Introduction of the Closed-Loop Technology for Geothermal Wells

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ABSTRACT

The productivity of geothermal wells has several challenges coming from several factors such as depletion of the reservoir over time, inherent low permeability in certain areas of the reservoir, and presence of high levels of non-condensable gases (NCG). The closed-loop technology is introduced as a solution to turn unproductive wells into productive wells. The main objectives of this innovation are to harvest heat without removing mass from the reservoir and to have both production and injection within the same well. Vallourec have been collaborating with GreenFire Energy for this closed-loop system where Vallourec, as the Oil Country Tubular Goods (OCTG) manufacturer, has provided its technology called vacuum insulated tubing (VIT) that enables GreenFire Energy to develop GreenLoop solutions. The GreenLoop technology has several configurations including Steam and 2-Phase GreenLoop (S2PGL) and GreenLoop for hot dry rock (HDR). Both GreenLoop configurations have its own functions and applications to enable unproductive wells to produce hot geothermal fluids.

1.INTRODUCTION

Geothermal resources have high potential to generate electricity with several benefits compare to other renewable energy resources. One of main benefits is that geothermal power plants can produce electricity 24/7 or all day-all year while other renewable energy such as solar panel and wind energy are very much dependent on diurnal changes. However, developing and managing geothermal resources also have some challenges as well. Over time, the geothermal reservoir gets depleted as reservoir pressure declines due to mass withdrawal. In some cases, geothermal wells do not encounter commercial permeability and are considered dry holes. An innovative technology that can be used to further monetize unproductive or underperforming wells is the use of the downbore heat exchange (DBHX) which has several configurations (Figure 1).

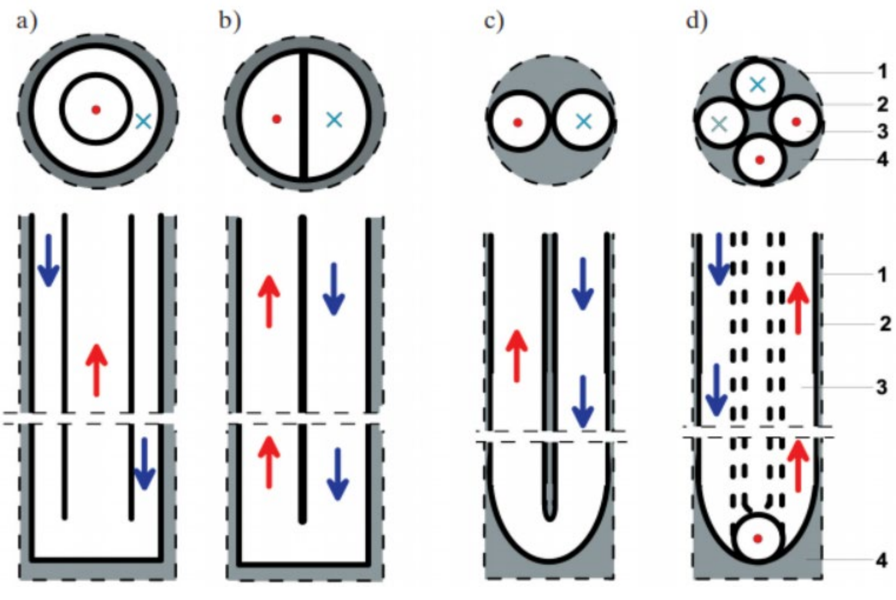

Figure 1. DBHX configuration types (1) wall of borehole, (2) heat exchanger pipe, (3) heat carrier, (4) sealant (Silwa, 2016)

a) Coaxial heat exchanger: This type of well design injects the fluid in the outer pipe and produces steam through the inner pipe. The working liquid is expected to be heated and reach the boiling point at the bottom of the reservoir.
b) Demi-type heat exchanger: This type of well design uses a separator to separate the injection liquid and production steam within the same pipe.
c) Heat exchanger with single U-pipe: This design is like the demi-type of heat exchanger; however, both the injection and production fluids are in separate pipes but connected through a U-shape configuration at the bottom.
d) Heat exchanger with double U-pipe: This type of well design is similar with the single U-pipe design, but with 2 injection and 2 production pipes to increase the flow rate.

