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A study of brine supply system to binary cycle unit at Namora I Langit Geothermal power plant

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Abstract. The geothermal binary cycle's power plant is formed by two cycles. The primary cycle that contains the geothermal fluid and the secondary cycle in which the organic working fluid is enclosed. The geothermal fluid can either be water or steam. In Namora I Langit Integrated Geothermal Combined Cycle Power Plant if its water is called brine unit and if its steam is called bottoming unit. Main issues to consider in binary cycle unit are corrosion, scaling, fouling, working fluid flammability, cascade use/cogeneration, vapour plume, large footprint and noise emissions from the fans in case of air cooling. This paper is focus on corrosion, scaling and fouling on surface equipment facility. As we know, the heat exchanger transfers heat from the brine to the working fluid in the pre heater and evaporator. Brine flows through the tube and working fluid in the shell tube. The problems found in the heat exchanger are corrosion, scaling and fouling. Because of that, for a heat exchanger can function properly, a lot of work should be made to mitigate scaling and fouling. This paper presents a study of brine supply system at Namora I Langit geothermal power plant. How the equipment, method and operation that used at brine line can deliver brine which is appropriate with binary unit.

1. Introduction

The exploration study shown that the geothermal energy throughout Indonesia is mainly high temperature (above 250°C). The most common type of geothermal reservoir is liquid dominated but some are vapour such as Kamojang and Darajat field. Furthermore, geothermal energy with this characteristic is suitable for electricity generation. Mostly in all existing geothermal power plant in Indonesia, after utilizing steam from separator to drive turbine generator, the brine from the separator is directly injected to the earth through re injection wells. In fact, the brine still has a temperature above 150°C and mass flow rate of one hundred tons per hour.

The thermal energy of the brine can be used by transfer via a heat exchanger to working fluid used in other processes (Binary cycle). This process is utilized in the Sarulla Geothermal Field and for the first times it's in Indonesia. In this paper, the focus will be on the study of brine supply system from well pad to power plant – binary cycle unit. What is being done in order to deliver the required brine to binary unit? Such as mass flow, pressure, temperature, and chemical treatment. Therefore, expected with this study can be determined the right operation condition so that problem in surface equipment facility can be minimized and the maximum net power output achieved.

2. Status Of Sarulla Geothermal Field

The 330 MW Sarulla geothermal power project is located in Tapanuli Utara, North Sumatra, Indonesia. The project will be constructed in three phases of 110 MW each, utilizing both steam and brine extracted from the geothermal field to increase the power plant's efficiency. The first and second phases are already commercial operation date in March and October last year. And third phase is scheduled to be completed in stages within five months thereafter. This project is in two places i.e. in Silangkitang and Namor I Langit. The project is developed, and will later be owned and operated, by the SOL consortium of which Ormat has a 12.75% share. Other members of the consortium that owns SOL include Medco Energi International Tbk (Medco); Itochu Corporation (Itochu); and Kyushu Electric Power Co. Inc. (Kyushu).

The concession holder for the project PT Pertamina Geothermal Energy (PGE) has provided the consortium the right to use the geothermal field under a JOC. PT PLN, the state electric utility, is the off taker for 30 years under the ESC agreement. Exploration of the project's geothermal resources started in 1993 but stopped in 1998 due to challenges presented by the Asian Financial Crisis which also led to the original developer to sell its development rights to PLN. When a law to promote private sector participation in the geothermal sector was signed in 2004 PLN opened an Independent Power Producers (IPP) bidding process for the Sarulla development rights, which the SOL consortium, in its original makeup of Medco, Ormat and Itochu as Kyushu only joined the consortium in 2008, won in 2005.

2.1. Reservoir Characteristic

The fields are located immediately adjacent to the Great Sumatran Fault (GSF), a major right-lateral strike-slip fault system which transects the length of the Sumatra volcanic arc. No active volcanism is present at Sarulla with the youngest intrusive domes dated at 120ky. The Namora-I-Langit field hosts a prolific gas-rich fumaroles area with boiling acid-sulphate springs atop a thick altered clay-cap exposed near surface, west of the Great Sumatran Fault.

