

USING UNTAPPED PROVEN RESOURCES AND IMPROVING EFFICIENCY OF FLASH PLANTS, BY RETRO FITTING BINARY CYCLE

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ABSTRACT

The East Africa Rift Valley has significant geothermal potential. With the exception of Kenya, that is one of the most active geothermal energy producer in the world, geothermal exploration and development in the other African regions have been limited up to now. Harnessing this untapped potential is of strategic importance for these countries growth. Developing a new steam field faces many challenges, which takes time, costs a significant amount of equity, has mineral risk, and face many challenges, environmental and regulatory. Frequently resources which have previously been drilled have been deemed uneconomical to use. Additionally, existing steam fields frequently use single flash, steam turbine power generation plants. Although efficient and reliable, a significant part of the total thermal capacity is lost in the liquid phase (hereinafter called brine). The following paper describes in detail how it is possible to safely and efficiently recover the energy contained in the brine from either existing, or unused resources. With developments in ORC technology it can now be economical to develop existing resources. In addition, just utilizing the energy contained in the existing brine of typical single flash plants, it is possible to add approximately 35% of the steam field rated electrical power output thanks to the Exergy GEX binary plant, based on its patented Radial Outflow Turbine (ROT).

The paper will focus on case studies of both unused, and single flash plants.

1. INTRODUCTION

Developing a new geothermal resource is a long and expensive process; initial development steps are risky and upfront capital costs are important. The cost and risk of exploration and the development of geothermal energy has been an issue in determining the future of geothermal energy in Africa, as these are seen by private investors to have a major impact on the price of geothermal electricity. Once the resource has been proven, it is necessary to optimize the heat from geothermal energy both for generating electricity and for direct uses before the fluid is rejected, while it is still sellable and attractive to developers.

Generally, in liquid-dominated areas, the energy conversion system which applies geothermal fluid to generate electricity uses single flash technology as the first step in development. Meanwhile, waste geothermal heat after flashing (brine) from the existing power plants could be better utilized and the utilization efficiency of the plant could be increased by using a binary plant.

In all existing power plants operating in Africa, after utilizing the separated steam, the brine from the separator is rejected to the earth through reinjection wells. The re-injected brine generally has a temperature higher than 150°C. The thermal energy of the brine can be recovered by transfer via a heat exchanger to working fluids used in other processes. Although the capacity is lower than the existing steam turbine, the upstream risk can be avoided and only two years are needed for complete project execution.

Previous studies have been made on the optimization of geothermal utilization for power production, using different cycles. It was concluded that a binary bottoming cycle using isopentane as a working fluid would

give more power output than a second flash or other combined cycles at discharged enthalpy below 1400 kJ/kg or at reservoir temperatures of 240°C or lower (Karlsson, 2008; Bandoro, 2009; Nugroho, 2011). In those studies, a water-cooled condenser was used and different assumptions on silica scaling prevailed.

The present paper will show how much power can be recovered from the brine stream coming out of a separator vessel of a hypothetical single flash steam plant with a total capacity of approximately 110MWe NET. Geothermal fluid inlet conditions, as well as ambient ones, are calculated by averaging actual power plants (liquid-dominated system) operating conditions.

2. TECHNICAL OVERVIEW OF GEOTHERMAL POWER PLANTS

2.1. Flash cycle

A flash cycle is the most known form for high-temperature geothermal power generation. Most geothermal wells produce two phase fluids, consisting of brine and steam. The fluids also contain non-condensable gases and solid particles.

The water and solid particles are separated from the steam and gases using a separator. Thus, the steam fraction of the geothermal fluid can be calculated based on the enthalpy and pressure. The process of an ideal separator is relatively simple since the outlets are saturated steam and saturated brine. The saturated steam will go directly to the turbine which is coupled with a generator to produce power.

Transferring heat from the exhaust steam into the cooling fluid causes the steam to condense. This creates a vacuum in the condenser due to the collapse of steam and creates a driving force for the steam flow. The effect is higher output from the turbine.

