JOURNAL OF PETROLEUM AND GEOTHERMAL TECHNOLOGY
ISSN: 2723-0988, e-ISSN: 2723-1496
Vol. 7 No. 1 2026

Analysis of Geothermal Well 'X' Productivity at Kamojang Using PTS Survey Before and After Broaching Method

Bima Aditya Octavian [1*)], Riska Laksmita Sari [2)]
[1]Petroleum Engineering, Universitas Jember
[2]Operation, PT Pertamina Geothermal Energy Area Kamojang – Samarang Garut, Laksana, Kec. Ibun, Kabupaten Bandung, Jawa Barat, 40384, Indonesia
*corresponding email: riskalaksmita@unej.ac.id

ABSTRACT

The decline in geothermal well performance remains one of the most persistent challenges in sustaining steam supply within vapor-dominated fields. Well X in the Kamojang Geothermal Field experienced a significant productivity drop caused by severe wellbore constriction due to composite scale consisting of silica minerals (Quartz and Tridymite) and iron oxides (Magnetite and Hematite). This study evaluates the effectiveness of the broaching method in restoring well deliverability through comparative analysis of Pressure-Temperature-Spinner (PTS) surveys conducted before and after intervention. PTS profiles were used to identify feedzone contributions, diameter reduction, fluid velocity anomalies, thermodynamic behavior, and mass flow degradation. Steam-table-based calculations were applied to determine fluid density and mass flow rate, followed by computation of the Productivity Index (PI). The results show that scale accumulation reduced the effective wellbore diameter from 0.32 m to 0.16 m, lowering mass flow from 3.56 kg/s to 1.77 kg/s and decreasing PI to 0.09 kg/s/bar. Mechanical broaching successfully removed the composite scale, restoring the diameter to 0.32 m, increasing mass flow to 3.56 kg/s, and improving PI to 0.31 kg/s/bar—equivalent to a 240% enhancement. The findings confirm that broaching is an efficient, low-cost intervention capable of recovering lost productivity without requiring chemical stimulation or drilling a new well, offering significant operational and economic benefits for geothermal field management.

Keywords: geothermal well; pressure-temperature-spinner (pts) survey; scale deposition; broaching method; productivity index (pi); mass flowrate

I. INTRODUCTION

Geothermal energy plays a strategic role in supporting Indonesia's transition toward sustainable and low-carbon power generation. The Kamojang Geothermal Field, operated by PT Pertamina Geothermal Energy, is one of the oldest and most mature vapor-dominated reservoirs in the world, producing electricity commercially since 1983. Long-term production from such high-enthalpy systems often faces operational challenges, particularly the decline in well deliverability caused by scale deposition, wellbore constriction, and reservoir pressure changes. Scale deposition is consistently reported as one of the most critical factors affecting geothermal well performance, as it alters wellbore geometry, reduces mass flow, and increases frictional pressure losses, ultimately lowering productivity.

In Well X of the Kamojang Geothermal Field, a significant decline in performance was observed, marked by reductions in wellhead pressure, temperature, and mass flowrate. Comparative analysis of Pressure-Temperature-Spinner (PTS) surveys revealed abnormalities in fluid velocity profiles and feedzone contributions, suggesting the presence of severe wellbore constriction. Subsequent sampling and laboratory analysis confirmed that the scale consisted of silica minerals Quartz and Tridymite and iron oxides such as Magnetite and Hematite, forming a composite scale that is difficult to treat using conventional chemical methods. These deposits reduced the effective wellbore diameter from 0.32 m to 0.16 m, resulting in more than a 40% drop in mass flowrate.

To restore well deliverability, a mechanical intervention using the broaching method was selected. Broaching is widely recognized as an effective technique for removing hard and complex scale in high-temperature geothermal wells because it physically scrapes and dislodges deposits regardless of mineral composition. Unlike chemical stimulation, broaching poses minimal risk to casing integrity and provides cost-efficient restoration without requiring drilling of a new well. However, quantitative evaluations of broaching effectiveness particularly through PTS-based assessment and Productivity Index (PI) calculation are still limited in published geothermal research.