Drilling of four deep exploration wells to over 1500m at NIL demonstrated a 275°C liquid dominated system. Silangkitang, hosts a 4km span of fumaroles, sinter and boiling hot springs along the main axis of the GSF. Equilibrated distal hot springs indicate temperatures of about 270°C. A total of five deep exploration wells were drilled at SIL between 1994 and 1998 to a maximum depth of 2300m demonstrating upwards of 310°C. Both the NIL and SIL reservoirs are hosted within a tectonic half graven forming to the west of the GSF with conjugate structures controlling the main permeability within a thick sequence of Quaternary age rhyolitic to diacritic volcanic underlain by a basement of Palaeozoic meta-sediments. A reservoir simulation study was carried out to verify the capacity of Silangkitang and Namora-I-Langit reservoirs to sustain a combined extraction of the mass to drive geothermal power units generating about 350 MW of gross capacity for 30 years [5].

2.2. Production Characteristic

To meet the design capacity of about 110 MW at 20 bara separation pressure at SIL and to supply the 230 MW expected units at 11 Bara separator pressure, as of July 2017, SOL has completed 15 production wells and 19 re injection wells. Another 3 development wells are now being flowing test and drilled. With averaged totals enthalpy at SIL 1390 kJ/kg and at NIL 1200 kJ/kg.

3. Theoretical Review

3.1. Type of High Temperature Reservoirs

High-temperature reservoirs extend over large areas but the target of most wells is to intersect fractures or layers with good permeability. These are zones with good flow that can draw in fluids far away from the well. There are three main types of high temperature reservoirs that have quite distinct characteristics, a) water dominated, b) boiling reservoirs, and c) steam dominated reservoirs. Many reservoirs are liquid dominated, which means that there is only geothermal liquid in the reservoir and most of the well. In a flowing well the liquid starts to boil at a depth which depends mainly on the temperature of the liquid but also on the wellhead pressure and the well productivity.

The higher the temperature the deeper will be the onset of boiling, and the higher the wellhead pressure the shallower will be the onset of boiling. Above the boiling point the fluid is transported in

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two-phase flow, steam and water together. If the well is not very productive or the temperature high in relation to depth, boiling can move out into the reservoir and over time turn it into a boiling reservoir. Then there will be a reduction in water flow but the stem flow will be less affected, as the liquid travels slower in the rock than the vapour and is left behind. Thus the average heat content of the produced fluid, measured as enthalpy (kJ/kg), increases. As far as steam production is concerned this can be beneficial.

3.2. Geothermal Fluids

The term geothermal fluid refers to geothermal liquid, steam and gas separately or together. Just what state the fluid is in, liquid or vapour, depends on the temperature and pressure. When the fluid travels as a mixture of liquid and vapour (gas and steam), it is referred to as two-phase flow. The dissolved minerals, silica and salts, are practically only found in the liquid phase. Another component of geothermal fluids is gas, mainly carbon dioxide, which is dissolved in the liquid phase until the water starts to boil. Other gases are hydrogen sulphide, hydrogen, nitrogen and methane. Upon boiling the gases are rapidly transferred to the steam phase, as the gas molecules prefer to reside in the steam rather than the water.

Geothermal fluids carry quite different concentrations of dissolved minerals and gases. The study of these is the domain of the geochemists who have now identified more than twenty chemical species and chemical ratios governed by temperature. Most minerals are more soluble in hot water than cold, e.g. Silica, and thus simply knowing the silica concentration in the water can tell us what the temperature in the reservoir is or has been. As the fluid is saturated at the reservoir temperature, any cooling will cause super saturation leading the excess concentration to eventually precipitate. Mineral deposits so formed are known to attach themselves to pipes and other surfaces. A few minerals on the other hand are less soluble in water at higher temperature, e.g. calcite and calcium sulphate, and this is an advantage because it limits the formation of such deposits when the fluid is exploited and cools down. Equally strong an influence on the chemical evolution of the geothermal fluids upon changes in temperature and pressure are changes in the pH value. Knowledge of the rate of the precipitation reaction is thus of importance in the design of the fluid handling system. Changing the pH of the fluid by acid or caustic addition is used for example to affect the precipitation rate of silica [3].

3.3. Geothermal Scale

Two of the most common geothermal scales are silica (SiO_2) and calcite ($CaCO_3$). Both these scales are white in colour and are not easy to tell apart visually. Silica scales are found to some extent in all geothermal installations but by maintaining the temperature above the solubility level for amorphous silica (the non-crystalline form of silica), the scaling rate is very low and thus this is one of the design criteria for most geothermal plants. In the reservoir, the silica concentration is usually in equilibrium with quartz, the crystalline form of silica. Once the water starts to boil and cool down, the silica concentration in the water increases.