As there is no need to recover the condensate for reuse in the process cycle, direct contact condensers are generally preferred since they have lower initial capital cost and require less maintenance work. Figure 1 shows a simplified schematic diagram of a flash cycle.

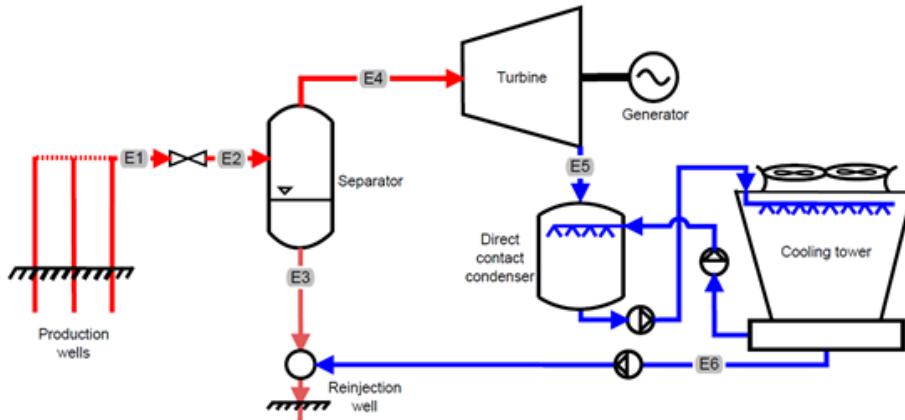


Figure 1: Single flash steam plant PFD

2.2. Binary plant

A binary system has two cycles: first is the heat exchange cycle of geothermal fluid where the working fluid absorbs heat from the geothermal fluid via the heat exchanger; second is the ORC working cycle as seen in Figure 2. These two cycles are separated so only the heat transfer takes place through the heat exchangers; shell-and-tube heat exchangers are most common.

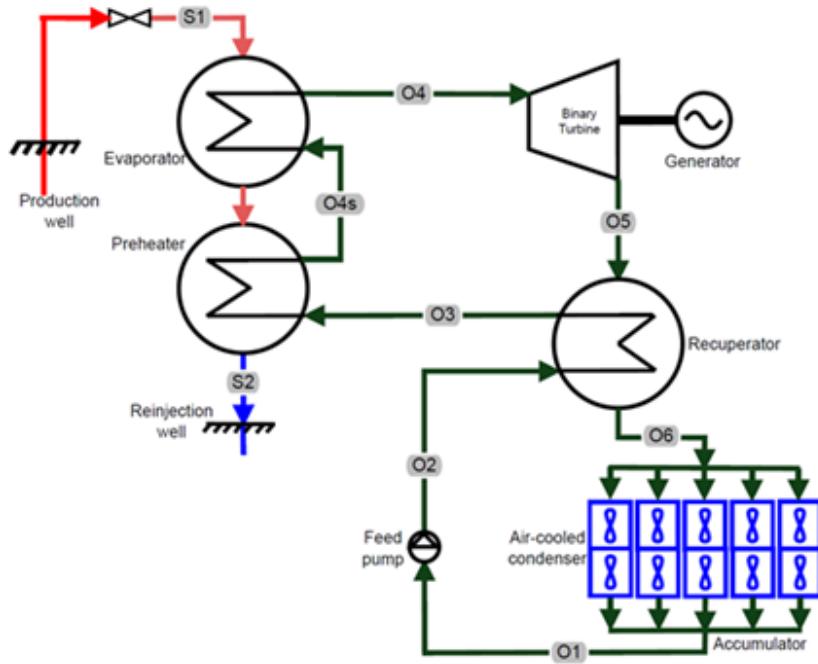


Figure 2: Binary plant PFD

The working fluid is selected both from the optimizing power output view and the critical temperature requirement.

The main components of a binary power plant are: heat exchangers (preheater, evaporator, condenser and recuperator), a feed pump, a turbine, a generator and a condenser (air or water cooled).

2.3. Limitation of reinjection temperature

Reinjection is a very important part of any geothermal development and it may become the key factor in the success or failure of the field.

