Reinjection Management Evaluation in Karaha Bodas Field 2022

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ABSTRACT

The Karaha Bodas Field features a two-phase system with a vapor fraction ranging from 50% to 98%, which is tapped by five production wells. As of 2022, the field includes one injection well, namely KRH-1.A, with an injection flow rate of approximately 60-100 tph. Geochemical monitoring has indicated an increase in dryness in KRH-A.1, as well as in wells originating from the Talaga cluster (TLG-C.1 & TLG-C.2), due to the absence of reinjection fluid contributing to the production wells. This observation is further supported by the findings of the 4D microgravity monitoring study, which reveals areas with reduced mass around the production wells in the Karaha Bodas Field. This trend aligns with the limited occurrence of micro-earthquake events around production wells. The Karaha Bodas Field presents challenges owing to its relatively high decline rate, patchy structure, and low-to-medium permeability. An inter-well connectivity study was conducted using the KRH-1.A injection well to confirm these indications. After six months of studies, it has become evident that there is no connectivity between the injection and production wells. The absence of reinjection fluid support for production wells has led to a decline in production by 9% annually. Tracer results also underline the absence of a structured path towards production wells or the presence of poor permeability due to the patchy structure, which is a contributing factor to the significant decline in output. To address this challenge, a modification in the injection strategy is imperative, involving the addition of the injection wells KRH-A.3 & KRH-B.3.

1. INTRODUCTION

1.1 Field Overview

Karaha Bodas Geothermal Field is one of the geothermal areas owned by PT. Pertamina Geothermal Energy. It is located at Tasikmalaya and Garut, West Java Province, Indonesia. The Karaha Bodas Geothermal Power Plant was built with a capacity of 30 MWe and began operations in April 2018. In 2022, Karaha Bodas Field had six production wells and one reinjection well, namely KRH-1.A, with an injection flow rate of approximately 60 -100 tph. The Karaha Bodas Field has a two-phase reservoir, with a vapor fraction between 50-98%, which is tapped by five productions Wells.

1.2 Background

In the realm of geothermal field development, reinjection wells are very important, holding equal importance as production wells in sustaining electricity generation. The multifaceted objectives of reinjection wells within a geothermal reservoir encompass a range of crucial functions. These functions include the disposal of waste-water generated by power plants and the return of water from direct applications; the provision of additional recharge to supplement natural replenishment to geothermal systems; the maintenance of reservoir pressure to counteract declines due to mass extraction; the enhancement of thermal extraction from reservoir rocks along flow pathways; the mitigation of surface subsidence arising from pressure declines caused by production; and the potential to improve or rejuvenate surface thermal features (Axelsson, 2012; Bromley et al., 2006).

1.3 Current Issue at Karaha

At present, the Karaha Bodas geothermal field faces a significant challenge in the form of production decline. This decline is suspected to be associated with suboptimal reinjection management practices. As an essential component of sustainable geothermal energy generation, reinjection plays a pivotal role in maintaining the health and productivity of the reservoir. Proper reinjection management is critical for addressing various factors that contribute to production decline, particularly by ensuring reservoir pressures are maintained.

1.4 Focus of the Paper

This paper aims to define reinjection management within the Karaha Bodas field in the year 2022. By digging into the specific practices, strategies, and challenges associated with reinjection, the paper seeks to provide a comprehensive understanding of how proper reinjection management can address the current issue of production decline. The year 2022 marks a pivotal juncture in the trajectory of the field, making it a crucial time to assess and optimize the reinjection processes.

Reinjection management will cover a thorough examination of the practices in place, potential deficiencies or inadequacies, and potential pathways for improvement. By focusing on the interplay between production and reinjection, the paper aspires to define how effective reinjection management can contribute to reversing or mitigating the decline in production, thus fostering a sustainable and efficient geothermal energy production system.

The importance of reinjection wells in geothermal field development cannot be overstated. In the case of Karaha Bodas, the challenges related to production decline highlight the vital role of effective reinjection management. By concentrating on reinjection practices and strategies within the Karaha Bodas field in 2022, this paper endeavors to offer insights into potential solutions that can counteract production decline and ensure the continued success of geothermal energy generation in the area.

