PASSIVE NCG REINJECTION AT TE HUKA GEOTHERMAL BINARY POWER PLANT

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ABSTRACT

Te Huka power plant is part of the Tauhara geothermal field in Taupo New Zealand. This 24 MWe binary plant started operation in July 2010. With 2 production wells and 2 injection wells it has produced around 209 GWh of electricity per year. As is the case for all geothermal reservoirs, Non-Condensable Gases (NCGs - CO_2, CH_4 and H_2S) are naturally occurring in the hot geothermal fluids underground and are released in gaseous form during the power generation process. However not all NCGs are released at Te Huka (and many other binary stations) - due to the relatively high pressure at which the geothermal steam is condensed. Approximately 18.8 % of NCGs are dissolved in the geothermal condensate, which is combined with the separated geothermal water and reinjected back into the reservoir where it came from. We refer to this process as “passive” NCG reinjection – where “active” NCG reinjection refers to an additional process of actively redirecting the NCG gas stream at the surface and dissolving those gases back into the geothermal fluid in the reinjection line.

This paper discusses the reinjection history at Te Huka and the effect of NCG reinjection on mineral precipitation and dissolution at the reinjection well feed zones. Reactive transport modelling with TOUGHREACT has been used to compare passive NCG reinjection to active reinjection. The modelling results are used to illustrate the advantages of passive and active NCG reinjection at Te Huka.

1. INTRODUCTION

The Te Huka power plant is located at the Tauhara-North field on the Taupo Volcanic Zone, New Zealand. The Tauhara field is considered to have 4 areas Tauhara North, Tauhara East, Tauhara Central and Tauhara South. Tauhara-North supplies the Te Huka power plant and other direct use applications (Figure 1). In addition, the Tauhara field has a hydraulic connection to the Wairakei field, to the North-West, which is why they are usually referred as Wairakei-Tauhara. Nevertheless, each field has its own upflow (Milloy and Lim, 2012) and have different characteristic areas. Before Tauhara production, from routine downhole pressure measurements, it was possible to see that although Tauhara wells were up to 10 km away from the Wairakei production area, the reservoir pressures at Tauhara were declining at the same rate as at Wairakei, but Tauhara’s were about 5 bar higher than the Wairakei pressures (McDowell et al, 2021). More recently both fields have seen their reservoir pressures increasing as a result of increased reinjection activity.

At Te Huka, electricity is generated through a binary (organic rankine cycle) process. This is similar to a number of other power stations in New Zealand, including Contact’s Wairakei binary plant. The process uses n-pentane, a hydrocarbon with a low boiling point as the working fluid. The heat contained in the geothermal fluid is transferred in heat exchangers to vaporize the n-pentane. The n-pentane vapor then drives the turbines. On leaving the turbines, it is cooled within an air-cooled condenser before it is pumped back to the heat exchangers for the heating cycle to recommence. The geothermal fluid leaves the heat exchanger and is sent to be reinjected back into the reservoir.

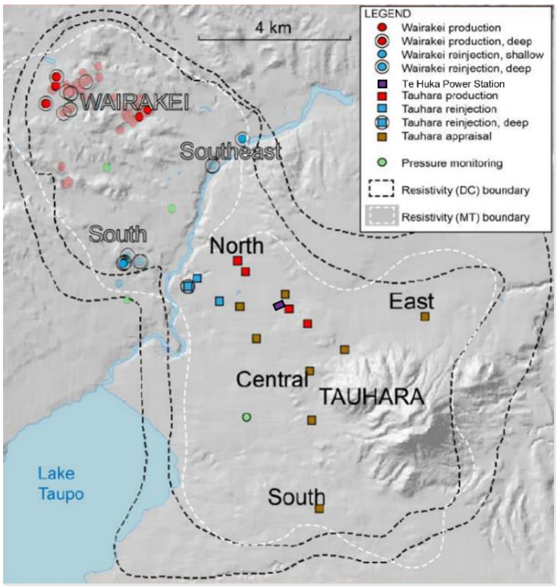

Figure 1: Location of Te Huka power plant on Tauhara Geothermal Field

In late-2007 the concept of a binary plant at Te Huka was developed, and in mid-2008 Contact entered into agreements with Ormat Pacific Inc. to construct the power station. Construction work started on site in February 2009. Thirteen months after construction commenced, first power was exported from the site. Te Huka was officially opened on 1 July 2010. This 24Mwe plant has produced around 209 GWh of electricity per year since it started operations. During 2021 the plant has gone through the final upgrade as an upper tier Major Hazard Facility.

