tower Performance:** The process operation depends on how effective is the heat transfer in the cooling tower, weather temperature and water condition may affect the performances. Wet bulb design temperature 15.5 °C will be 23.5 °C outlet water temperature. The best condition of the cooling tower performance is in new condition where the fill and water distribution condition are in clean condition at commissioning stage. However following years operation some sediment include sulfur showed at h the fill and water distribution side. The historical data

showed that microbiological site performances was far away from the manufacture operational limit. The average SRB was 1,000 CFU since maximum limit is 10,000 CFU, but the cooling water approach showed 0.3 °C increased every years.

Referring some assessment in the company case from all three main components above, only the cooling tower that is directly related with the potential external factor such as dirt from the environment that may affect water quality, sun, water, and air that could potentially affect the growth of microorganism in the system etc. The cooling tower is the most potential equipment as barrier that can manage to get potential improvement in the cooling tower area. The component of cooling tower is basically thermodynamic engine and is excluded from the investigation done by the team. We consider only process operation that flows through this equipment, in this case the water quality that circulates in the system.

The temperature cooling water can be increased in the cooling tower area, the cooling tower can be shut down one to perform mechanical cleaning and to optimize the program. Perform mechanical cleaning is the effective way but need to shutdown cooling tower fan each cells 2 times per years for a week and generation loss 0.6 MW during one cell CT fans off line for each unit.

Case Study

Based on the 3 main components of cooling water equipment, we decide that the cooling tower performance can potentially be managed for the performance without plant outage. The cooling water performance is affected by external factor such as weather, dust etc while condensate water inlet temperature is basically steady as a result of steam outlet temperature from the turbine through condenser. In reference to operational data there is some increasing of cooling tower approach temperature from 6.86 °C in May 2000 (1st operation) and showing 10.68 °C in 2009 after 9 years operation, that is equivalent with 0.44 °C per year. This condition causes the decreasing of cooling tower performance to affect the condenser vacuum and thus affecting the whole operational process in the plant. As a matter of fact, we can manage the weather main challenges, and to manage cooling tower steady is by maintaining the cooling water system quality. The potential cause that affects cooling water performance is the microbiological growth that becomes sediment in some equipment's that may be flowing together with the circulating water in the distribution water or etc.

The microbiological site where SRB level in the system is average since the 1st operation < 1500 CFU (limit 10,000 CFU). Based on this condition, some other potential factors should be controlled. The power plant has applied

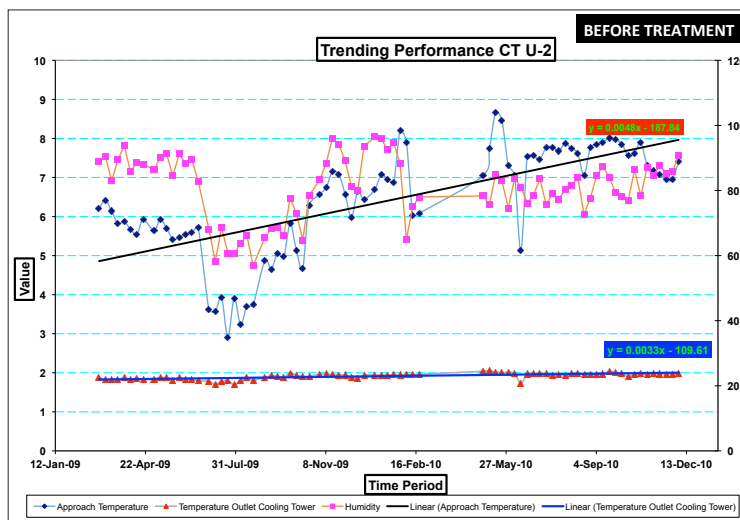


Figure 4. Trend Unit-1 Temperature outlet Cooling Tower.