This study aims to (1) analyze the mechanism and impact of scale formation on the productivity decline of Well X, (2) evaluate changes in well characteristics before and after the broaching intervention using comparative PTS surveys, and (3) quantify productivity improvements by calculating the Productivity Index. The findings provide practical insight into diagnosing scale-related problems and demonstrate the technical and economic value of broaching as a highly effective intervention for restoring lost productivity in vapor-dominated geothermal wells.

II. METHODS

This study was conducted on Well X in the Kamojang Geothermal Field, located within the Kamojang–Darajat geothermal working area in West Java, Indonesia. The research workflow consisted of four primary stages: data acquisition, diagnostic analysis, mechanical intervention, and post-intervention evaluation.

1. Data Acquisition
   The primary datasets used in this study include:
   - Pressure-Temperature-Spinner (PTS) surveys conducted during three operating conditions:
     (a) baseline (optimal production)
     (b) post-decline (after productivity drop)
     (c) post-broaching.
   - Static pressure logs for determining reservoir pressure.
   - Scale samples retrieved using a scale catcher at targeted depths identified from PTS anomalies.
   - Laboratory X-Ray Diffraction (XRD) results for mineralogical identification of scale composition. All raw data were sourced from PT Pertamina Geothermal Energy's field measurements.
2. PTS Interpretation and Feedzone Diagnosis PTS data were analyzed to determine:
   - pressure and temperature gradients along the wellbore
   - spinner frequency, used to compute fluid velocity
   - feedzone depth and individual contribution to total mass flow
   - anomalies in spinner response indicative of wellbore constriction.

   Fluid velocity v v was calculated by calibrating spinner frequency f f using slope analysis obtained from regression between spinner rotation and cable speed. Multiple logging modes (LU30, LD30, LU45, LD45) were averaged to minimize directional bias.

3. Scale Characterization Scale samples collected at depths 1659 m and 2802.61 m were analyzed through XRD to determine dominant mineral phases. The analysis identified silica polymorphs (Quartz, Tridymite) and iron oxides (Magnetite, Hematite), forming a composite scale responsible for severe wellbore narrowing. These results guided the selection of broaching as the mechanical remediation method.
4. Broaching Intervention A mechanical broaching tool was deployed to physically remove scale from the wellbore. The tool's high-pressure jetting and abrasive cutting beads were used to scrape and dislodge deposits adhering to the casing and open-hole sections. Broaching was executed selectively at depths identified from PTS diagnostics to restore the effective wellbore diameter.
5. Post-Broaching Evaluation
   A repeat PTS survey was performed after broaching to evaluate improvements in:
   - wellbore diameter
   - fluid velocity profile
   - feedzone reactivation
   - temperature and pressure gradients.

   Fluid density was determined using steam-table thermodynamic properties corresponding to measured PTS conditions. Mass flowrate $\dot{m}$ m ˙ was calculated using cross-sectional area and density, while Productivity Index (PI) was computed using reservoir static pressure and flowing wellhead pressure.

6. Quantitative Comparison All pre- and post-intervention parameters including diameter, density, mass flowrate, spinner velocity, and PI were tabulated for direct comparison. Improvements were benchmarked against historical Kamojang field performance and referenced against industry cases involving broaching interventions in high-enthalpy geothermal wells.

The research stage flowchart is shown in (Figure 1).