The water immediately becomes quartz supersaturated but no quartz precipitates are formed because of the slow formation of quartz crystals. Silica scales are first formed when the amorphous silica solubility curve is passed (Figure 1).

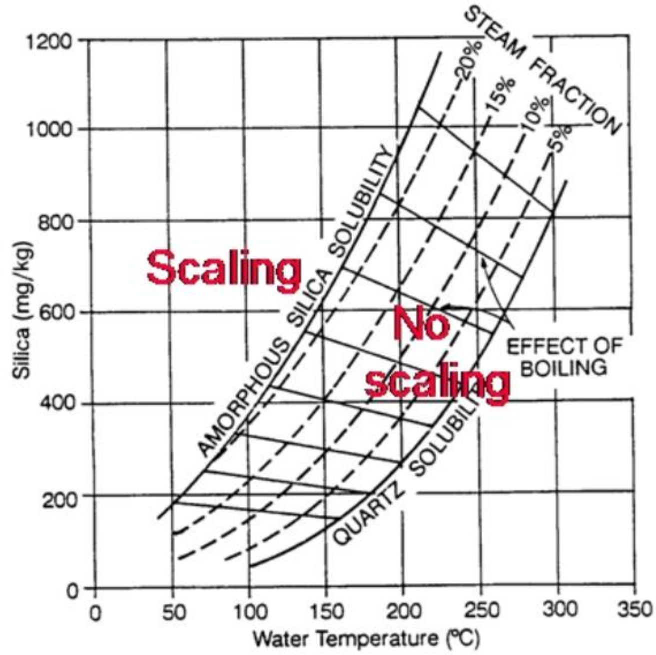

Figure 1. Solubility of silica in water. Scaling occurs above the amorphous silica solubility curve [4].

Looking at these two curves it is clear where the "window of opportunity" lies for operating the geothermal plants without silica scaling. It is the temperature vs. Concentration area between the quartz and amorphous curves that is "safe" from scaling. This means in practice that only some 25% of the water can be converted into steam without the danger of silica scales, almost independently of the temperature of the resource. A silica "rule of thumb" may say that it is only possible to cool the water by some 100°C without scaling. Calcium carbonate scales (in the crystalline forms Calcite or Aragonite) are common in wells with reservoirs of 140-240°C, and are primarily found where the water starts to boil in the well. This scaling is due to the degassing of CO_2 and the resulting increase in ph. Calcite has retrograde solubility, is more soluble at lower temperatures, and thus upon further flashing as the water and steam travels up the well, the calcite stops rather suddenly to form scales [3].

4. Study Of Brine Supply System

4.1. Basic Binary Cycles

Basically, there are two types of binary cycles, the organic rankine cycles (ORC) and the kalina cycle. If the geothermal brine temperature is below 180°C, the ORC system is considered more economical and commonly using hydrocarbons as the appropriate working fluid. And when geothermal brine temperature lower than 120-130°C, a kalian cycle with a mixture of water as the working fluid seems superior to the ORC cycle [1].

The main components of a basic geothermal binary cycle's power plant are the preheater, evaporator, turbine, condenser, and working fluid pump (Figure 2). The geothermal brine enters the system through heat exchangers, where heat is transferred to the working fluid. After being heated in the heat exchanger (preheater and evaporator), the working fluid goes to the bubble point, and is vaporized into steam inside the evaporator. After the vaporizing process, the steam goes directly to the turbine to convert thermal energy into mechanical energy. After passing through the turbine; the steam is condensed through a condenser from a steam phase into a liquid phase. After leaving the condenser, the working fluid enters the pump, where pressure is increased and the fluid goes through the heat exchanger to repeat the working cycle.