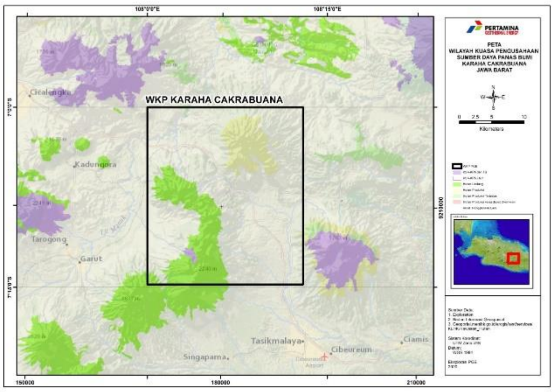

Figure 1: The Location of Karaha Bodas Geothermal Field

2. THEORY

1.2 Tracer Test

Several types of tracers are available, including fluorescein, radioisotopes, and chemical tracers. In terms of detection capability at very low concentrations and low initial concentrations in the reservoir fluid, radioisotopes stand out as the best option. However, chemical tracers are the most used tracers in geothermal applications. Tracers employed in surveys should exhibit non-reactivity with reservoir rocks, ease of analysis, temperature stability within the reservoir, and minimal presence in the reservoir fluid. Designing a tracer injection survey involves considering aspects such as the type of tracer, the quantity of tracer to be injected and the sampling frequency.

The most recent tracer injection survey at Karaha Bodas employed Naphthalene Disulfonic Acid (NDSA) as liquid tracer and Perfluorocarbons (PFC) as steam tracer. One hundred kilograms of 2,7 NDSA were dissolved in 1000 liters of water with a pH range of 6 to 7, giving a solubility of 25%. This solution injected into well KRH-1.A. The wellhead pressure at KRH-1.A was -0.7 bar, and the injection involved 300 t/h of cold fluid at a temperature of 40°C. Notably, 2,7-NDSA exhibits thermal stability with no thermal decay even at 330°C, for over a week, making it suitable for use in reservoirs as hot as 350°C or even hotter.

Perfluorocarbons (PFC), on the other hand, are stable up to at least 280°C in the presence of reservoir rock and water. They are highly insoluble in water and show minimal decay at 250°C for several days and negligible decay at 280°C after one week.

The study encompassed the tracer sampling and monitoring of five production wells. These wells were selected based on their geological locations in relation to the injection well, representing each cluster within both production zones. The observed results from the samples were presented as tracer concentration versus time, forming tracer profile curves. These curves provide insights into breakthrough times correlated with maximum tracer velocity, average velocity indicated by maximum tracer concentration, dispersion amount within the reservoir denoted by curve width, and tracer recovery as a function of time. Figure 3 illustrates the tracer scenario map for the Karaha Field.

Quantitative analysis of tracer data, involving mass recovery determination, breakthrough time assessment, temperature decline, and thermal breakthrough of production wells, was carried out using the method proposed by Axelsson et al. (1995). This method employs a fluid flow model in fracture media, utilizing the tracer inverse simulator (TRINV) from the Icebox Package for calculations. Parameters required by the software include tracer concentration over time, injector-to-producer distance, production rate, and injected tracer mass. Output parameters encompass tracer velocity (u), dispersion coefficient (D), recovery factor (RF), and flow path area (AØ). The Axelsson model integrates dispersion factors into fluid flow within the reservoir, considering advection, convection, mechanical dispersion, and molecular diffusion. It acknowledges factors such as pore or fracture wall effects, pore or fracture width effects, and flow path tortuosity effects. While the analysis in this paper represents a semi-analytical calculation with only moderate accuracy, it serves for the preliminary interpretation of temperature effects resulting from injection. Thermal breakthrough, defined as the point at which the reservoir temperature begins to decline due to injection, was analyzed using a model by Axelsson et al. (1995). This model factors in convective heat transfer along flow paths and conductive transfer within reservoir rocks. The calculation assumes that temperature decline and thermal breakthrough in a production well are solely influenced by the injection fluid.