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Te Huka reinjection

The plant started production in 2010. Initially, it was producing from wells TH14 and TH13 and reinjection was going to TH15 and TH16. In 2011, additional drilling resulted in another production well TH20, and a new deep injection well TH19. After the new additions, production was obtained from TH20 and TH14 and reinjection was sent to TH15 and TH19.

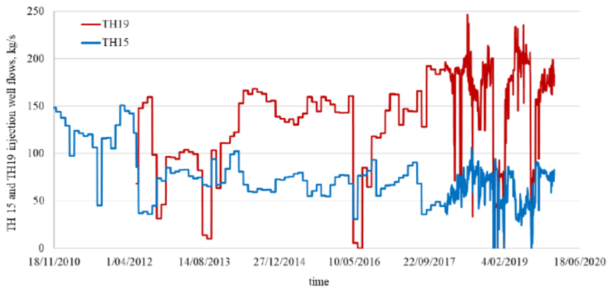

Figure 2: Reinjection history at Te Huka

The production wells tap from the Tauhara-North outflow (Figure 4) and reinjection is both shallow (TH15) and deep (TH19). In the ten years of operations no tracer reinjection returns above the detection limit have been reported on production areas from shallow reinjection (2010, Tracer test TH8-TH15-TH16 Organic Tracer Injection Report). The production wells have shown stable chemistry, with no evidence of mixing with cooler fluids. The main impact of reinjection in the different areas of the fields has been to provide pressure support across both Wairakei and Tauhara fields. At Tauhara North the reinjection takes place at two depths: Shallow ~0mRL at TH15 and deep below -1400mRL at TH19.