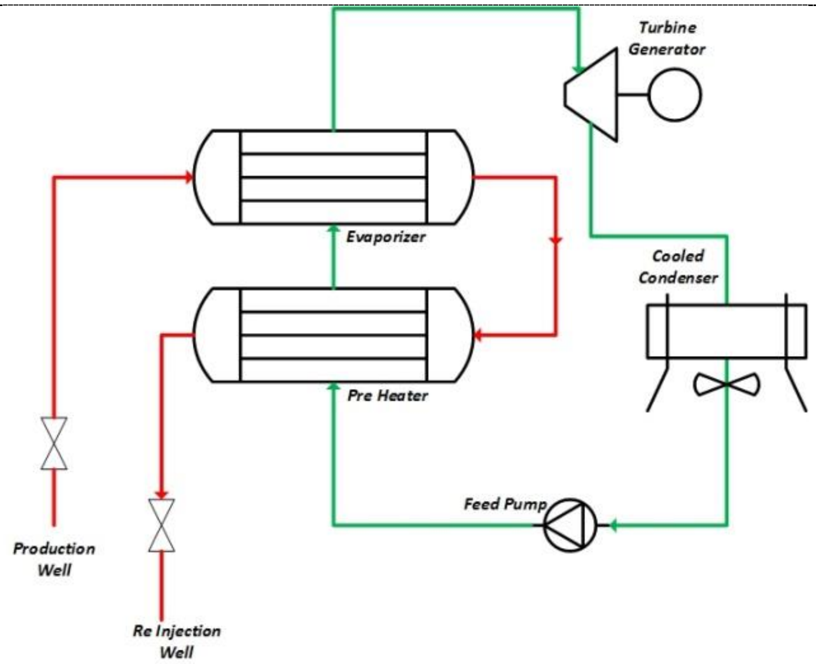

Figure 2. Basic Binary Cycle.

4.2. Case Study: Namora I Langit Binary Plant

Following a comprehensive study, taking into consideration the thermodynamic efficiency, the geothermal fluid characteristics and environmental aspects, a combination of technologies as developed by Ormat was selected as that best configuration for energy conversion in both Namora I Langit and in Silangkitang. This configuration consists of a GCCU, IGCCU or an "Integrated Geothermal Combined Cycle Units" (Figure 3). The brine OEC units utilize the brine as it leaves the separation station, thus, rather Bethan just being re injected it is flows via the OEC brine units and provide additional power that otherwise, if only steam units were installed, would have be wasted.

The organic Rankine cycle is utilized to generate electricity and this binary power plant uses Pentane as its working fluid. The gross power output is 15, 4 MW each unit. In Namora I Langit binary cycle unit, the process is divided into three loops. The first loop is the geothermal brine circulation, heat resource. The second loop is the working fluid process, and the third loop is the air cooled circulation. In the first loop of this binary power plant, the heat source is coming from brine accumulator, one pipeline collects the geothermal brine and the system is called Brine Collector. The brine collector system supplied 3100 kg/hr. of brine at 12, 5bars.

The geothermal brine exchanges heat with the working fluid in the preheater and the vaporizer. This exchange takes place in both systems and the vapour of the working fluid leaves the evaporators at 16, 5 bars. The geothermal brine is then cooled down from 185 to 130°C before being re-injected. The second loop is the Pentane process cycle. Pre-heated in the preheater pentane enters the vaporizer. Pentane is heated to saturation in the vaporizer or with superheat in some cases and next the vapour leaves the vaporizer than enters the organic turbine. The third loop corresponds to the air cooled condenser cycles. In this loop, the air fan removes the heat from the working fluid through the condenser, which is an induced draft type.