Between the four types of DBHX, the coaxial heat exchanger type is the most applicable and has been proven in several geothermal fields to increase the productivity of the field. The vacuum insulated tubing (VIT) is the enabler of this technology which is used as the barrier to maintain the temperature between the injection and production pipes. The other types of DBHX have several application challenges, especially in their installation and operation.

2. THERMOCASE® VACUUM INSULATED TUBING (VIT)

Vallourec, as a seamless pipe manufacturer, has some innovative product such as the vacuum insulated tubing (VIT) called THERMOCASE® where a smaller diameter welded (at their ends) pipe is installed within a bigger pipe (Figure 2). The annulus between the pipes is vacuum sealed to create a barrier against the temperature difference of the inner and outer layer of the pipe.

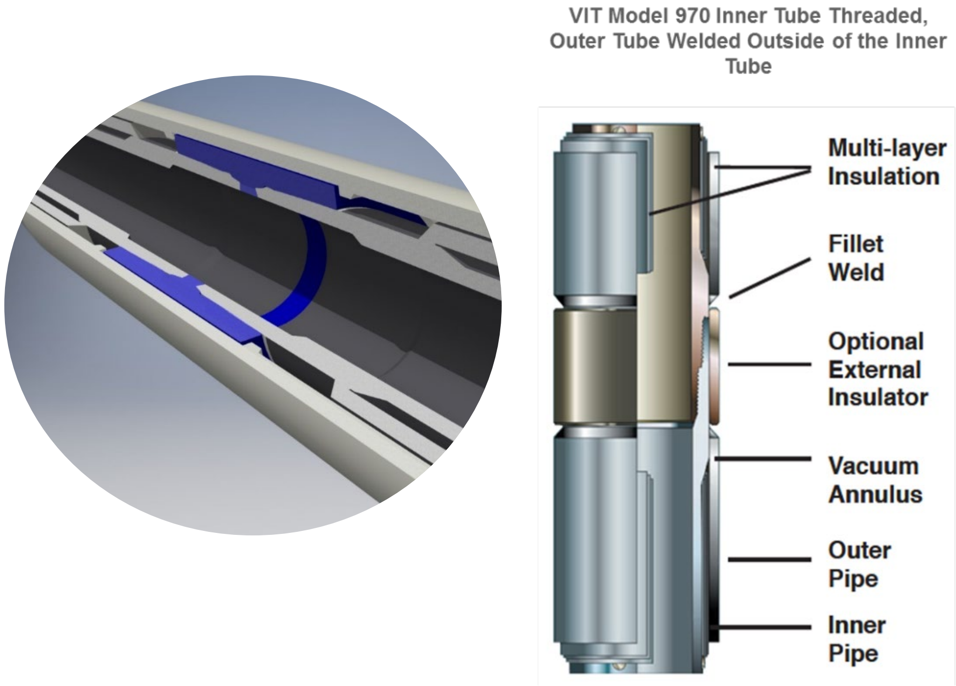

Figure 2. Vacuum insulated tubing (VIT) configuration by Vallourec Tube Alloy.

The air between pipes is removed and a sealed chamber is created between the inner and outer pipes and used as the primary insulator in the pipe body. Multi-Layer Insulation (MLI) is used inside the vacuum chamber to minimize the heat transfer trough radiation. This configuration has enabled the development of the closed-loop geothermal system (Figure 3) where the injection fluid and production fluid temperature stay maintained.

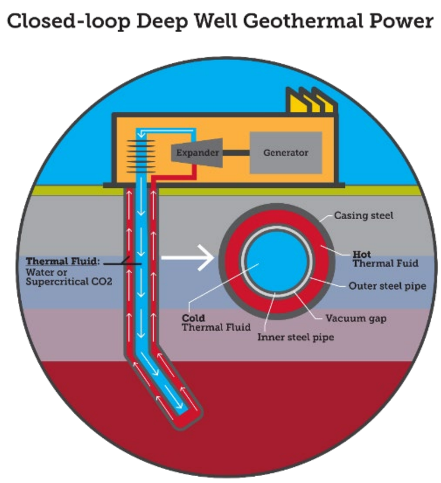

Figure 3. Close-loop geothermal system with VIT where a cold working fluid is injected in the inner pipe and hot fluids are produced in the outer pipe.