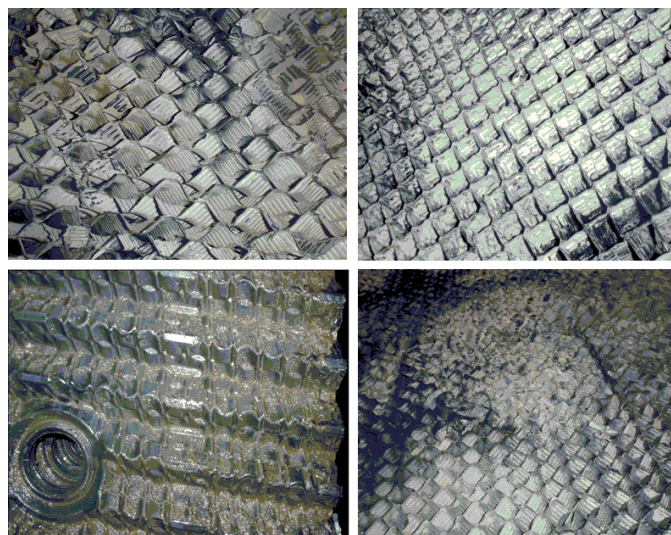


Figure 5. Cooling Tower Fill Condition (2010).



Figure 6. Cooling Tower Water Distribution (2010).

microbiological treatment in the system by injecting some bio dispersant regularly in the system since the 1st operation. Referring to our inspection of cooling tower, the upper layer is relatively clean but the second layer, however is dirtier in hot temperature side such as water distribution, and this indicates some sediments. Based on the laboratories analysis, sulfur makes up majority component of the sedimentation in the water distribution.

Sulfur sediment in the water distribution of cooling tower could reduce water quantity spray to the system and some of sediment in the fill could reduce the contact area for cooling system. This case study, we apply more in sulfur sediment mitigation since the microbiological performance showed excellent since the 1st operation. As the figure 5 & 6 above the sulfur sediment occurs at the hot water spray and the fill of the cooling tower.

The Program of Cooling Water Sulfur Deposit

The Sulfur Deposition in the geothermal cooling system is mainly elemental sulfur (S⁰). The elemental sulfur is an oxidation product of H₂S that stems from the steam. The properties of sulfur S = (from H₂S in the steam) will be chemically and biologically to elemental sulfur (S⁰), thiosulfate (H₂S₂O₃) and sulfate (SO₄). The elemental sulfur (S⁰) is insoluble, Sulfate (SO₄) has high solubility. The following reaction is deemed to occur in the cooling water system and the formation of sulfur supposedly depends on the balance reaction



Chemicals and biological are considered to be involved in the above reaction and governed by the oxidation reduction potential and PH, while bacteria such as sulfur bacteria participates in the formation of sulfur from biological. Sulfur stems from high concentrate of sulfate and hydrogen sulfide in the cooling water that make up of geothermal fluid (condensate). The impact of sulfur sediment would reduce cooling tower performance as well as cooling water supply temperature to condenser and could increase condenser back pressure, and consequently this would reduce overall turbine performance and increase steam supply. The investigation process will be conducted for main reference where there is no mechanical equipment or process change. At unit 1, there are some modifications in the cooling tower area. Referring to operational data of cooling tower of unit 2 is 5.94 °C in 2009 and then increase 8.91 °C in the following years. As our calculation impact of 1 °C of cooling water temperature will increase steam rate to 0.017 kg/s/MWe steam consumption = 410 tons per year. There are some potential improvement in the cooling tower side by managing potential sulfur deposit in the system. As a matter of fact, the potential sulfur deposit comes from H₂S content that will always be available in the steam supply as NCG. The plant average NCG content is about 1% of steam. Some potential factors that affected H₂S and Sulfur Oxidation process are as follows:

1. PH: The higher the pH (pH > 8.0) will be lower elemental sulfur production and oppositely (average steam PH in the plant is 4.6)
2. Temperature: < 50 °C, elemental sulfur is dominant (outlet condenser temperature is ± 45 °C).
3. The amount of the oxidants: The higher oxidants level, the lower elemental sulfur production.

Potential methods to control elemental sulfur formation and sulfur sediments are as follows:

a) Chemical Oxidation — Remove H₂S before entering the cooling system — Maintaining high pH (above 8.0) — Increase SO₄⁴⁻ by forced oxidation (oxidants addition)	b) Biological Oxidation — Manage SOB population at minimum level — Maintaining pH (above 8.0)	c) Dispersing the sulfur deposit from cooling system in regular basis — Mechanical cleaning — Sulfur dispersant — Enhanced by oxidation process
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*Removed H₂S before entering process potential needs high cost and low impact since H₂S content in our plant basically is very low, however in the oxidation process may affect other process such as corrosion level in some part of the plant operational system.