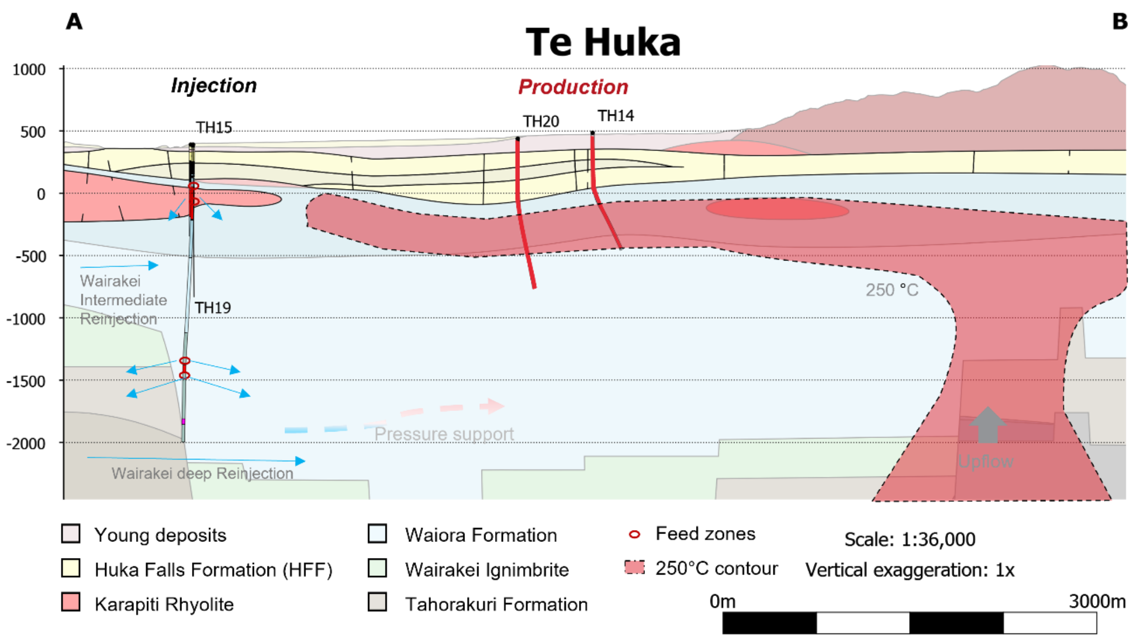

Figure 4: Cross section W-E from Tauhara North. Te Huka production (in solid red) and injection.

TH15

This well was drilled in 2007 as one of the first injection wells in Tauhara North. It has a total depth of 735m. TH15 has been an injection well since the commissioning of Te Huka. It is responsible for the shallow reinjection into Karapiti Rhyolite. Both TH15 feed zones are located in this formation. The shallow feed zone is at 345-380m [44.1 / 9.81mRL] and the major feed zone is at 520-560m [-130.19 / -170.19mRL]. The rhyolitic body where the feed zones are located is around 0mRSL, extended to the west of the well, can reach a maximum thickness of 489m and is the largest (6.5 x 4 km in plan view) lava extrusion in the Wairakei-Tauhara system.

TH19

Drilled in 2011, TH19 was targeted for deep injection and exploration of the edge of the resistivity boundary. It has a total depth of 2396m and three deep feed zones:

- FZ1: 1800-2000 m [-1408 / -1607 mRL]
- FZ2: 2190-2210 m [-1797 / -1817 mRL]
- FZ3: 2230-2280 m [-1837 / -1887 mRL]

The amount of fluid injected into the feed zones has changed over the years without significantly affecting the overall injectivity of the well. Figure 3 shows the calculated historic TH19 capacity, however, in the periods of no WHP, the well is partially loaded the and the full well capacity cannot be accurately calculated.

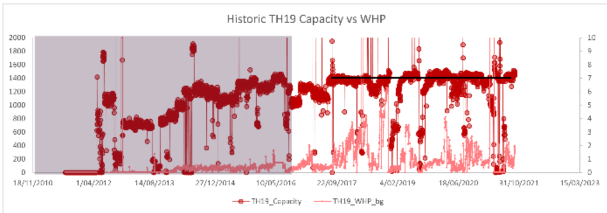

Figure 3: TH19 Historic well capacity

In 2011, the feed zone FZ1 1800-2000 m was taking 47% of the reinjection fluid and FZ2&FZ3 2200-2300 m were taking 53%. By 2018 the proportion had changed to 81% and 19% respectively.

The well has been taking most of the reinjection flow since it was put online Figure 2. Over time there has been an increase in Well Head Pressure (WHP) and a change in balance of its feed zones. This change could be attributed to a combination of factors, including:

1) Overall field pressure recovery due to reinjection in Wairakei-Tauhara.
2) Changes in the fluid density, Bottom Hole Temperature (BHT) showed the well temperature has adjusted to the injection temperature 120°C from its initial 230°C.
3) Potential mineral dissolution and precipitation.

2. GEOTHERMAL NON-CONDENSABLE GASES (NCG)

Geothermal reservoirs contain NCGs that occur naturally in the geothermal fluid. They result from degassing of magma chambers underground and the fluid-rock interactions within the reservoir. For some geothermal reservoirs, the gases come out through natural features such as fumaroles and bubbling hot pools which vent the gases slowly to the atmosphere and degas the reservoir over time, where others just maintain the gasses dissolved in the geothermal fluid. For the first ones a large proportion of the NCGs reside in the reservoir, where they are dissolved in the reservoir fluid. Some geothermal reservoirs have naturally high levels of CO_2 (such as Ohaaki) and others have naturally low levels (such as Mokai) (McLean et al., 2020)

When extracting fluid from the reservoir for production the fluid carries the NCGs to the surface, which become less soluble as the pressure is reduced. Some of the most common Geothermal NCGs are CO_2, H_2S, NH_3, CH_4, N_2, H_2 and Ar. More than 99% of the NCGs accounted at Te Huka are CO_2, H_2S, and CH_4. The other gases are considered trace gases. It is important to mention that although H_2S is not a greenhouse gas there are other environmental considerations associated with it.