Table 1. Threshold Detection Limit of 2,7 NDSA and PFC Monitoring of Tracer Test (refer to PT. TCI)

Tracer name	Typical detection Limit (ppb)	Detector
2,7 NDSA	0.2	Fluorescence
PFC	0.01	Electron Capture

3. DATA

3.1 Geochemical Monitoring

The year 2022 marked a significant period for injection activities in the Karaha field, with KRH-1.A serving as a pivotal injection well throughout this timeframe. Since its Commercial Operation Date (COD), KRH-1.A has been actively engaged in the injection process, contributing to the overall operations in the field. Notably, the well has an impressive Injection Capacity of 600 tons per day (t/d), highlighting its substantial capacity to facilitate fluid injection into the reservoir.

Over 2022, a substantial quantity of fluid was injected into the reservoir through KRH-1.A. The total injection volume for the year amounted to an impressive 248,880,360 tons. This noteworthy figure underscores the significant role that injection wells play in maintaining reservoir pressures and optimizing geothermal energy generation (Figure 2).

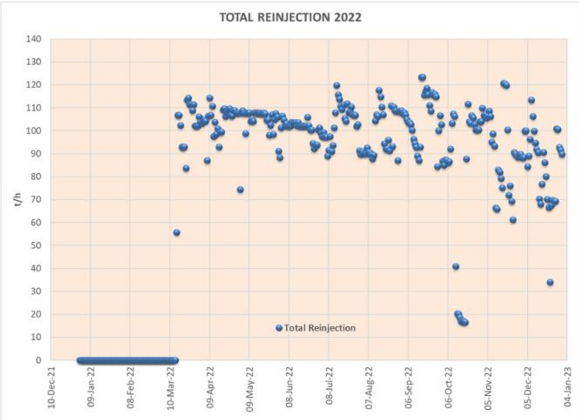

Figure 2. Total Brine and Condensate Reinjected to KRH 1.A from Production Wells

The injection rate was not only high but also exhibited a consistent pattern of activity throughout the year. On average, a remarkable daily injection rate of 97 tons was maintained, highlighting the consistent effort to recharge the reservoir with the necessary fluids to sustain its productivity. This daily injection rate reflects the dedication and meticulous approach taken to ensure the sustainability of the reservoir.

Table 2. Fluid Geochemistry Monitoring over period of 2018-2022

Well	WHP (barg)	FCV (%)	Brine Rate (t/h)	Steam Rate (t/h)	TMF (t/h)	Dryness (%)	H (kJ/kg)	Cl (ppm)	NCG (ppm)	Indication
KRH-A.1	↓	↓	↓	↑	↓	↑	↑	↑	↑	Increase in Dryness
KRH-B.1	↓	↓	↓	↓	↓	↑	↓	↔	↔	
TLG-C.1	↓	↔	↓	↓	↑	↑	↑	↓	↑	Increase in Dryness

Between 2018 and 2022, an extensive geochemistry monitoring initiative was undertaken, as delineated in Table 2. The primary aim of this effort was to gain insights into the fluid characteristics within the Karaha geothermal field. The results of this comprehensive monitoring endeavor yielded significant indications, particularly regarding the state of the reservoir near the KRH A.1 and TLG C.1 wells. These indications strongly suggested the occurrence of reservoir dryness, as evidenced by notable increases in parameters such as dryness, enthalpy, and non-condensable gas (NCG) content.

Tracer Reservoir Test were conducted through injecting 2,7 NDSA and PFC from KRH 1.A (reinjection well) and monitoring the appearance of the tracers in all the production wells in KRH-A, KRH-B, and TLG-C for about six months of sampling and fluid composition monitoring as shown in Figure 3.