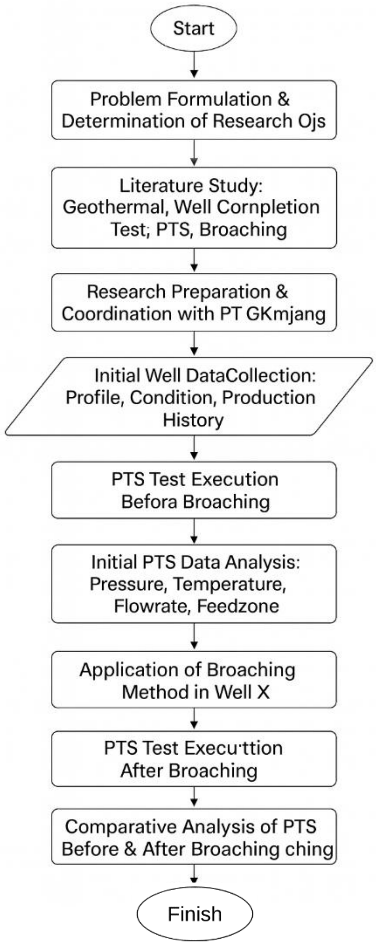

Figure 1. Research Stage Flowchart

III. RESULTS AND DISCUSSION

The analysis of the Pressure-Temperature-Spinner (PTS) datasets collected before and after the broaching intervention provides a comprehensive understanding of the mechanisms behind the productivity decline of Well X and the effectiveness of the mechanical remediation. The comparative behavior of temperature, pressure, spinner velocity, and mass flowrate across multiple logging runs reveals clear differences in wellbore hydrodynamics and feedzone performance. These differences form the basis of the conclusions regarding the well's degraded condition and subsequent recovery.

In the pre-broaching state, the PTS temperature profile showed several anomalous drops at depths around 450 m, 920 m, 1320 m, and 1650 m. These anomalies indicate zones where the natural thermal continuity of the wellbore was disrupted, consistent with the presence of scale acting as an insulating layer. Spinner profiles supported this diagnosis: despite the declining production at surface, the spinner velocity increased sharply in constricted sections. This pattern is characteristic of wellbore narrowing fluid velocity increases due to reduced cross-sectional area even though mass flow decreases. Such a contradiction between velocity and production metrics is a diagnostic hallmark of scale deposition in geothermal wells.

The X-Ray Diffraction (XRD) analyses confirmed that the scale consisted of hard silica polymorphs (Quartz and Tridymite) combined with iron oxides (Magnetite and Hematite). This composite scale significantly reduced the effective wellbore diameter from 0.32 m to 0.16 m, doubling frictional pressure losses and impairing the contribution of key feedzones. With 40–50% reduction in mass flowrate and a dramatic fall in flowing pressure, the well's deliverability was severely compromised.

To quantitatively interpret the PTS readings and substantiate the diagnosis, a series of calculations were performed. Spinner frequency was converted into fluid velocity using a calibrated slope value obtained from multiple logging modes. The general formulation used throughout the interpretation is summarized in Equation 1, which expresses the linear relationship between spinner rotation and fluid velocity. This method ensures that cable-speed bias is minimized and that the computed velocity reflects actual downhole flow conditions. The calculated velocity values were then combined with wellbore cross-sectional area and fluid density (derived from steam tables at corresponding pressure–temperature points) to estimate mass flowrate for each depth interval.

3.3. Post-Broaching Performance Recovery

A PTS survey performed after broaching showed significant improvement across all parameters:

- Wellbore diameter restored from 0.16 m → 0.32 m
- Flowing pressure increased from 9.94 bar → 18.44 bar
- Temperature in primary feedzone rose from 181.92°C → 209.75°C
- Mass flowrate doubled from 1.77 kg/s → 3.56 kg/s
- Spinner velocity normalized, indicating restored cross-sectional area

These changes demonstrate that broaching successfully removed the scale and restored hydrodynamic continuity within the wellbore.

3.4. Equations

The first step is identifying the feedzones, which are the depths where reservoir fluid effectively enters the wellbore. Feedzones are typically recognized by distinct temperature anomalies sharp increases or changes in the temperature gradient caused by the inflow of hotter reservoir fluid. The next step is determining fluid velocity using spinner rotation frequency. The spinner frequency is converted into actual fluid velocity using Equation 1:

$$v = a \times f + b$$

where v is fluid velocity (m/s), f is spinner frequency (Hz), and a and b represent the slope and cable-speed correction, respectively. Fluid velocity is then used to calculate the mass flowrate. The wellbore cross-sectional area is obtained using Equation 2:

$$A = \pi \times r^2$$

where A is the internal flow area (m²). Combined with fluid density ρ, obtained from steam tables at the corresponding pressure–temperature conditions, mass flowrate is calculated using Equation 3:

$$W = \rho \times A \times v$$

This mass flowrate represents the amount of fluid entering the well per second. It is then used to determine the Productivity Index (PI), calculated using reservoir static pressure Ps and flowing pressure Pw, as shown in Equation 4:

$$PI = \frac{W}{Ps - Pw}$$

Based on the equations above, the mass flowrate prior to broaching was calculated to be 1.77 kg/s, whereas after broaching it increased significantly to 3.56 kg/s. This doubling of mass flow, despite similar reservoir conditions, indicates that the intervention successfully restored hydraulic continuity in the wellbore. Flowing pressure also increased from 9.94 bar before broaching to 18.44 bar afterward, reflecting decreased frictional losses and improved connectivity to the reservoir. Temperature profiles after broaching displayed smooth gradients throughout the wellbore, with the elimination of all previously observed temperature drops. The main feedzone at 1550–1650 m showed the most substantial recovery, with temperature rising from 181.92°C to 209.75°C and mass flow contribution increasing by more than 100%. The second feedzone also exhibited improved contribution, rising from 0.09 kg/s to 0.12 kg/s. The overall improvement is most clearly expressed through the Productivity Index (PI), which increased from 0.09 kg/s/bar to 0.31 kg/s/bar and a 240% enhancement. This remarkable increase confirms that broaching effectively removed the composite scale and reinstated the well’s ability to transmit fluid efficiently. Such recovery aligns with trends reported in recent geothermal literature, where mechanical interventions outperform chemical stimulation in cases of silica-rich scaling.

3.5. Tables and Figures

Figure 2 illustrates the baseline PTS profile of Well X under optimal production conditions. Two major feedzones are clearly identifiable from the temperature gradient changes and spinner velocity peaks at depths of 1550–1650 m and 2000–2300 m. The smooth decline in pressure and stable temperature profile indicate an unobstructed wellbore and efficient reservoir inflow. This baseline serves as a reference for interpreting the subsequent productivity decline.