The process improvement mitigation process follows these following steps:

1. Concentrate to Single Potential Selection Process With Reasonable Cost to Be Applied

From the technical literature, there are potentially many possibilities we can adopt during literature review. From 3 potential methods above, we are consent in the 3rd selection, as the other 2 methods need to increase PH up to 8 for processes that will cause in increasing cost of chemical consumption for plant operation. The mechanical cleaning has been regularly performed in 2-year basis since 2008 where we found some sediments of sulfur at cooling tower

water distribution getting worse time by time. The improvement process disperse to be conducted since mechanical cleaning of cooling tower cell at least needs 10 days of the cell that is equivalent of almost 0.6 MWe generation opportunity losses to perform the mechanical cleaning. We have complete spare for 1 cell of water distribution facility. The main goals are trial possibility removal of sulfur sediment in the main cooling system operational process that can extend mechanical cleaning in periodical basis to minimize potential generation opportunity loss. Any process commences didn't interrupt operational process.

2. On Site Study and Investigation Method

There is potentially a lot of chemicals Specialty Company that can help, but most of them will be offering their products with various capability that will be great result as promise. If we quote question what the potential effect will be nothing as their preference. Remember some incompatible chemical potentially produce foaming in potentially interrupted plant operational and caused condenser vacuum dropped, especially for the oxidation process operation that the air produced in the foam potentially happen. The chemicals process for the sulfur treatment basically can perform through 3 selections as follows:

Chemicals	Advantages	Disadvantages
Bio detergent (surfactant)	Could remove existing organic and inorganic fouling	• Heavy foaming potentially occurs • Can't prevent Initial deposit formation
Biocide and surfactant	Could remove existing organic and inorganic fouling	• Can't initial deposit formation • Generally this material is expensive. • Foaming but will not create heavy foam.
Polymer dispersant	Could prevent initial sulfur deposit Could remove organic and inorganic fouling	• Impact to slow biological fouling, the result will take longer time.

Cooling water may have some combination to become foam such as chemicals, over cycling, excessive solid, high alkalinity etc. the easiest way to check compability of the chemicals is to mix with our cooling water sample in the laboratory with several temperature trial process. In case there happened anti foaming injection needed, however, better to take other potential chemical rather than to take a risk of process operational. Incapability of chemicals reaction with different branch potentially become dispute of quality, but however the process selection is our decision. As some at lab

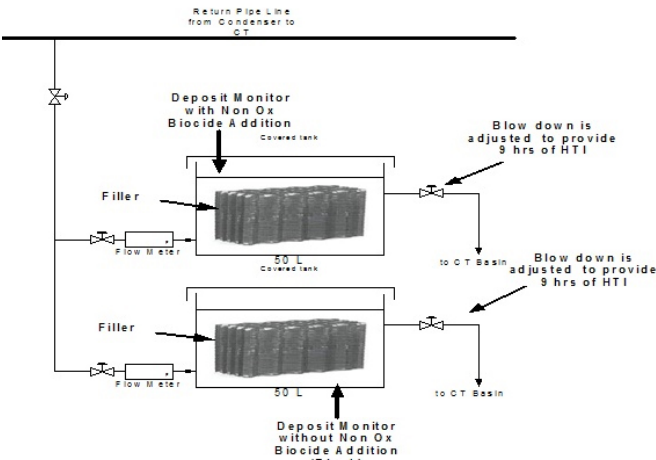


Figure 7. schema bio box installation.

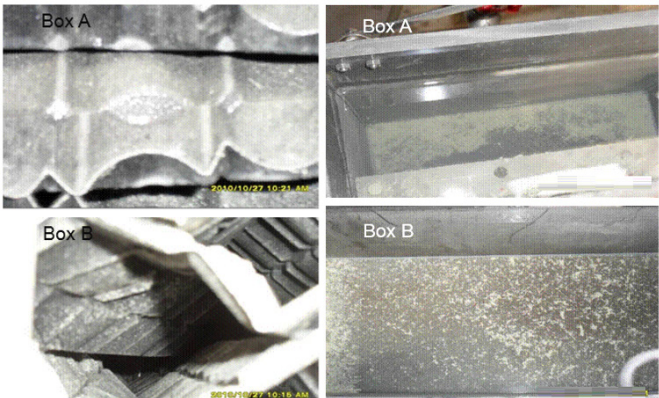


Figure 8. Bio box trial result.

trial that there are some chemicals potentially compatible to disperse the sulfur sediment sample. Directly injection with high quantity in the cooling water potentially gets different result such as process operation and weather that may affect.