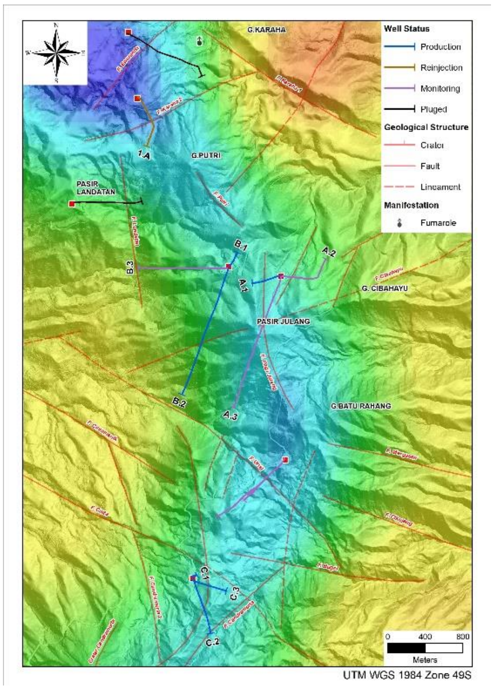

Figure 3. Tracer Injection Scenario Map in Karaha Bodas

3.2 Geophysical Monitoring

The left map provided in Figure 4 shows the Gravity Monitoring data spanning the period from 2022 to 2016. This map serves as a comprehensive tool for understanding the variations in gravity readings during this timeframe.

One notable observation from the map is the presence of areas with negative anomaly zones encircling the cluster of Production Wells, specifically KRH A and KRH B. These negative anomalies indicate deviations from the expected gravity readings and could potentially signify geological or fluid-related variations in these zones.

In contrast, the western and northern regions of the Reinjection Well (KRH 1.A) exhibit positive anomalies. Interestingly, these anomalies form a protective ring around the area characterized by low anomalies associated with the Production Wells. This interplay of positive and negative anomalies highlights the complex interactions within the geothermal reservoir.

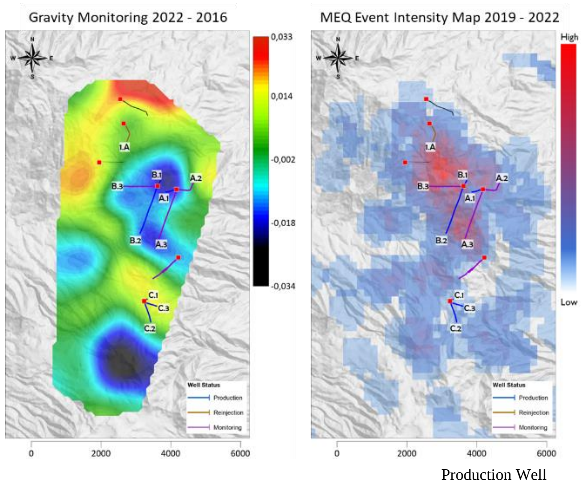

Figure 4. Geophysical Monitoring of Karah Bodas Field

Examining the distribution of intensity of Micro-Earthquake (MEQ) events provides further insights. Specifically, the areas between Cluster KRH 1 (Reinjection) and Clusters KRH B and KRH A exhibit elevated intensity of MEQ events. This observation suggests a potential correlation between the activity of these clusters, whether from Production or Reinjection wells, and the occurrence of MEQ events.

The interplay between MEQ intensity and the gravity anomalies is particularly intriguing. The convergence of high MEQ event intensity and the presence of negative gravity anomalies in the 4D Microgravity map from 2022 to 2016 points toward a deficiency in fluid mass support within the production zone. This relationship underscores the connection between subsurface fluid dynamics and seismic activity.

Lastly, Cluster C is notable due to its moderate MEQ intensity and its tendency to follow a pattern like the gravity anomaly. The low anomaly at the South tends to show the mass deficiency and lack of support from either reinjection fluid or natural recharge. This anomaly suggests becoming a caution for field development.

3.3 Reservoir

The correlation of the depth distribution of the feed zone and the permeability characteristics of the feed zone within the geothermal reservoir situated in the Karaha region has yielded significant insights. This mapping endeavor provides a comprehensive understanding of the variations in permeability levels across different elevations within the reservoir.

The findings indicate that the permeability of the Karaha reservoir extends across a substantial elevation range, spanning from -900 meters above sea level (mASL) to 100 mASL.