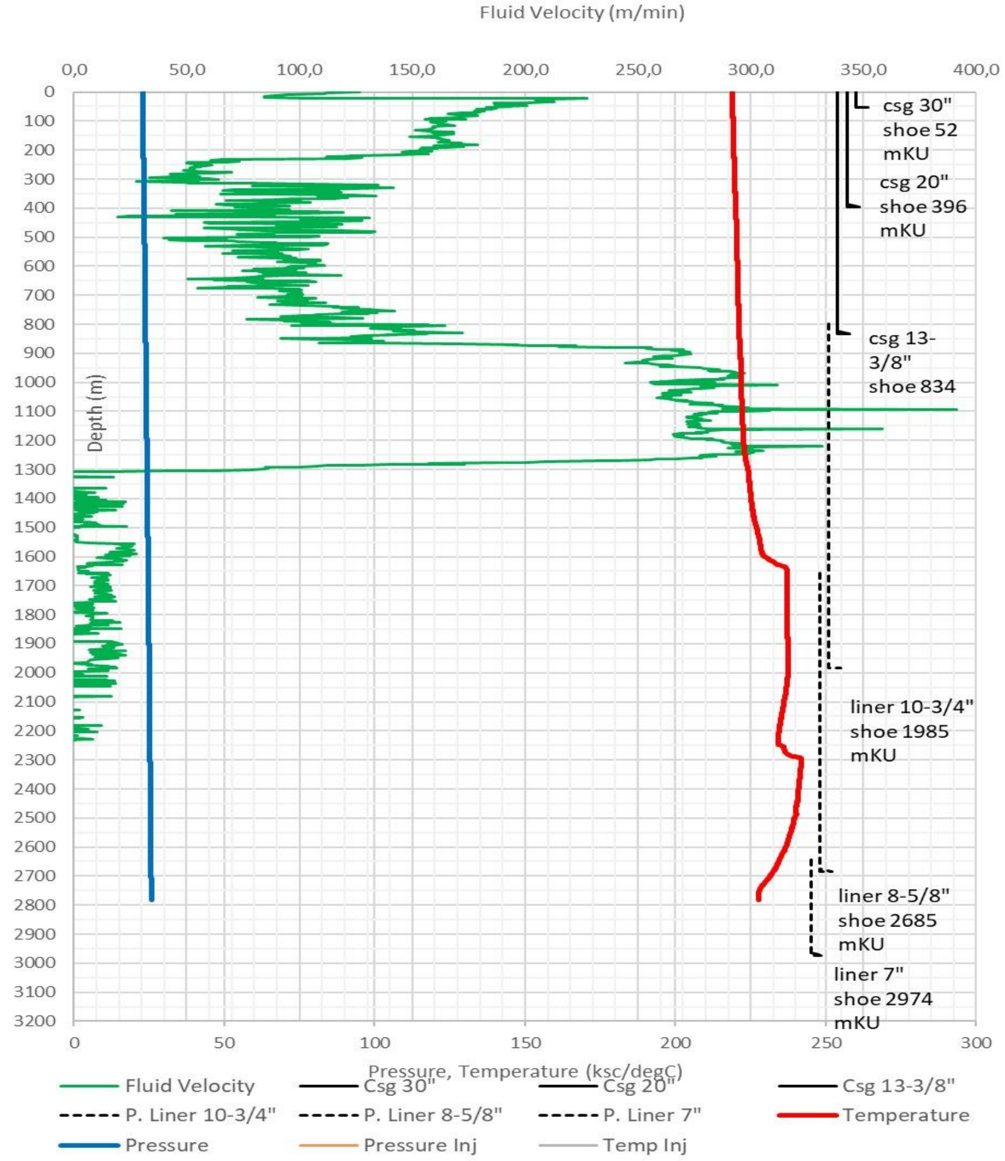

Figure 2. Optimal PTS Profile

Figure 3 shows the PTS profile after the onset of productivity decline. Unlike the baseline, spinner readings exhibit abnormally high velocities particularly in the upper casing and feedzones indicating significant wellbore constriction. Temperature anomalies appear at several depths (450 m, 920 m, 1320 m, and 1650 m), consistent with thermal insulation caused by scale buildup. Flowing pressure also drops sharply, confirming hydraulic impairment. These patterns collectively demonstrate that scale deposition severely restricted fluid flow into and along the wellbore.

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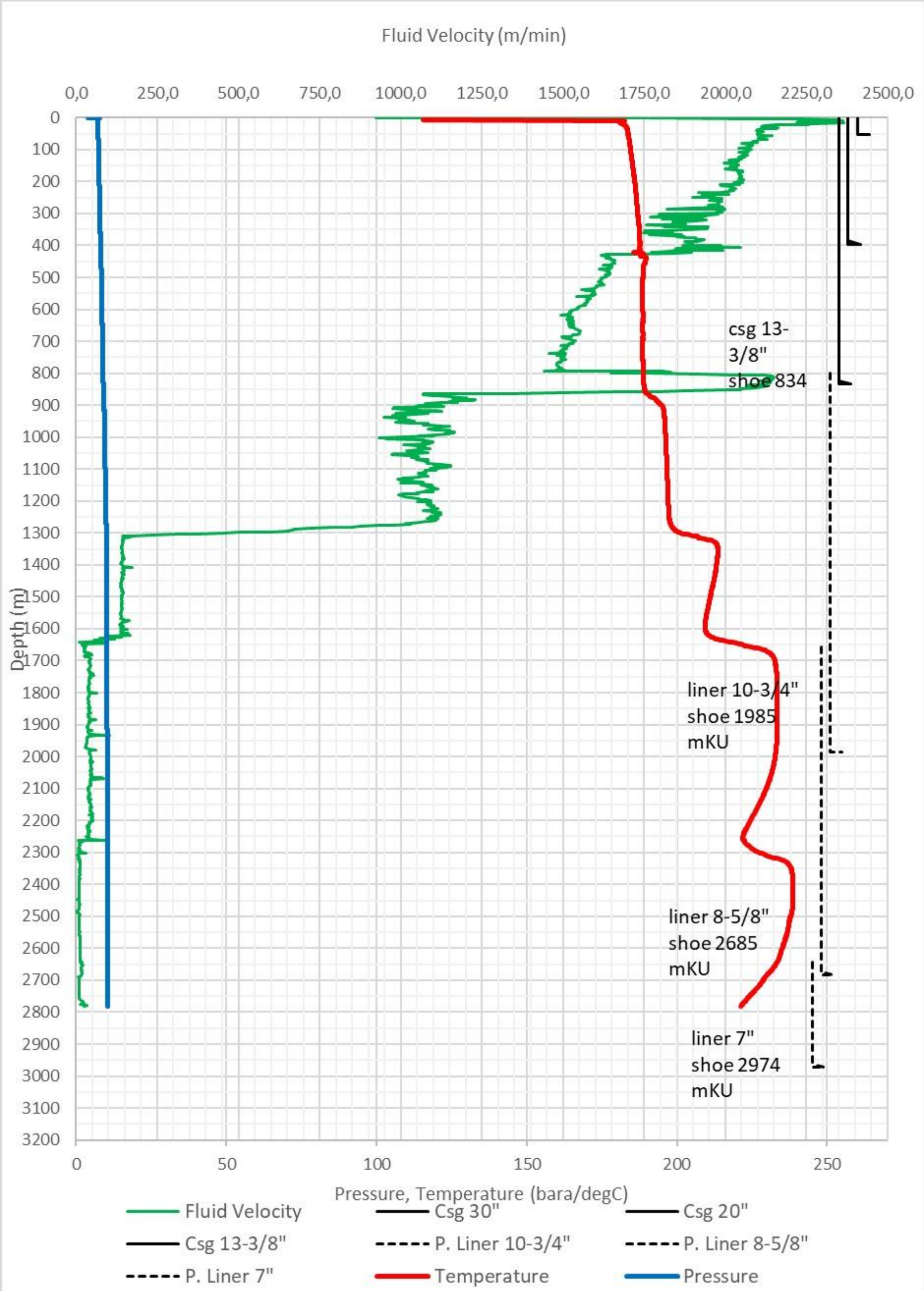