During the power generation process NCGs are removed from condensers (or the binary plant equivalent – vaporisers) and released to the atmosphere so they do not build up and prevent the efficient operation of the plant. McLean and Richardson (2021) show the emissions values for New Zealand geothermal power plants. Wairakei and Tauhara are two of the lowest emission fields. Tauhara (Te Huka plant) has an emission factor of 0. 0078 tCO_{2e}/ t steam and total annual emissions of 10,718 tCO_{2e} (McLean and Richardson, 2021)

Te Huka NCGs

The NCGs come with the geothermal fluid from production wells: Table 1 shows average samples from TH14 and TH20. The values represent a particular well output contribution proportion of 64.1% and 35.9% respectively. In reality, the proportion of steam contributed from each of the production well changes at Te Huka to optimize power output. Consequently, the amount of NCGs changes quite significantly, as TH14 has a significantly higher gas content than TH20 (McLean and Richardson, 2019).

The combined output from the wells goes to the separator and then with the steam to the vaporiser (where it gives up heat to vaporise the pentane, (Figure 5). At the vaporiser the NCGs are separated from the steam condensate and discharged to the atmosphere. However, not all the NCGs are vented. Due to the relatively high pressure inside the vaporiser a fraction of the NCGs dissolves into the steam condensate.

3. PASSIVE NCG REINJECTION AT TE HUKA

The reinjection of NCGs has been studied around the world. Active processes to capture and redirect NCGs back to the reservoir have been developed at places like Helliisheiði (Hengil Iceland), Umurlu (Turkey), Coso (California USA), and Puna (Hawaii USA). NCG injection that requires any additional process to redirect the NCG stream at the surface towards reinjection is referred to as "active NCG reinjection" (e.g. dissolving those gases back into the geothermal fluid in the reinjection line or redissolving the gases in the well through downhole tubing). "Passive NCG reinjection" is the term used when the NCGs (or a portion of them) dissolve into the geothermal fluid that is reinjected as a part of the normal plant operation, without additional process equipment or considerations (essentially it occurs as a by-product of the plant process).

Figure 5: Vaporiser

Since the beginning of operation Te Huka has naturally dissolved a portion of its NCGs into the condensate and that condensate has been mixed with the brine and reinjected into the reservoir. This is "passive NCG reinjection", as it occurs as a result of standard plant operating conditions. Comparing the effects of this passive NCG reinjection to the Wairakei binary plant, the heat exchanger scaling rates are considerably lower at Te Huka. The Wairakei plant only uses geothermal brine, as the separated steam and NCGs are transported to steam turbines at other plants. The effects of scaling on plant performance can be seen within 6 months of cleaning heat exchangers at Wairakei. At Te Huka far less reduction in heat exchange performance has been observed during the plant's life with few heat exchanger cleans required. Different source fluid, separation pressures and temperatures contribute to these differences, however the returned steam condensate and accompanying NCG content is an important factor.

Rotoflow samples were collected at Te Huka to determine how much of the total NCGs from the production wells are dissolved and transported back to the reservoir through the reinjection line. These concentrations were then compared to the amounts estimated for 100 % NCG reinjection through modeling (Table 1).

Table 1: Te Huka NCG Chemistry

	Theoretical 100 % NCG	Current NCG Reinjection
pH	4.87	5.58

CO_2 (mg/kg)	1565.25	282.03
$H_2S(aq)$ (mg/kg)	83	44.5
NH_3 (mg/kg)	3.3	3.3
CH_4 (mg/kg)	11.2	2.1
Trace gases (mg/kg)	65.3	30.7

Based on the data it was possible to see that ~20 % of the total production wells NCGs are going to reinjection line.