Examine the preventing effect of the chemicals reaction in the real process. To minimize the risk, the team decided to apply bio box that was connected in the inlet of cooling water return line. The process is basically trial condition with same water quality but in mini scale process operation. Bio-box trial is basically built from 2 transparent boxes and connected with the flowing cooling water from the inlet off cooling water, into 2 bio boxes that some fill material has been added inside (the fill material added to two boxes is the same with actual fill of the cooling tower). The 1st box is injected with selected chemical regularly and another one is left as current operational process operation. The ultimate goal of the process is to investigate potential controlling sulfur sediment in the cooling water area to improve cooling system performance, while the other parameter that potentially impact TDS is through routine monitoring.

The Holding Time Index (HTI) in the system must not be too short, on the other hand, these items will degrade chemically after a specified time, and to hold them in the system longer than the effectiveness of the application.

$$\text{HTI formula} = \frac{0.693 * \text{HC (Holding capacity)}}{\text{BD (Blow downrate)}}$$

During bio box test manual feeding of chemicals injection with estimation of 9-hour of HTI setting. The team decides at least 6 month of continual operation of the bio-box than visually inspected as well, the weight of fill inside operates with different treatment. During the trial bio box period, the cooling water system remains the same as previous than following the agreed time. The sulfur sediment study will go on. With this method, the potential affected of the additional process will be earlier identified and with small content in the part of the system, the potential process failure that may cause process loss such as incompatible chemistry that may cause heavy foam can be eliminated. Based on 6-month operation, the bio box with additional chemical is injected in regular weekly basis with manual feed, showed that this has smaller particle of sulfur sediment but the weight is almost the same. With this result, the team could decide that, by using the chemical injected and could potentially remove some sulfur deposit, however, in the beginning process, the TDS content in the cooling water could potentially increase, and that can be anticipated, as this may be trapped in different location such as at low point on condensate injection, as this result of smallest particle is found in the box with injected chemicals. There is no indicating of increase TDS on the bio box result, this condition may cause the flow too low in the process. As a matter the fact that sulfur deposit in bio box with injected chemicals showed more lenient and potentially easy to remove by spraying water with high quantity flow, the continuous injection will be potentially getting better effect if the sulfur is removed from the existing sediment location.

The study process continued with full capacity in cooling tower area, the team decides to perform economical Analysis basis on at least 6 month with continuous injection program. This process affected the injection program for a long time operational process can be managed. The original goal is to keep existing sulfur sediment to stay at the current level, and thus the approach temperature can be managed as the existing level, the result gets, however, even better performance for the approach temperature before and after injection and in the real operation process could show the decrease of 0.13 °C, that means the overall efficiency of the cooling system improved with 5 ppm injection rate. Thus based on the injection showed that approach temperature gets increase again as the previous original

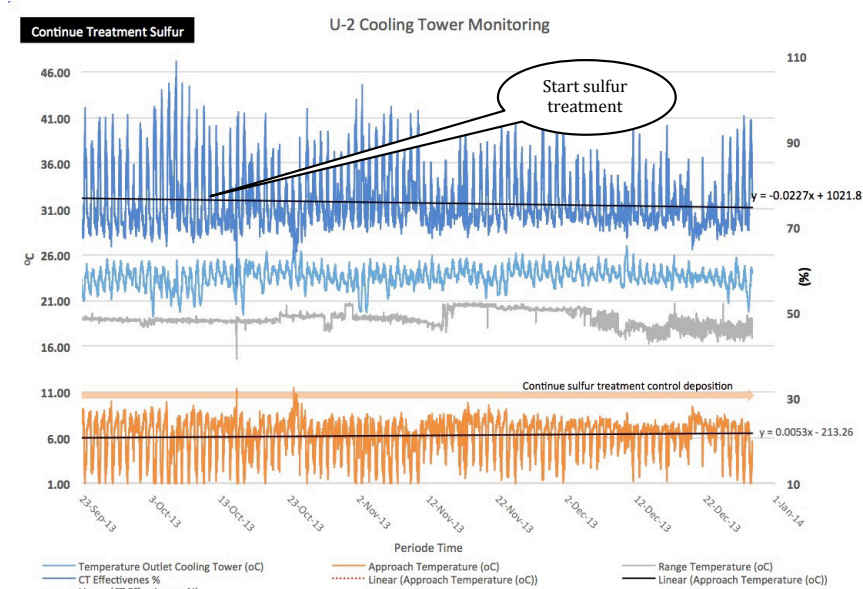


Figure 9. The trend of Cooling Tower Approach Temperature (after post trial 6 month).