The performance of the THERMOCASE® VIT is determined by the thermal conductivity (k-value) of the design configuration because there is no convection (heat transfer trough the moving media) with the vacuum insulated tubing since there is no media separating the pipe and radiation (heat transfer trough electromagnetic waves) between the inner and outer pipe. Each end of the pipes is welded together, and this is the only place where the heat transfer might happen trough thermal conductivity between the welded areas.

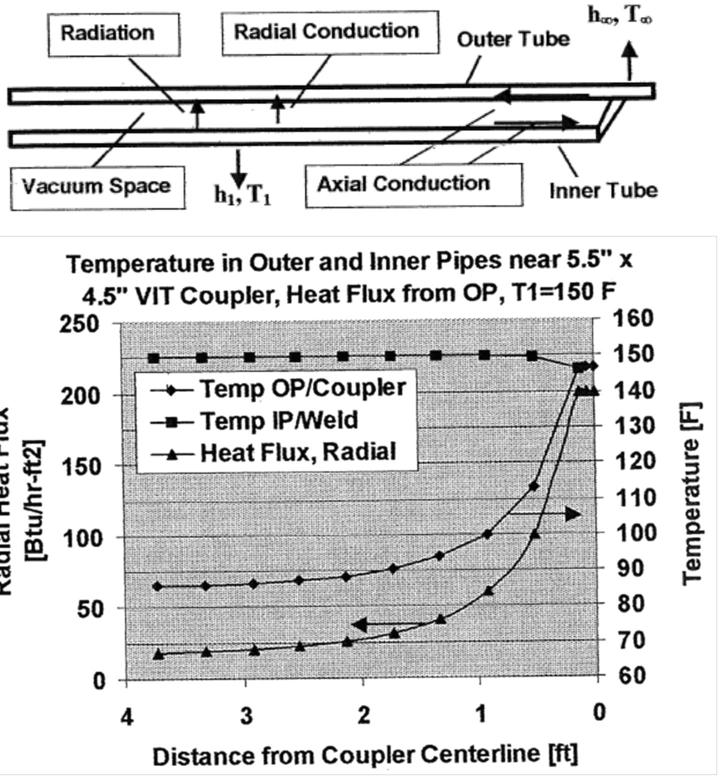

Figure 4. Temperature difference between the inner and outer pipes and the distance with the coupler centerline (Azzola et. al. 2004)

Figure 4 above shows that the temperature of the outer pipe remains low while the temperature of the inner pipe is high. The temperature reaches equilibrium at the center line or the welded area of the pipes – the outer pipe temperature increases and attain the same temperature as the inner pipe. The radial flux still appears due to the electromagnetic characteristic of the steel pipe which facilitates heat transfer through radiation although it has insignificant effect on the heat transfer.

3. GREEN FIRE ENERGY CLOSED-LOOP SYSTEM

GreenFire Energy has developed a geothermal closed-loop system, aka GreenLoop, that can make a well produce hot fluids with several benefits as listed below:

- Limited sub-surface risks: existing wells with known characteristics are utilized;
- Minimal impact on the environment: a well with GreenLoop acts as both production and injection well and a small footprint is used;
- No reservoir depletion: there is no mass withdrawal and only harvesting of heat energy with the condensate around the DBHX acting as recharge to the hydrothermal system;
- Full control on the working fluid: no wellbore scaling nor corrosion and can use several types of working fluids (e.g., water, supercritical CO_2, the low flash point organic fluids for binary power plants);
- Can be implemented almost everywhere: GreenLoop only needs heat that, theoretically, can be accessed by drilling deeper; and
- Truly scalable: as GreenLoop can be implemented everywhere, it can be scalable by drilling another well without the risk of a dry hole.