4. MODELING EFFECTS OF NCG REINJECTION

Understanding the effect of long-term reinjection on the reservoir is key for any field. The principle of NCG reinjection is to return the gases to the reservoir where they originated. When assessing the impact of NCG injection there are several factors that need to be considered, including rock and fluid interaction (permeability/porosity alteration caused by mineral precipitation and dissolution), and pressure changes. Initial modelling work has been conducted with the University of Auckland to better understand the effects of NCG reinjection on the reservoir. The objective of the modeling is to compare the current passive reinjection scenario at Te Huka (~20%NCG reinjection) with a potential future active 100% NCG reinjection scenario (Table 2).

The modelling of fluid and heat flow, solute transport, and reactive chemistry was performed using TOUGHREACT, a non-isothermal multicomponent reactive fluid flow and geochemical transport simulator developed at Lawrence Berkeley National Laboratory (Xu et. al. 2012). Fluid reinjection was simulated, and dissolution and mineral precipitation processes were observed. Two simple TOUGHREACT models were developed to simulate 1) the shallow TH15 feed zones and 2) the TH19 deep feed zones.

Table 2: TOUGHREACT modeling scenarios

Well	Scenario	Historic [0-10 Years]	Future [10-50 Years]
TH15	Passive reinjection	Current 18% NCG reinjection	
	Active reinjection	Current 18% NCG reinjection	100% NCGs reinjection
TH19	Passive reinjection	Current 18% NCG reinjection	
	Active reinjection	Current 18% NCG reinjection	100% NCGs reinjection

The 1D-radial models were set up using AUTOUGH2 (Yeh et al., 2012) and TOUGHREACT to simulate the response at the feed zones. For the radial models, EOS1 of TOUGHREACT was used. The radial model was divided into two main zones to represent around the well (skin) and reservoir zones to allow the representation of heterogeneity and modification of the separate zones during the calibration process (Figure 6). To calibrate the model, injection history and well head pressure were used to compare the pressure response observed on the well. It is important to note that the pressure at Tauhara is also impacted by other nearby injection areas utilised by the Wairakei operation.

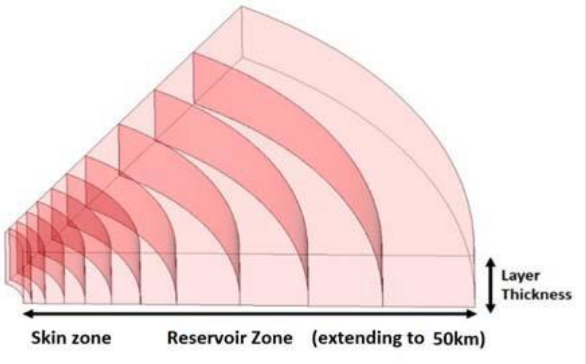

Figure 6: Representation of radial model grid and distances

To consider the current feed zone conditions after 10 years of injection history (Figure 2), the simulations were made in two parts: Historic and Future (Table 2). For the first 10 years of all the scenarios the model run assuming current passive NCG reinjection, after those "historic" 10 years the model changes depending on the scenario.

Results of the modelling

The simulations showed the benefits of NCG reinjection in the long-term state of the feed zones. Lower increase in pressure, and lower decline of permeability and porosity is found at higher NCG reinjection.

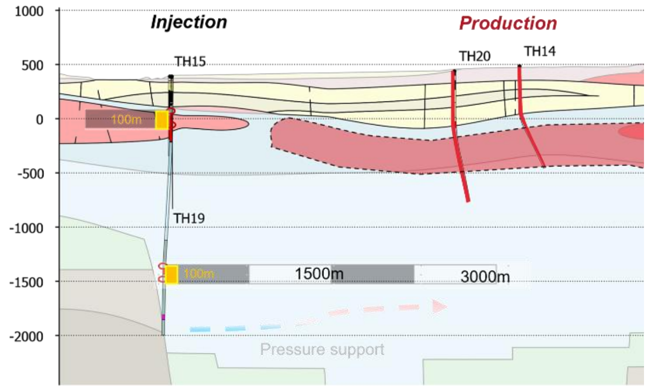

Figure 7: Graphical representation of the radial model vs production area.