In order to achieve maximum conversion of geothermal energy into electricity, the geothermal fluid must be cooled to as low a temperature as possible. In many cases, the geothermal fluid becomes supersaturated with silica as it is cooled. A hotter resource temperature will lead to higher silica saturation in the disposal brine, the consequences of which could lead to greater silica scaling precipitation in reinjection wells, piping, heat exchangers and other production facilities (DiPippo, 1985).

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 (Thórhallsson, 2005). To reduce silica concentration and keep a high enough temperature before reinjection, mixing between brine and condensate is a good idea, as experienced in some fields like at Svartsengi plant in Iceland (Thórhallsson, 2011).

Potential problem with silica scaling in high temperature geothermal system such as the considered one is very high. Silica is in equilibrium with quartz when the hot water is underground. However, when the two-phase mixtures are brought to the surface, a considerable drop in temperature due to flashing occurs, and the difference in the solubility of quartz and amorphous silica allows the latter to be supersaturated in the

solution. Hence the form of silica that normally precipitates at the surface is amorphous silica (Brown, 2011).

The potential for silica to precipitate is dependent on the degree of silica saturation in brine in respect to amorphous silica. The silica limit temperature is the temperature below which the silica dissolved in geothermal fluid may be expected to precipitate and deposit. An estimation of that temperature is given by using the following equations (DiPippo, 2008):

$$(1) Qc(t) = 41.598 + 0.23932 t_{water} - 0.011172 t^2_{water} + 1.1713 \times 10^{-4} t^3_{water} - 1.9708 \times 10^{-7} t^4_{water}$$

and

$$(2) S = Qc(t)/(1 - x_1)$$

and

$$(3) \log_{10} Samorphous = -6.116 + 0.01625 T_{water} - 1.758 \times 10^{-5} T^2_{water} + 5.257 \times 10^{-9} T^3_{water}$$

and

$$(4) SSI = S/Samorphous$$

where

$Qc(t)$: quartz solubility in reservoir [ppm]

t_{water} : reservoir temperature [$^{\circ}$ C]

SI : silica concentration in the brine after flashing [ppm]

x_1 : steam quality from first flashing

$Samorphous$: equilibrium solubility of amorphous silica for zero salinity [ppm] (must be multiplied by 58,000 to obtain ppm)

T_{water} : absolute reinjection temperature [K]

SSI : Silica Saturation Index

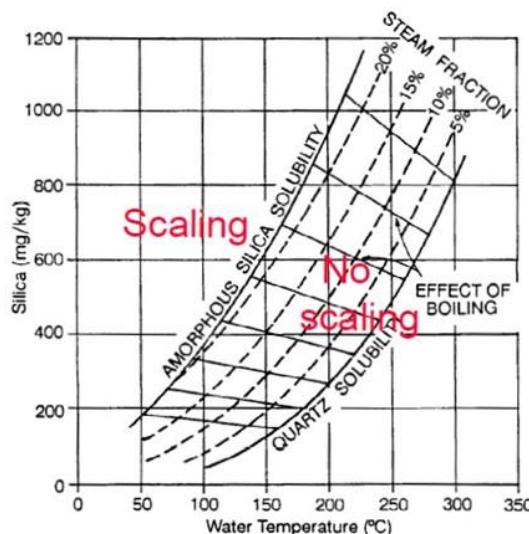


Figure 3: Solubility of silica in water

Amorphous silica and quartz solubility in water as a function of reservoir temperature are shown in Figure 3. To determine whether silica will tend to precipitate or not, the value of the silica concentration after flashing (S_{actual}) is compared with the equilibrium amorphous silica concentration given as the ratio in Equation 4. If SSI (is higher than 1, the brine is supersaturated. Then, there is a risk of silica scaling in the surface equipment, reinjection wells and reservoir.

Together with the correct reinjection temperature, also the proper inhibition system is to be provisioned.