GreenFire Energy has developed two general types of closed-loop systems depending on the application, namely, the Steam and 2-Phase GreenLoop (S2PGL) and the Hot Dry Rock (HDR) Straw Loop. Both systems require the VIT as the enabler of each system.

3.1 Steam and 2-Phase GreenLoop (S2PGL)

The Steam and 2-Phase GreenLoop (S2PGL) is mainly used to retrofit existing geothermal wells and either revive or increase the productivity of a well (Amaya et al., 2021). As observed in many mature geothermal fields, some geothermal wells become idle because of reservoir depletion over time, inherent low permeability encountered by the well, and presence of high levels of non-condensable gas (NCG) among others.

In general, the S2PGL is installed into an existing well at least to the depth of the primary feed zone to directly interact with the inflow of geothermal fluids from the reservoir. Condensation of steam on the outside surface of the DBHX extracts the latent heat of vaporization and transfers it through the DBHX into the working fluid on the inside of VIT pipe. By varying the DBHX flow rate and wellhead pressure, the geothermal productivity of the feed zone is controlled. Optimization of these conditions allows the system to maximize the power production potential of the well. Through this system, an unproductive geothermal well can become productive and useful again while further depletion of the reservoir is prevented because mass is not withdrawn.

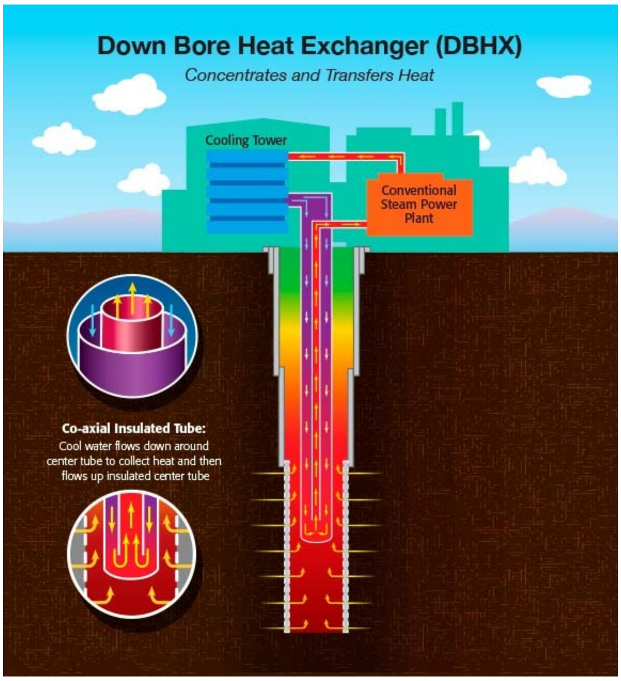

Figure 5. DBHX well schematic of the Steam and 2-Phase GreenLoop (S2PGL).

GreenFire Energy, together with the California Energy Commission, Shell GameChanger Program, Electric Power Research Institute, and J-POWER funding, and with the strong support of the Coso Operating Company and the US Navy, installed a demonstration project of the S2PGL at the Coso geothermal field, California. The test well is a high NCG producer that cannot be connected to the system. The bottom of the DBHX was set at just 300 m from the surface. Results of this project validated the DBHX modeling predictions and show that hot fluids can be produced at the surface using the DBHX (Higgins et al., 2019 and Amaya et al., 2020; Figure 6).