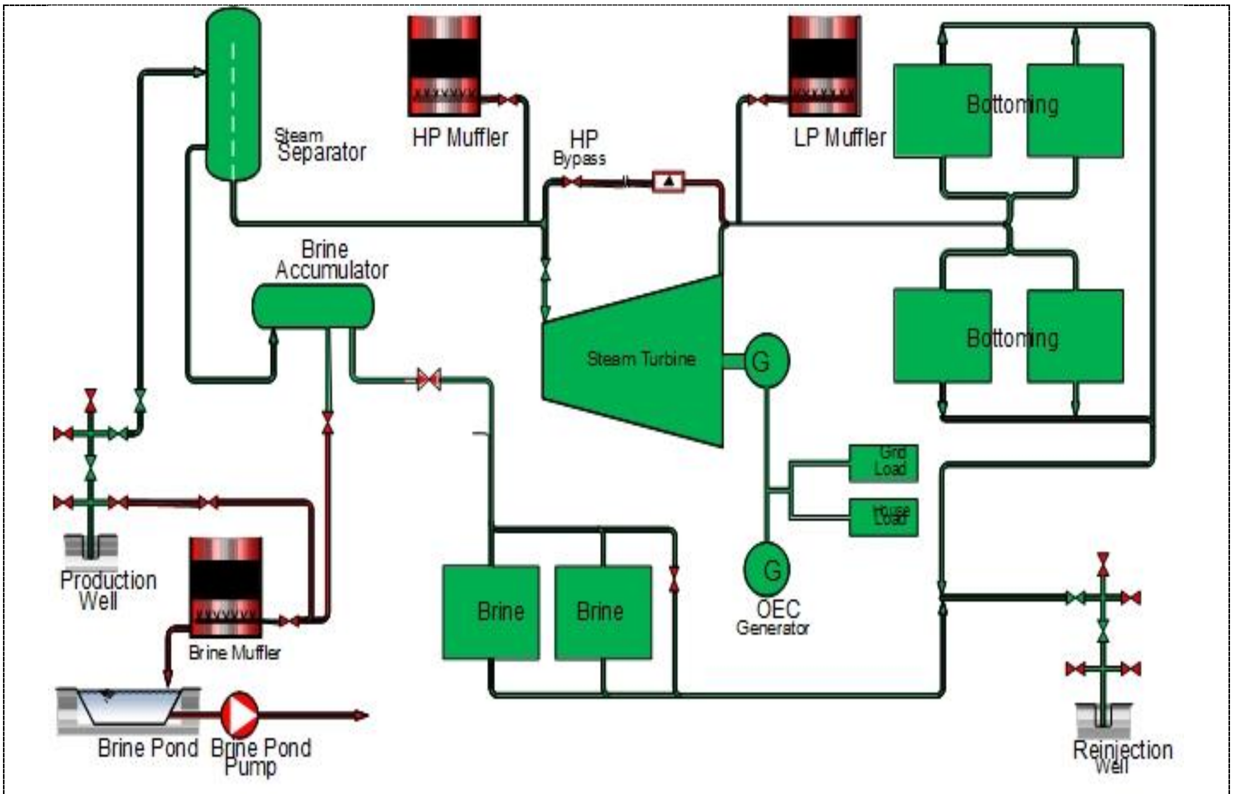

Figure 3. Integrated Geothermal Combines Cycle Unit.

As shown in the figure 4. Geothermal brine flowing from accumulator to brine collector by gravity. Brine collector pressure depends on and related with separator pressure. If separator pressure up or down, then brine collector pressure will change and of course brine mass flow to binary unit changed too. The change in separator pressure is caused by several things, among others are fluctuation pressure from production well, dump valve brine accumulator opened, Steam Turbine Generator (STG) - flash system load unit up or down, routine test that required main steam pressure decrease, and upset condition – STG tripped, auto safe mode active (all High pressure and Low pressure muffler open).

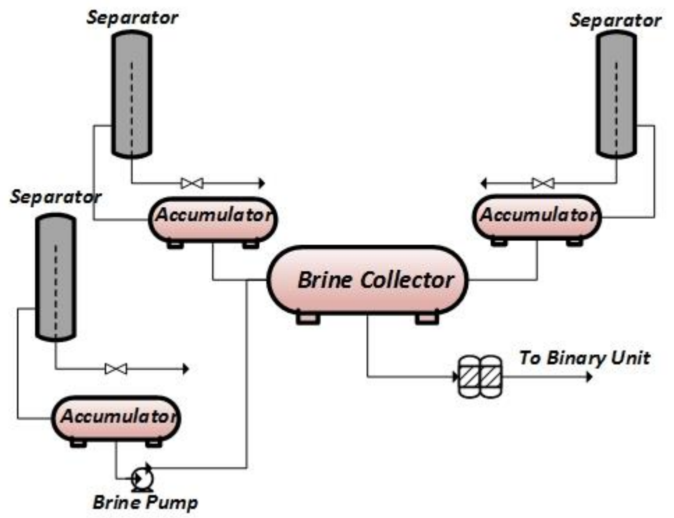

Figure 4. Schematic brine supply system from well Pad to binary unit.