Many works were already conducted in order to overcome the silica scaling problem. Silica precipitation on surface facility and possibly in reservoir could happen if geothermal fluid is not properly handled before reinjection. Brown (2011) suggests several treatments to cope with silica scaling. Among them, pH modification could be the most widely used now in geothermal industry. It reported that at about pH 5, the silica polymerization has been delayed, while at the normal pH, silica polymerization is very rapid.

In the same way, raising the pH to 9 also prevent the silica scaling without any problem with corrosion of steel. However, the major disadvantage is the cost of alkali.

Horie et al, (2010) reported successful application of pH modification by dosing the HP brine with sulfuric acid (H_2SO_4) in the double flash plant in Kawerau, New Zealand. The acid injection rate is precisely adjusted by variable speed dosing pump to target the LP brine to the reinjection system at pH 5.0. Gray (2010) also reported the same application in the triple flash plant Nga Awa Purua power plant, in Rotokawa, New Zealand. However, extremely corrosive nature of sulfuric acid should be considered when selecting material for mixing.

Silica scaling mechanisms are fairly complex and poorly quantified; therefore it has been common to manage scale on the basis of local experiments.

3. BOTTOMING BINARY PLANT DESIGN

The brine stream represented in the shown H&M balance flowsheet gets normally reinjected back into the reservoir. It is then possible to retrofit the existing steam plant with a bottoming binary plant, which will cool the brine down to a certain reinjection temperature (Figure 4).

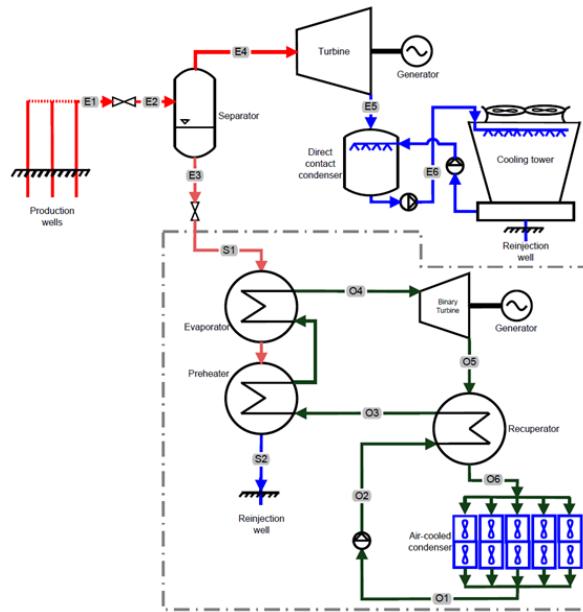


Figure 4: Binary plant retrofitting PFD

As said, this temperature is mainly set according to the silica saturation curve. In fact, lower the temperature, lower the silica solubility. Silica deposition has to be foreseen accurately in order to prevent the whole system from rapidly depleting its performance.

The minimum reinjection temperature is set considering the acidized water quality chart and it is equal to 90°C.