Figure 10. Water Distribution Spray Nozzle Post Injections 2013.

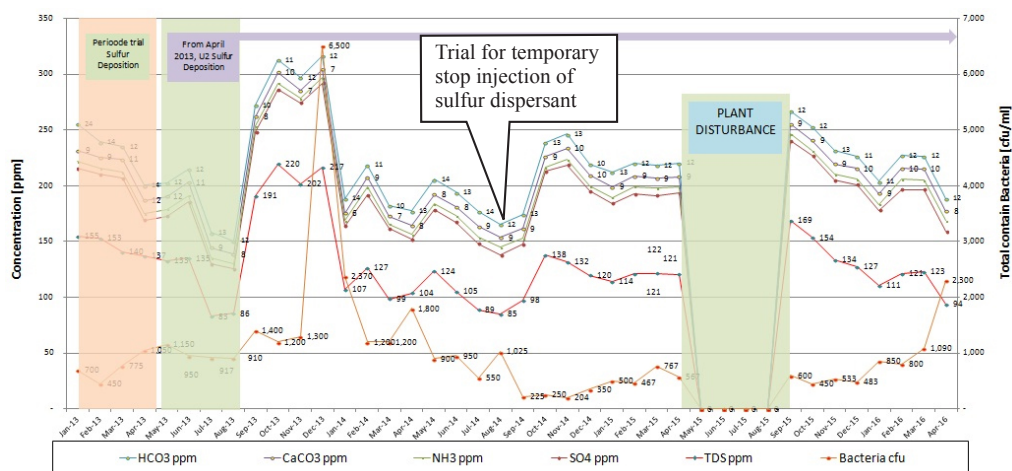


Figure 11. Trend Result of Water Analysis.

pattern. However, 6-month operation didn't represent all condition within years where in the tropical condition there are 2 season rain and dry that may weather condition also impact to the overall process.

The 6-month service, the operation team forecasts in 2-year basis program to define the potential improvement process and the Key Performance Indicator (KPI) of process is implemented. In this continuous injection program, some online parameter is checked to verify the established process. This didn't have the potential effect on other process, the other part of cooling system includes in condensate line injection process operation. In early step of injection program seems that the TDS increases highly, compared with the previous condition but gets normal following four-month injection program. Almost 2-year operation of sulfur treatment injection approaches the targeted temperature with the decrease from 7.16 °C (June 2013) to 6.93 °C 0.23 °C (August 2014) for 14-month operation with 4 ppm chemical injection rate. The increasing of TDS in the beginning program indicates that the removal of some sediments in the whole operation has started.

At that situation, some adjustments are performed to get an optimum injection rate, increasing TDS that potentially comes from sulfur sediment removal from some locations. After 14-month continuous injection for mechanical cleaning water distribution, the water distribution site seems to look cleaner than the previous condition that is why the mechanical cleaning process is canceled. Spray the water nozzle cleaner than the previous condition at the same period.

Some sulfur sediment still there but thinner than previous conditions at the same period also easier to clean out.

Refer the trend above showed that the TDS significant increased at early injection, however the condition back to balance process operation following month operation. Based on the site inspection when scheduling mechanical cleaning in water distribution site scheduled (every 2 yearly basis), from the condition, after 14-month continuous injection, the water distribution nozzle and pipe line showed thinly sulfur sediment that in 2013 the process mechanical cleaning was skipped. Besides, the thinner of the sediment, the sulfur sediment inside pipe seem softer so that it is easier to cleanout compared with the previous conditions. After 2 cell of cleaning and inspecting CT, we decide that the next mechanical cleaning process is skipped to other cell in the next 2 years for further process based on water distribution condition that is relatively clean. The approach of cooling water temperature also showed a decrease of 0.2 °C, which means the cooling tower performance increases also without performing any mechanical cleaning.

The program decides to continue at least to maintain a current approach temperature cooling tower. It is not as a result of sulfur sediment in the fill and or cooling water distribution site of Plant operation that apply to both operation. Consumption of chemical injection at the plant operation is about 450 kg/month. Assume each 0.1 °C is equivalent with 0.1 MW as previous historical Wayang Windu geothermal data. There is an increase generation of 0.2 MW following 1st year of sulfur deposit injection program. The injection program could save about 3,400 MWh in this period (with the decrease of 0.2 MW, approaching the temperature about 0.4 MW saving at end of the year for both units operations). However when the plant cooling tower performance is impossible to back the original commissioning stage, but by maintain sediment level of the sulfur at the main cooling water system will kept maintain approach temperature than kept generation produce at the same level following year's operation.