On brine line from accumulator to binary unit, it installed two sand filters / sand remover – type bucket strainer with mesh installed, next it said strainers. One in service, one stand by, and one by pass line without strainer. The function is to filter dirt or small materials that carried away in brine line not enter to tube heat exchanger. Maximal differential pressure between inlet and outlet is 0, 5 bar. Figure 5 shown related between differential pressure suction strainer, power output, and brine flow rate. Directly proportional with brine flow rate and inversely proportional with differential pressure suction strainer. During the three months running has been done four times exchange and of course cleaning of strainers. This is done because the differential pressure reading has already reached 0, 5 bar and brine mass flow decrease so that the maximum net power cannot be achieved.

At supersaturated conditions, silica and metal silicates take some time to equilibrate. The reactions are strongly influenced by pH, temperature and salinity. The lower values slow down the scaling rate of silica and this is often taken advantage of in process design. An example of this is the acidification of silica supersaturated solutions to lower the pH sufficiently (to approximately pH 4.5-5.5) to slow down scale formation, for example in the heat exchanger of binary units. This may increase the corrosion rate in the pipeline. It is relatively simple to inject sulphuric acid or hydrochloric acid by means of a chemical metering pump into the brine pipeline (Figure 8) [3].

In Namora I Langit binary cycle, to keep pH value had done acidification process. There are two dilution pumps and two acid pumps. This way the pumps are operated routinely, in order to maintain their internal components under normal operation. If the system is stopped because there are no sources, sulphuric acid or condensate, binary unit should be stop. Condensate from bottoming unit combined with sulphuric acid, and pumped into the brine pipeline. Mixing condensate, sulphuric acid and brine at static mixer after brine pass sand removal. Remember importance to maintain pH value then it was installed on line pH monitoring system and also as comparison, taking and measurement sample at Laboratory every four hours for 24 hours. If any parameter is out range, a correction action is taken to adjust the system as soon as possible to normal conditions. If result shown tends to acid so supply sulphuric acid was decreased and vice versa. Corrective maintenance as well as electrical, instrument, and mechanical follows yearly programs which have been improved continuously. This is again done considering its importance to keep pH value. By monitoring well, it can be known the changes of geothermal fluid from production well.

In the Namora I Langit binary cycle is used to transfer heat from the geothermal brine to the working fluid in the preheater and vaporizer. There are two shells unit preheater that connected in series. Tube side inlet temperature is 157, 2° C and outlet is 129, 6° C. For vaporizer, also two shell side that connected in parallel. Tube side inlet temperature is 183, 7° C and outlet is 157, 2° C. For tube diameter, both preheater and vaporizer are same that is OD/ID: 25, 4/23, 62 mm. With diameter bigger that mesh strainer, expected brine that into tube side already clean.

Vaporizer brine inlet pressure preheater, brine inlet pressure, and preheater outlet pressure are closely monitoring. If differential pressure between vaporizer inlet and preheater inlet reach over 0, 5 bars for period of time, then unit will normal stop. And if differential pressure between preheater inlet and preheater outlet reach over 0, 7 bars for period of time then unit will normal stop too. This shows brine flow obstacles at tube line, also used to determine the effects of scaling, and at once for protecting heat exchanger from damage. Especially for preheater that used NFN type heat exchanger where if different pressure between inlet and outlet too big can cause pass divider plate bent.