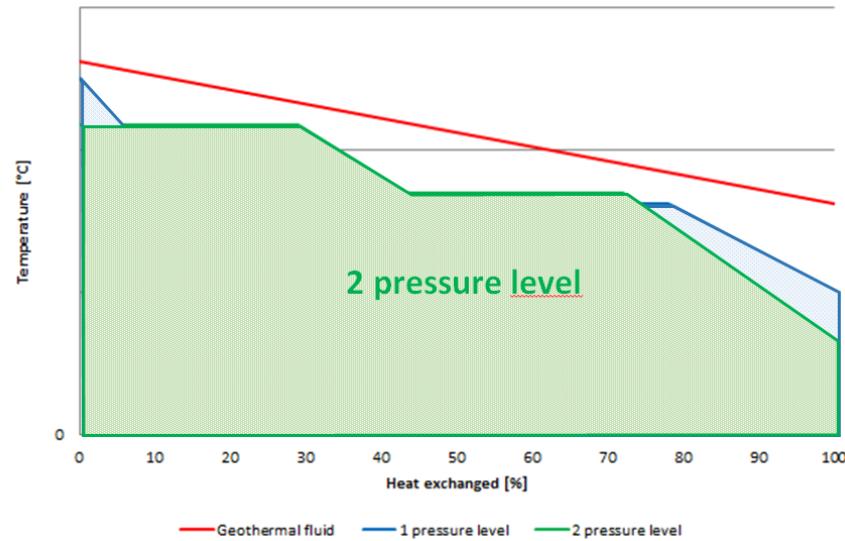


Figure 5: Temperature-load diagram for binary plant

In order to maximize the power output, a two pressure level cycle, based on the unique Radial Outflow Turbine, is selected. As represented in Figure 5 a two pressure level cycle recovers energy from the geothermal fluid more effectively than a single pressure level one, matching closely its heat release curve (red line). In fact the recovered energy is graphically represented by the two colored regions beneath the red curve. The green region extension is bigger than the blue one, meaning that for the same total heat input, a two pressure level cycle will have higher conversion efficiency.

Both low pressure and high pressure turbines are directly coupled with a double ended synchronous generator. In order to ease the retrofitting, two twin modules are foreseen, each cooling half the brine flow down.

3.1. Boundary conditions

Based on general conditions of geothermal high-temperature and liquid-dominated areas in Indonesia, the design of the binary plant is conducted considering:

- Bottom hole temperature: 266.5°C
- Geothermal fluid mean enthalpy: 1167.5 kJ/kg
- NCG content: 2% WGT (total geofluid flow)
- Average dry bulb temperature: 23°C
- Average wet bulb temperature: 21°C
- Reference atmospheric pressure: 0.93 bar (@810m elevation a.s.l)
- Cooling method: Air
- Limitation of reinjection temperature is calculated at SSI=1, considering acid dosing

3.2. Steam plant operative conditions

- Separation pressure: 9.3 bara
- Separation temperature: 175°C
- Total geothermal fluid mass flow rate: 3610 ton/hr
- Steam+NCG mass flow: 838 ton/hr

- Brine mass flow rate: 2772 ton/hr
- Condenser pressure: 0.12 bara
- Steam turbine isoentropic efficiency: 80%

3.3. Results

Steam and brine flow and characteristics were obtained from an operational single flash power plant harnessing a medium/high enthalpy liquid dominated reservoir in the Asia Pacific Region. Aspen Hysys was used to verify, confirm and match steam turbine boundary conditions and actual power output at present time.

EXERGY proprietary NIST Refprop based software was used to calculate the bottoming binary plant harnessing the brine stream, whereas the minimum injection temperature was set in accordance with brine chemistry and relevant silica scaling inhibition.

Table 1: Results

Description		Steam plant	Binary plant
Gross power output	MWe	116	43.96
ORC auxiliaries power consumption	MWe	-	1.28
ACC auxiliaries power consumption	MWe	-	1.1
BOP auxiliaries power consumption	MWe	4.7	0.3
Step-up transformer power losses	MWe	1.16	0.440
Step-down transformers power losses	MWe	0.14	0.08
NET power output	MWe	110.0	40.8
Relative NET power increase	%	-	37.1%

4. CONCLUSIONS

Power production increases gradually by decreasing the reinjection temperature. In order to obtain the maximum power output, the bottoming units must be designed at the minimum reinjection temperature level that is free from scaling possibilities, both in power plant components and the reinjection well itself.

The retrofitting configuration was studied in order to evaluate the power output produced at a given amount of heat source. The calculation indicates binary cycle produces 40.8 MW net, reinjecting at 90°C, using a 2 pressure level binary cycle, and a Radial Outflow Turbine.

Relative to the existing 110 MW power plant, the bottoming cycle generates 37.1% more power from utilizing the hot brine. For liquid dominated geothermal fields, such as the one considered in the present paper, the bottoming cycle contributes to more efficient use of its resources.

Aside from the potential increase in output of each bottoming technology, financial aspects, environmental issues, land requirement, compactness, ease of operation and simplicity should be considered before making a final decision.