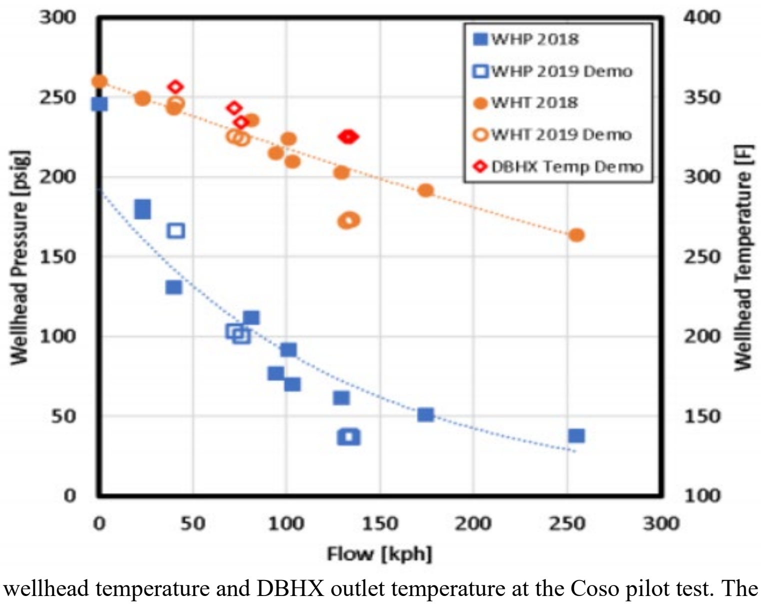

Figure 6. Wellhead pressure, wellhead temperature and DBHX outlet temperature at the Coso pilot test. The red diamonds show the temperature of the produced fluid from the DBHX, which is higher than the well's normal wellhead temperature (Higgins et al., 2019).

During the pilot test at Coso geothermal field, the closed-loop system was evaluated with three different flow rates: low (41 kph[1]), medium (74 kph) and high (133 kph). For the Coso low-pressure turbines, about 30 kph of steam produces a megawatt of electricity. Figure 7 shows the experimental profiles of temperature of the wellbore and the DBHX temperature conditions using water as working fluid. Note that the temperature of the working fluid increases as it descends and is maintained isothermally as it ascends through the VIT (bold black line in Figure 7).

[1] kph is kilo-pounds per hour.

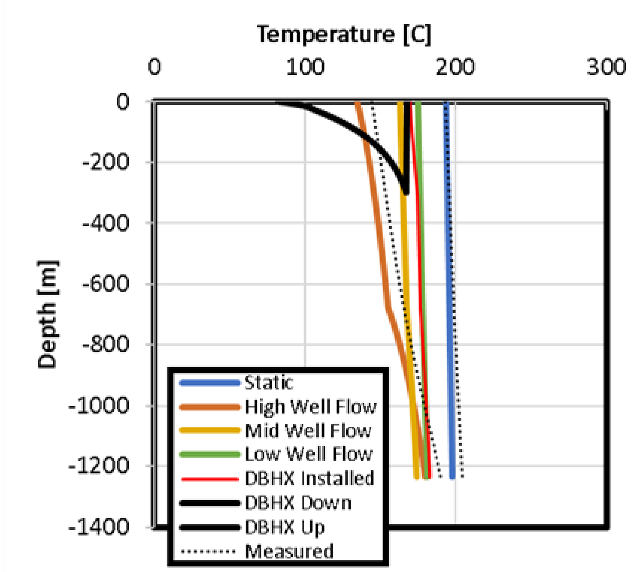

Figure 7. Temperature profile of DBHX at Coso Demo Project using water as working fluid (Higgins et al., 2019).

Figure 8 shows that more power is produced when the flow rate of the working fluid is reduced as there is more efficient heat transfer between the descending working fluid and the reservoir in the DBHX. Using water as working fluid and setting the bottom of the DBHX at just 300 m from the surface, about 1 MWe of produced fluids was extracted from reservoir. These results shows the high efficiency of the DBHX, and the potential of the technology to retrofit geothermal wells.