Table 3. Summary of Feed Zone Distances between Production Wells to KRH 1.A (Reinjection Well)

Production Wells	FZ Distance (meters)
	KRH-1.A
KRH-A1	1850 - 1935
KRH-B.1	1490 - 1620
KRH-B.2	2460 - 2820
TLG-C.1	4615 - 4760
TLG-C.2	4840 - 5360
TLG-C3	4750 - 4960

4. ANALYSIS

4.1 Chemical solution of the tracer

Table 4. Mixing solution of chemical tracer in Karaha

Injection Well	Tracer Name	Target Mass Injected	Tracer Purify	Initial Solution
KRH 1-A	2,7 NDSA	300 kg	95.3%	10 wt.%

Injection Well	Tracer Name	Injected Quantity	Tracer Purify	Initial Solution
KRH 1-A	PFC	25 kg	>99%	17 wt.% in emulsion

The mixture of tracer (Table 4) in Karaha composed with 300 kg of 2,7 NDSA and 25 kg of PFC to be injected from KRH 1.A.

4.2 Monitoring duration of 2,7 NDSA

Table 5. Time intervals for monitoring of 2,7 NDSA concentrations

No	Well	Inject	1st Analysis	End of Analysis	Duration (days)
1	KRH-A.1	21-Apr-2022	28-Apr-2022	9-Oct-2022	171
2	KRH-B.1	21-Apr-2022	28-Apr-2022	12-Oct-2022	174
3	TLG-C.1	21-Apr-2022	28-Apr-2022	9-Oct-2022	171
4	TLG-C.2	21-Apr-2022	28-Apr-2022	9-Oct-2022	171
5	TLG-C.3	21-Apr-2022	28-Apr-2022	15-Aug-2022	116

4.3 Monitoring duration of PFC

Table 6. Time intervals for monitoring of PFC concentrations

No	Well	Inject	1st Analysis	End of Analysis	Duration (days)
1	KRH-A.1	21-Apr-2022	28-Apr-2022	29-Sep-2022	161
2	KRH-B.1	21-Apr-2022	28-Apr-2022	9-Oct-2022	171
3	TLG-C.1	21-Apr-2022	28-Apr-2022	29-Sep-2022	161
4	TLG-C.2	21-Apr-2022	28-Apr-2022	15-Aug-2022	116
5	TLG-C.3	21-Apr-2022	28-Apr-2022	15-Aug-2022	116

On average, based on Table 5 and Table 6, the total duration from injection to the end of analysis for each of the chemical tracers is about 116-174 days, this allows for the completion of analysis of tracer appearance in production wells.

5. RESULT

Table 7 and Table 8 show that concentration of 2,7-NDSA and PFC are below limit in all production well. So, it can be assumed there are no tracer fluids that flows from reinjection well to production well. After six months of studies, it has become evident that there is no connectivity between the injection and production wells.

Table 7. Monitoring results for Tracer 2,7-NDSA

Well	Date	Time	mg/kg
KRH-A.1	02-Jun-22	08:31	<0.0002
TLG-C.1	02-Jun-22	09:31	<0.0002
TLG-C.2	02-Jun-22	10:19	<0.0002
TLG-C.3	02-Jun-22	10:40	<0.0002

Table 8. Monitoring result for Tracer PFC

Well	Date	Time	mg/kg
KRH-B.1	19-May-2022	09:49	<9.35E-05

KRH-A.1	19-May-2022	11:22	<1.48E-04
TLG-C.1	19-May-2022	12:39	<7.88E-05
TLG-C.2	19-May-2022	13:23	<2.21E-04
TLG-C.3	19-May-2022	14:21	<2.36E-04

3. CONCLUSION

From all tests and studies that had been done for Karaha, it can be concluded that production wells in Karaha Geothermal Field have no support from reinjection well. This statement is based on Geophysics monitoring studies as well as Tracer Reservoir Test.

Tracer results also underline the absence of a structured path towards production wells or the presence of poor permeability due to the patchy structure, which is a contributing factor to the significant decline in output.

To address this challenge, a modification in the injection strategy is imperative, involving the addition of the injection wells KRH-A.3 & KRH-B.3.

DISCLAIMER

In this paper, the wells name is not the real name due to confidentiality.

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