Conclusion

Based on the control of sulfur sediment of the cooling water as follows:

1. The chemical injection couldn't stop the formation of solid sulfur but will disperse in smallest particle and easier to flow among cooling water injection of condensate. The sulfur dispersant program helps to keep particle in small size, preventing agglomeration and particles precipitation, with small particle, the equipment at cooling system of cleanest surface of the line could be maintained, thus the performance can be managed and better also for the injection of condensate TDS

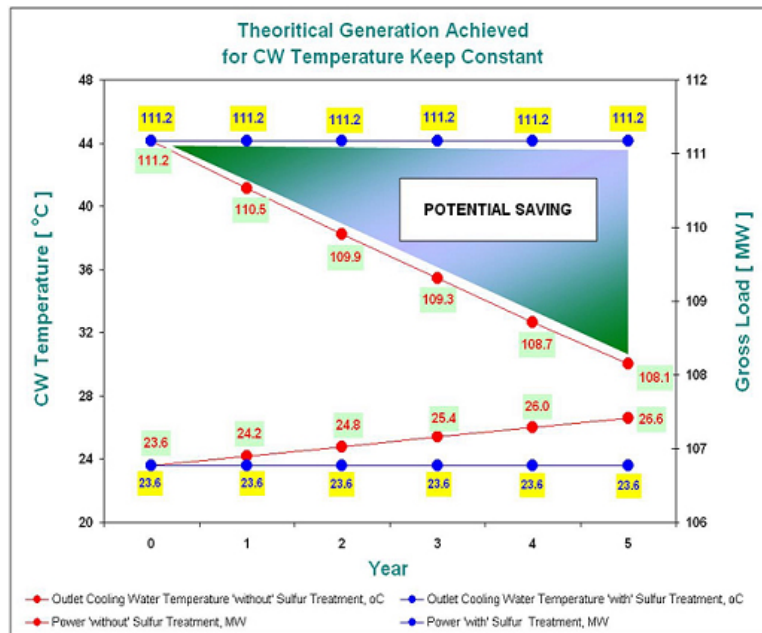


Figure 12. Potential saving with sulfur deposit injection program.

2. The sulfur chemicals injection more effective compare with mechanical and or leave as its condition for geothermal power plant operations
3. Sulfur sediment in the geothermal cooling water system has significant impact to overall cooling system performance. Mechanical cleaning is effective to return main cooling system from out of service.
4. Chemical injection is possible to delay sulfur sediment in operation, trial process would be performed to minimize operational risk of overall cooling water performance.
5. Trial process to get compability of chemicals that will be used will help plant operation to minimize potential risk.

Recommendation for Future Research

Increasing of TSD (total dissolved solid) condensate injection that potentially stems from sulfur sediment removal in the cooling water site could be moved to other location such as condensate injection line. In the company case, that all injection line is thoroughly gravity injection and potentially will be accumulated somewhere else in low point loop and or may in the injection well bore. In our case so far, we didn't find any abnormalities such as reduced injection capacity rate of the condensate injection wells. Research of potential impact of the sulfur sediment in condensate well injection will be challenging for continues operation of the geothermal power plant.

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Glossary / Abbreviations

No	Abbreviation	Remark
1	Approach of cooling tower	Differences in temperature between cooled water temperature of cooling tower and the entering air wet bulb into cooling tower
2	CFU	Colony Forming Unit; a unit used to estimate the number of viable bacteria or fungi cells in a sample
3	H ₂ S	Hydrogen sulfide; is a chemical compound colorless gas with the characteristic foul odor of rotten eggs in geothermal usually stemming from the steam as NCG.
4	MWe	Megawatt Electricity, is a measure of a power plant output or the amount of electricity
5	MCW	Main cooling water
6	NCG	Non Condensable Gases
7	PLN	Perusahaan Listrik Negara (Indonesia State-Owned Enterprise)
8	PERTAMINA	Perusahaan Pertambangan Minyak dan Gas Bumi Negara (Indonesia State- Owned Mining Oil & Gas Enterprise)
9	TDS	Total Dissolved Solid; a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal sol) suspended form.