Figure 3. Pre-broaching PTS Profile

Figure 4 presents the PTS profile after the broaching intervention. The spinner velocities normalize significantly, indicating restoration of the effective wellbore diameter from 0.16 m back to 0.32 m. Temperature gradients along the entire wellbore become smooth and consistent, confirming the removal of insulating scale deposits. Flowing pressure increases almost twofold, and feedzone contributions return to levels consistent with the baseline survey. These improvements validate broaching as an effective mechanical method for removing composite silica–iron oxide scaling.

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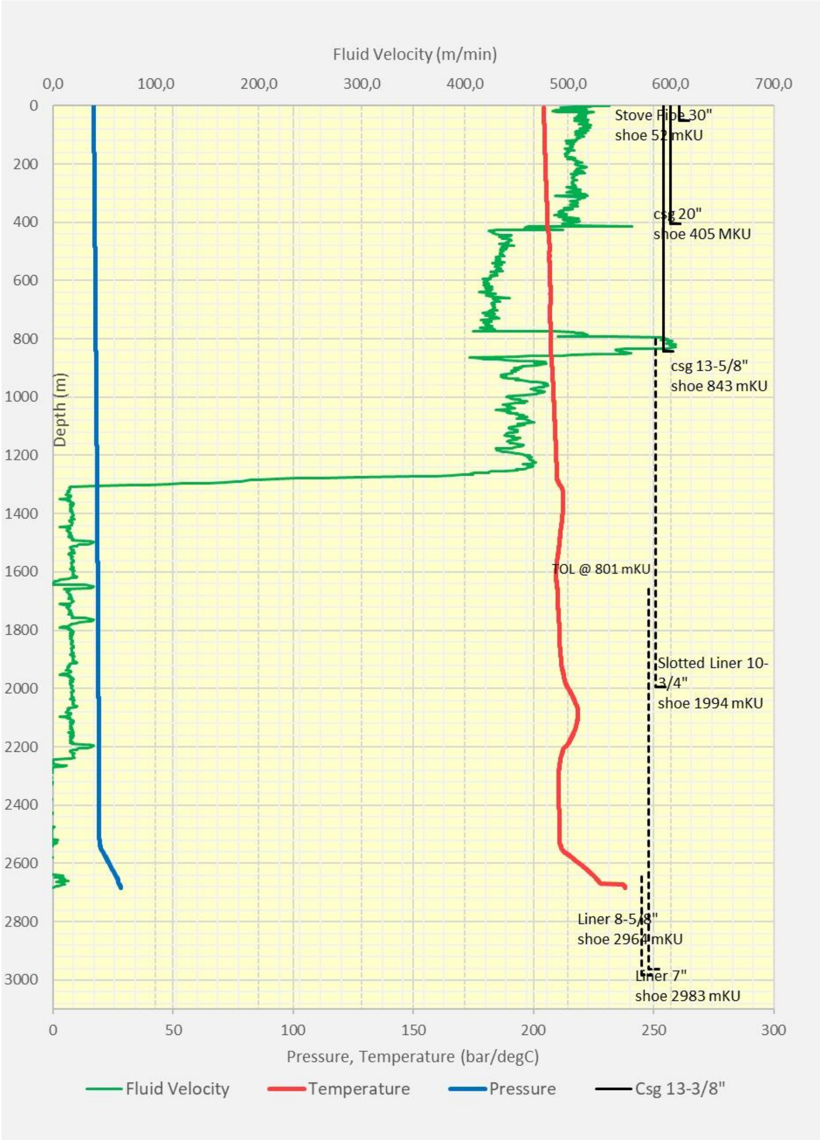