Concerns on the impact of reinjection of cooler fluid such as cold brine influx, silica scaling in the surface facilities, reinjection wells and reservoir should be thoroughly studied. Tracer test can be applied to analyze a proper injection strategy in order to prevent the cooling water breakthrough in reservoir, while pH modification is widely used to eliminate or to delay silica precipitation. Sulfuric acid (H₂SO₄) injection to maintain pH at 5 is already common practice in geothermal power plant worldwide.

If pH modification does not work, the brine can be simply disposed to retaining tank for a while to settle down the silica then pumped into reinjection wells.

REFERENCES

Agahi, R., Behrooz, E.: Power Cycle for Low Temperature Heat Recovery and Geothermal applications. ANIMP – ATI, Milan, Italy (2010).

Axelsson, G., Bjornsson, G., Montalvo, F.: Quantitative Interpretation of Tracer Test Data. Proceedings World Geothermal Congress 2005, Antalya, Turkey (2005)

Brown, K.: Thermodynamics and Kinetics of Silica Scaling. Test rig Experiments for Silica Scaling Inhibition. Proceedings, International Workshop on Mineral Scaling 2011, Manila, Philippines, Indonesia (2011).

Brown, K., Rock, M.: Test rig Experiments for Silica Scaling Inhibition. Proceedings, World Geothermal Congress 2010, Bali, Indonesia, (2010).

DiPippo, R.: Geothermal Power Plants – Principles, Applications, Case Studies and Environmental Impact, Second Edition, Elsevier, Burlington, USA (2007).

Gray, T.: Power Plant Selection in Mighty River Power Development Project. Proceedings, International Workshop on Mineral Scaling 2011, Manila, Philippines (2011).

Horie, T., Muto, T., Gray, T.: Technical Features of Kawerau Geothermal Power Station, New Zealand, *Proceedings World Geothermal Congress 2010*, Bali, Indonesia (2010).

Kiyota, Y., Uchiyama, N.: Silica Scale Prevention Effects of Brine pH Modification at Hatchobaru Power Station, Japan.

Proceedings, World Geothermal Congress 2010, Bali, Indonesia (2010).

Kjartansson, G.: Low Pressure Flash-Steam Cycle at Hellisheiði – Selection Based on Comparison Study of Power Cycles, Utilizing Geothermal Brine, Proceedings, World Geothermal Congress 2010, Bali, Indonesia (2010).

Jalilinasrabiadi, S., Itoi, R., Fujii, H., Tanaka, T.: Energy and Exergy Analysis of Sabalan Geothermal Power Plant, IRAN,

Proceedings World Geothermal Congress 2010, Bali, Indonesia (2010).

Karlsdottir, M.R., Palsson, H., Palsson, O.P.: Comparison of Methods for Utilization of Geothermal Brine for Power Production, World Geothermal Congress 2010, Bali, Indonesia (2010).

Nikolskiy, A.I., Shipkov, A.A., Tomarov, G.V., Semenov, V.N.: Creation of Pilot Binary Geothermal Power Plant on Pauzhetsky (Kamchatka) Site, Proceedings, World Geothermal Congress 2010, Bali, Indonesia (2010).

Suryadarma, Purnomo, A., Pramono, A., Brahmantio, E.A., Kamah, Y., Suhermanto, G.: The Role of Pertamina Geothermal Energy (PGE) in Completing Geothermal Power Plants Achieving 10,000 MW in Indonesia, Proceedings World Geothermal Congress 2010, Bali, Indonesia (2010).

Swandaru, R., Pallson, H.: Modelling and Optimization of Possible Bottoming Units for General Single Flash Geothermal Power Plants, Proceedings World Geothermal Congress 2010, Bali, Indonesia (2010).

Taghaddosi, M., Moghacy, H.: Geothermal Power Plant in Meshkin-Shahr Iran, Proceedings World Geothermal Congress 2010, Bali, Indonesia (2010).

Opportunity and Barriers to Develop a Bottoming Unit by Utilizing Separated Hot Brine in Ulubelu, Indonesia, Mawardi Agani, Salvius Patangke, Drajat B Hartanto, Marihot Silaban, PT Pertamina Geothermal Energy, Jakarta, Indonesia (2015)