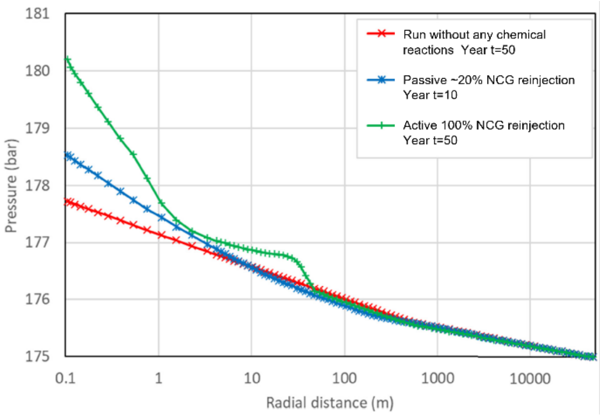

Figure 8: TH19 radial pressure for specific scenarios and years

Figure 8 Figure 8 shows TH19 pressure response in radial distance from the well for different scenarios. The model shows no evidence of strong pressure changes further than 100m from the wellbore (Figure 7). The red line is the model run without any chemical reactions for 50 years with only 2.8bar difference in 50 years from initial feed pressure. Blue line represents the model simulation of the feed zones status after 10 years of injection showing ~3.5bar higher pressure than the initial conditions, this aligns to the well head pressure increase. Note the model run without any chemical reactions only addressed to compare. The green line showed ~5.2 bar difference from initial condition in 50 years with 100% NCG reinjection and suggest ~2.7bar higher pressure from todays “pressures”.

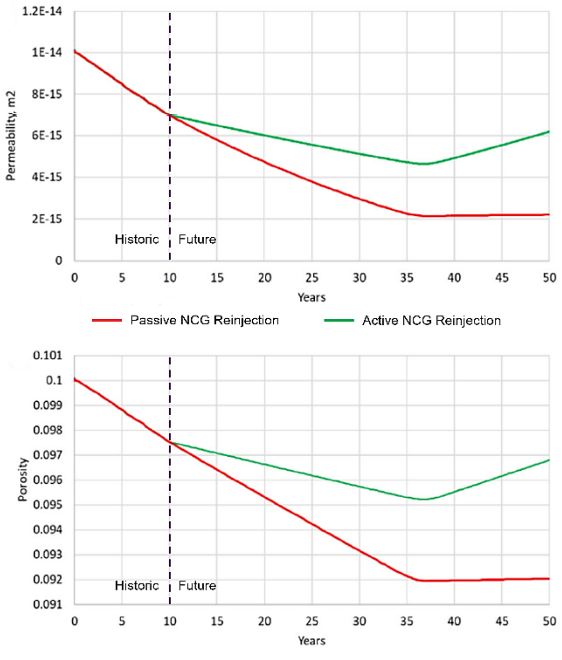

Figure 9: TH15 permeability and porosity changes in time of passive reinjection and active reinjection scenarios.

When comparing passive NCG reinjection to active NCG reinjection, it is evident there is a positive effect on porosity and permeability with active reinjection. Figure 9 shows the TH15 results on the skin zone of the model (Figure 6). Porosity and permeability have a lower decline in the “Active” 100 % NCG reinjection than the “Passive” only 18% reinjection. For the active scenario (Figure 10a) a high dissolution rate of minerals like calcite, chlorite, and albite is evidenced by a negative volume fraction change. Chalcedony, smectite and pyrite are the main minerals that precipitate and result in a slight reduction of the permeability and porosity. In the later years of injection, the amount of chalcedony deposition rate decreases, resulting in the net positive volume fraction change to start trending downwards and therefore creating an increase of permeability and porosity (Figure 10).