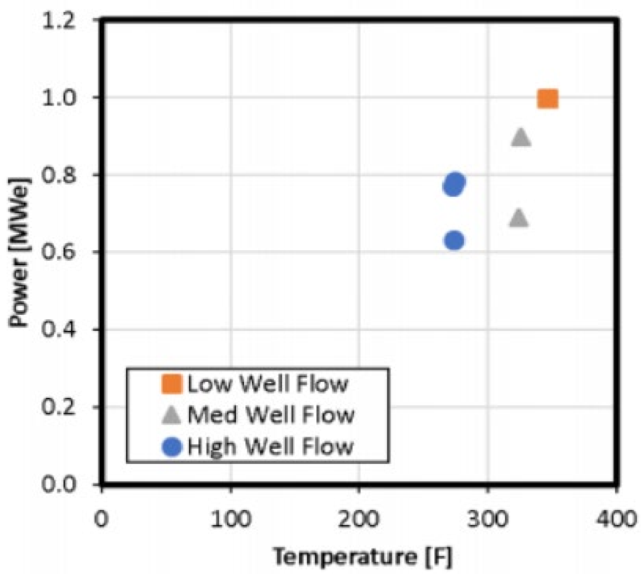

Figure 8. Electric power production potential using water as working fluid (Higgins et al., 2019).

3.2 Hot Dry Rock (HDR) Straw Loop System

In some cases, the geothermal prospect has limited permeability and wells drilled are non-commercial but encounter high temperatures. Instead of abandoning the wells, another GreenLoop system, the Hot Dry Rock (HDR) Straw Loop, can be utilized to monetize the unproductive wells. Like the S2PGL, heat is extracted from the reservoir through the DBHX that has a VIT inside a larger pipe. Figure 9 shows a schematic of the HDR Straw Loop system. In this case, the DBHX extracts energy from less permeable and higher temperature regions that conventional technology cannot use.

For HDR GreenLoop systems, the temperature gradient, VIT efficiency, and drilling depths are the main variables responsible of the overall heat transfer performance. Temperature is related to the resource; however, both the VIT and drilling are related to design and drilling capabilities. The down bore surface area can be increased either through deviated drilling or drilling multiple wells vertically on a well pad or through multi-lateral configurations. The economic analysis, price of energy and the application of the geothermal energy are also other important variables to consider in a techno-economic analysis.

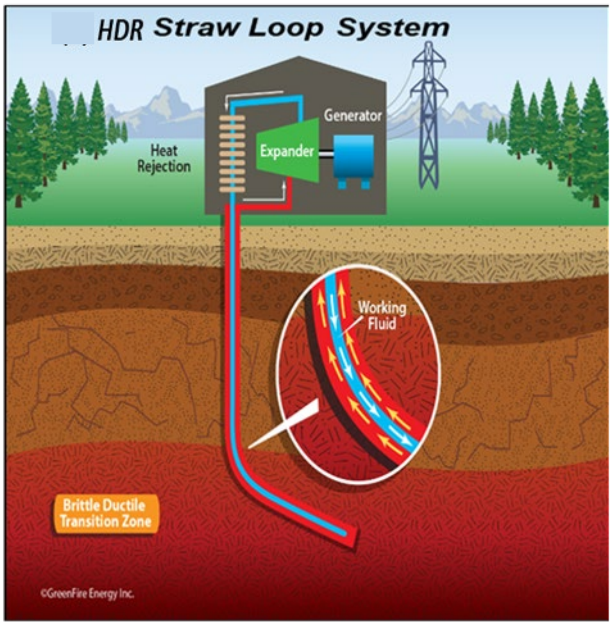

Figure 9. HDR Straw Loop System schematic (HDR GreenLoop)

4. POTENTIAL APPLICATIONS IN INDONESIA

With many mature geothermal fields operating in Indonesia since the early 1990s, there are several potential well candidates in where the GreenLoop closed-loop system can be utilized. Below are two potential examples retrieved from public information:

- On well retrofit application, the GreenLoop technology is best applied in geothermal wells with either steam or two-phase production. The main reason is because high enthalpy reservoir can efficiently heat the working fluid to saturation temperature. At the Patuha geothermal field, which has been operating since 2014 at 55 MWe using eight (8) production wells, the average initial production decline is about 5% per year (Kristiati et al., 2019). In a recent study by Hapsari (2022), the decline rate has increased to as much as 9.1% currently (Figure 10). This type of rapid reservoir depletion can be a good example to retrofit the well with the S2PGL system to regain the well's productivity.