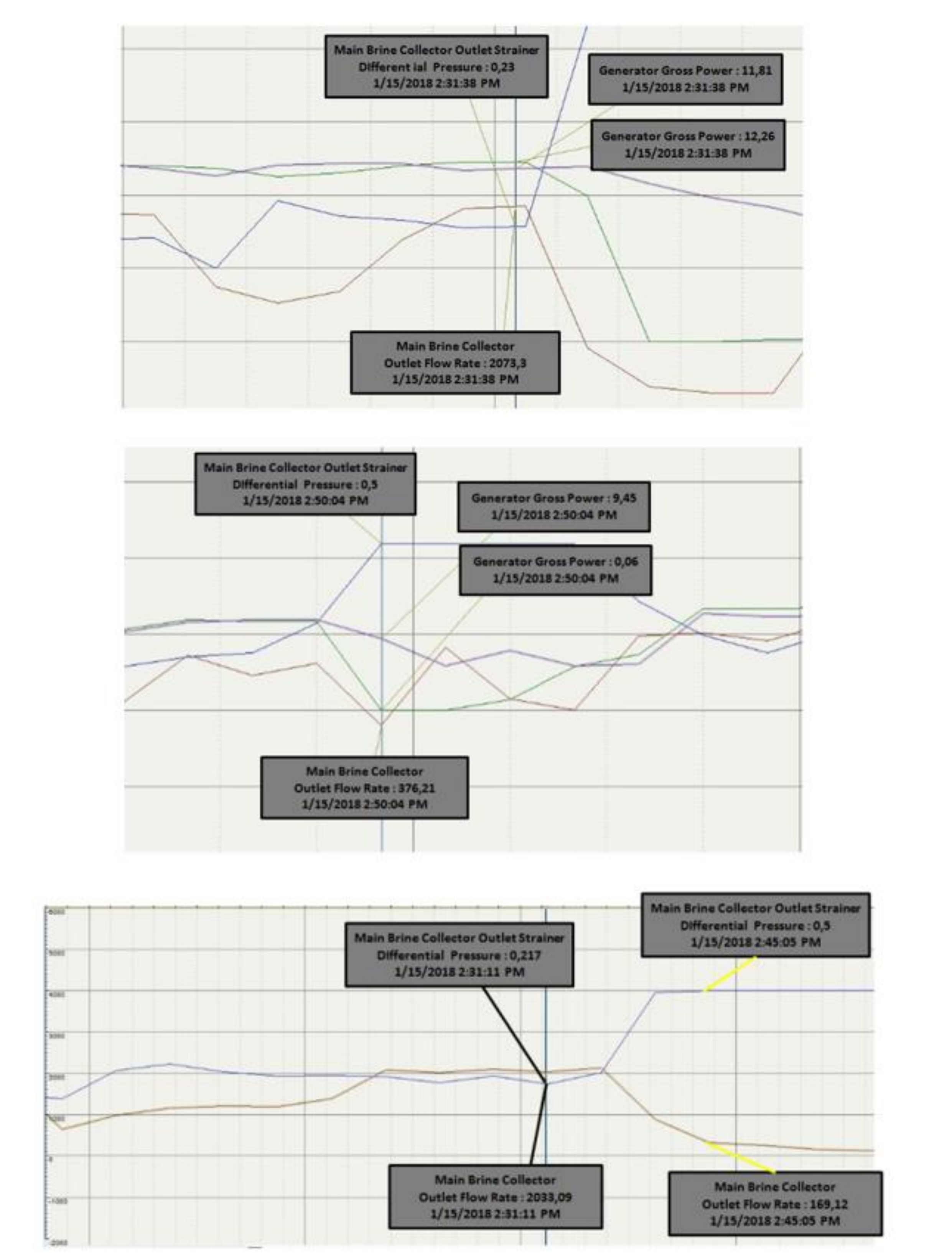

Figure 5. Correlated between main brine collector's outlet strainer, power output, and brine mass flow.

Figure 6. Replacement suction strainer.

Figure 7. Inside condition and cleaned up process suction strainer.

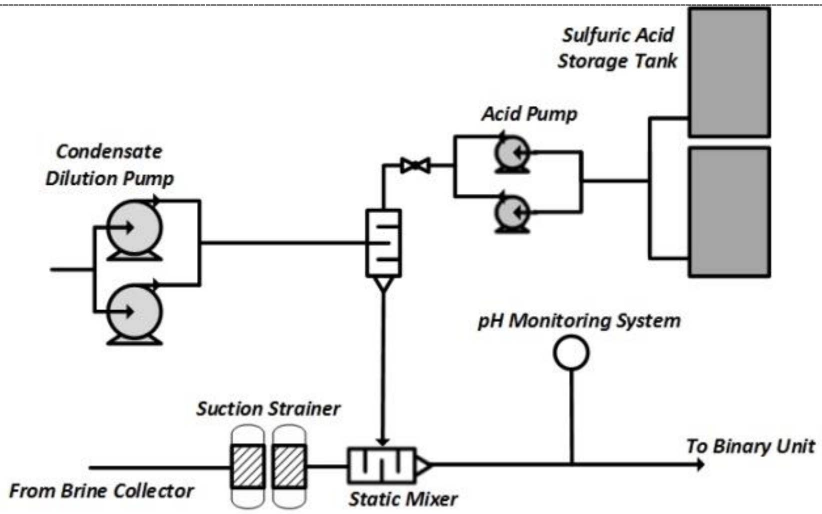

Figure 8. Chemical System.