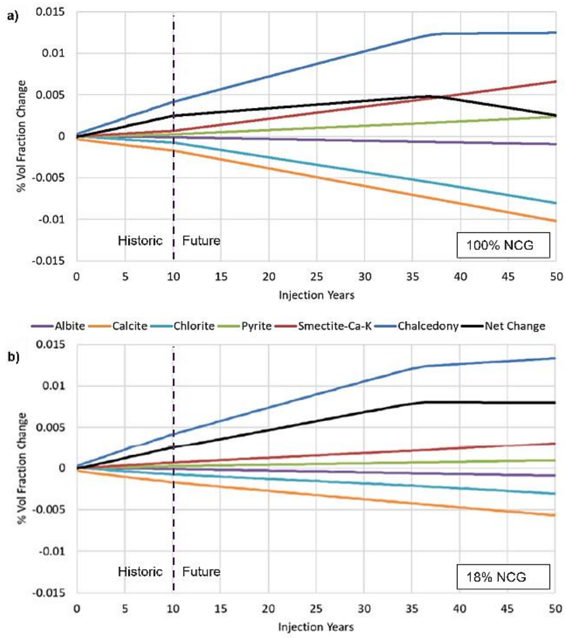

Figure 10:TH15 Mineral % volume fraction change in time. a) Active 100% NCG reinjection b) Passive 18% NCG reinjection.

In the passive injection only scenario there is a larger drop in permeability and porosity as less minerals are dissolved, while chalcedony continues to precipitate at a similar rate to that seen in the active NCG reinjection scenario.

The modelling for TH19 shows a similar benefit for the 100 % NCG reinjection case in terms of better permeability and porosity when compared with that seen for the passive injection scenario (Figure 11).

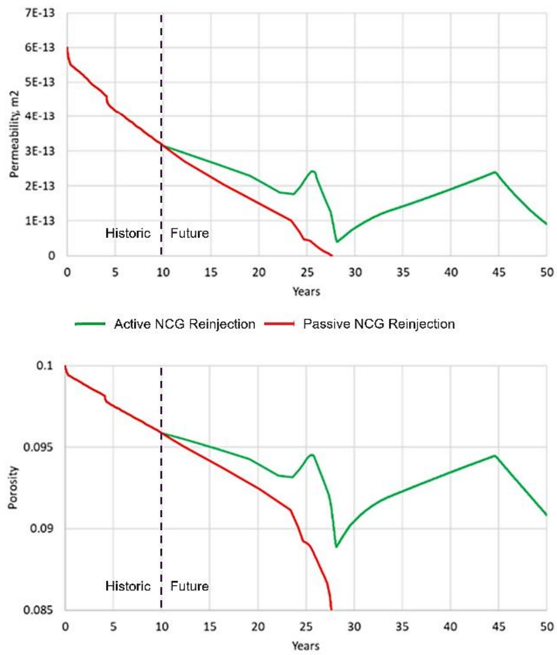

Figure 11: TH19 permeability and porosity changes in time of passive reinjection and active reinjection scenarios.

In the passive injection scenario, injection at the current flow rate becomes unsustainable after around 25 years due to blockage of the fractures through precipitation of chalcedony and amorphous silica. Active injection of 100 % of the NCGs allows the current injection flow rate to be maintained for the duration of the 50 years modelled.

While these initial modelling results suggest that active NCG reinjection will be beneficial from the point of view of maintaining injection capacity, further work and modelling is required to study any impacts on injection in more detail.

5. CONCLUSION

Passive NCG reinjection has been occurring at the Te Huka binary power plant since it was commissioned in 2011. Chemistry sampling showed that ~18.8 % of the plant NCG has been passively reinjected. Current field data does not suggest any negative impacts of this passive reinjection of NCGs.

Initial modelling results suggest there is high value in pursuing active NCG reinjection. Injection of 100 % of the NCGs appears to slow down the permeability and porosity decline in the injection wells based on the results from the TOUGHHREACT modelling. Active NCG injection will help to reduce emissions to the atmosphere from Te Huka power plant and potentially preserve the life of the injection wells while also returning the NCGs to the reservoir to realise a true 100 % reinjection of geothermal fluid.

More work is underway to increase the understanding of the effects and risks that could be caused by moving towards active NCG reinjection.

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