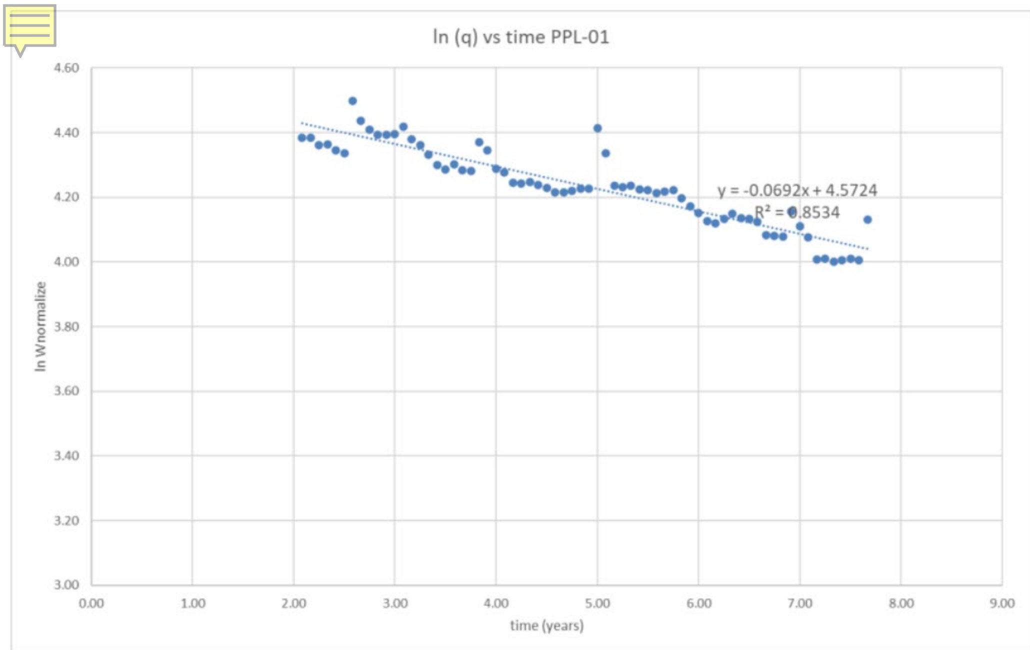

Figure 10. Exponential Decline in PPL-01 (Hapsari, 2022)

- Located in Nusa Tenggara Timur, the Nage geothermal prospect is currently being explored by the government to determine its potential. In 2021, exploration drilling resulted in the identification of a hot, dry rock system with low steam production potential. Figure 11 shows the depth vs. temperature profile of the exploration well with a conductive temperature gradient. Although there is no convection identified in geothermal prospect, the ~250°C temperature encountered by the well at 1,500 m makes it a prime candidate for the HDR Straw Loop System, which can be a solution to turn the dry well to become profitable.

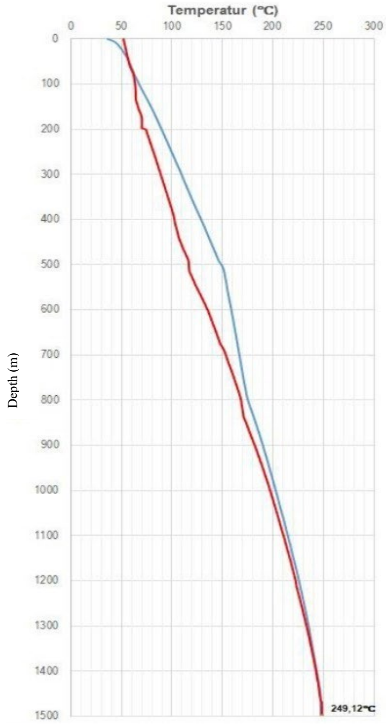

Figure 11. Depth vs. temperature profile of a well at Nage field. (Kementrian Energi dan Sumber Daya Mineral, 2017)

5. SUMMARY

The closed-loop geothermal system is a fairly recent innovative technology in the geothermal industry. GreenFire Energy's GreenLoop solutions has been proven and is shown to extract heat energy from the reservoir that can be converted to electricity. With several mature geothermal fields and active geothermal exploration in Indonesia, GreenFire's S2PGL and HDR Straw Loop System can make unproductive and dry wells become profitable.

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