Generally, the function of the heat exchanger is to earn fluid flow on appropriate temperature for next process, for steam condensing, fluid evaporated, make use of heat waste, and for power generation (Figure 9).

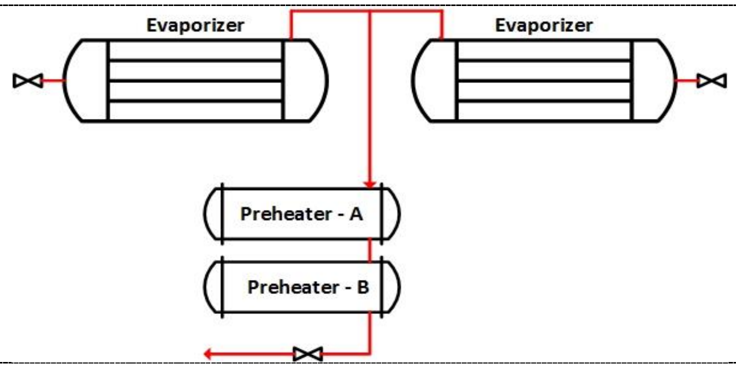

Figure 9. Brine flow at heat exchanger.

5. Result and Discussion

For the first time when flow well or bleed well to atmosphere, with the intention of throw away all debris and other material from well casing line through 3⅛ inch line. It seems needed additional line said it start up line with size bigger than 3⅛ inch, so flow well can be done maximum before it is entered to the system. Because if the line too small , feared can make restriction to flow, that will cause a large pressure loss and consequent temperature drop.Performing aaditional steps and updating procedures put brine into sysrtem. Before brine inserted into the system should do some of theses things. Make sure the brine that comes out in the pond is completely clean and clear. Done by looking directly at the output of the pond. The next is sampling by the lab team to know the chemical composition. And then the lab team recommends wheter brine can be put into system or not. Thus expected all debris and others material filtered at suction strainer can be minimized. Intensity of replacement and cleaning suction strainer can be reduced (Figure 6 and 7).

The silica scaling potential occurs due to the characteristics of geothermal water. Scaling speed varies significantly depending in the silica concentration in hot water, pH and temperature. An important parameter in relation to silica precipitation is the silica saturation index (SSI), which is the ratio between silica concentrations in solution with amorphous silica solubility under the same condition. If SSI > 1.0 then silica scaling is possible, if SSI<1.0 then, generally, silica scaling will not occur. It is necessary to be aware of piping blockage and performance deterioration of the heat exchanger caused by scaling. Therefore, it is important to take measures to prevent scaling as necessary, such as the management of pH that has been done all this time. To further consolidate monitoring scaling or corrosion in the pipeline it is possible to install retraceable coupon that can be removed for periodic inspection without affecting the flow or operation of the plant and to periodically measure SSI values to estimate the likelihood of silica scaling.

In a binary system, since the fluid is maintained in liquid phase, silica concentration remains constant as the fluid is being cooled in the process of extracting heat from the fluid [2]. Keeping the outlet pressure brine collector steady to binary unit is a must. When there comes a time separator pressure changed, wherever possible to be minimized pressure at brine collector. Certainly not easy because of gathering system and also must be supported with good valve control performance and response. Source of brine to brine collector now only from one well pad. Next when the unit is fully operational, brine source will add from two well pad. While one well pad will supply brine by gravity and the other well pad will be supply by pump. Therefore, with three source of brine to brine collector is expected outlet pressure brine collector keep stable despite changes. Using pumps to supply brine to binary unit so the flow, pressure, and temperature are stable can be considered.

6. Conclusion

Problem such as equipment damage and failure, valves, strainers, and line plugging, reduce brine flow and power production losses are some at the experiences associated with brine supply system.
Do the flow well to the maximum and make sure the brine came out was clean and clear before brine inserted into the system. Adding additional equipment to monitor scaling and corrosion. And use of pumps to deliver brine. So some things can be given as a recommendation in order to supply the required brine. Of course, advanced engineering analysis and other considerations are mutually adjusted.

The wellhead pressure may go down over time, chemical change over time, and enthalpy either goes up or down. Most of these changes are the inevitable effects of production. Good understanding at such changes is important to be ready to accept them and take countermeasure in time. Carry out this study is one of its efforts. Thus expected the existing geothermal power plant in Indonesia can operate efficiently over its expected life and especially than it can improve national prosperity.

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