Figure 4. Post-broaching PTS Profile

To quantify the impact of scale accumulation and evaluate the effectiveness of the broaching intervention, a series of analytical calculations were performed using PTS-derived parameters. These calculations include determining fluid velocity, wellbore flow area, mass flowrate, and ultimately the Productivity Index (PI). Each variable is obtained through step-wise interpretation of spinner readings, temperature–pressure data, and thermodynamic properties from steam tables. The following equations summarize the computational framework used to convert raw PTS measurements into quantitative performance indicators for Well X.

Table 1. Summary of Well Parameters Before and After Broaching

Parameter	Pre-broaching	Post-broaching	Change (%)
Fluid Velocity, m/min	1111.24	456.56	-58.91
Diameter, m	0.16	0.32	100.00
Density, kg/m³	7.46	9.32	24.93
Total Well Mass Flow, kg/s	1.77	3.56	101.13

Parameter	Pre-broaching	Post-broaching	Change (%)
First Feedzone Mass Flow, kg/s	1.68	3.44	104.76
First Feedzone Contribution, %	98.82	96.63	-2.22
First Feedzone Temperature, °C	181.92	209.75	15.30
Second Feedzone Mass Flow, kg/s	0.09	0.12	30.00
Second Feedzone Contribution, %	1.18	3.37	185.59
Second Feedzone Temperature, °C	211.53	218.49	3.29
Static Pressure, bara	30.00	30.00	0.00
Flowing Pressure, bara	9.94	18.44	85.51
PI Wellhead	0.09	0.31	240.00

IV. CONCLUSION

This study demonstrates that the productivity decline of Well X in the Kamojang Geothermal Field was primarily caused by severe wellbore constriction resulting from composite scale composed of silica polymorphs (Quartz and Tridymite) and iron oxides (Magnetite and Hematite). PTS diagnostics revealed significant reductions in temperature, flowing pressure, and mass flowrate, confirming impaired feedzone performance and restricted hydraulic conductivity.

The mechanical broaching intervention proved highly effective in removing scale deposits and restoring wellbore geometry. Post-intervention PTS surveys showed substantial improvements across all operational parameters: the effective diameter returned from 0.16 m to 0.32 m, mass flowrate increased from 1.77 kg/s to 3.56 kg/s, and flowing pressure nearly doubled. The Productivity Index (PI) rose from 0.09 to 0.31 kg/s/bar, indicating a 240% enhancement in well deliverability.

These results confirm that broaching is a reliable, economically efficient method for recovering lost productivity in vapor-dominated geothermal wells, especially when scale composition is resistant to chemical dissolution. Routine PTS monitoring and timely mechanical intervention are recommended to sustain long-term well performance and optimize geothermal field operations.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to PT Pertamina Geothermal Energy, Area Kamojang, for providing access to field data, operational support, and permission to conduct the PTS surveys and broaching evaluation used in this study. Special thanks are extended to the Kamojang Field Operations and Laboratory Testing Unit for facilitating the acquisition of XRD results and supporting the scale sampling process. The authors also acknowledge the valuable contributions of the technical personnel and field respondents whose cooperation made the data collection and analysis possible. Their support was essential to the successful completion of this research.

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