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Comprehensive Approach in Geothermal Drilling and Workover to Address Cementing Uncertainties and Well Integrity Challenges Using Metal Expandable Packers

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ABSTRACT

The design and construction of wells in low-pH fields present several challenges, as extreme conditions can compromise well integrity throughout the well's operational life. According to Phi et al. (2019), maximizing steam recovery in geothermal development requires well designs that preserve integrity and prevent operational and environmental risks, which also affect energy costs. Geothermal energy is a valuable renewable resource, but drilling and maintaining wells remain costly and technically demanding. According to Phi et al. (2019), maximizing steam recovery in geothermal development requires well designs that preserve integrity and prevent operational and environmental risks, which also affect energy costs. The design and construction of wells in low-pH fields present several challenges, as extreme conditions can compromise well integrity throughout the well's operational life. In the Philippines, many geothermal wells operate in low pH environments with pH levels around 3, resulting in rapid corrosion and frequent well integrity issues. These challenges, combined with complex geological formations, significantly increase drilling and workover costs. The absence of effective, durable well completion technologies further complicates these operations. This paper investigates the use of high-temperature, corrosion-resistant Metal Expandable Packers (MEPs) as a solution to improve well integrity and reduce maintenance expenses in such harsh environments. The study presents an innovative MEP design used alongside a reline/tieback casing string, demonstrating how it optimized workover operations while preventing further damage to liners. The solution also achieved improved cementing quality and control by providing a pressure-tight annular seal that prevents fluid migration, while its self-centralizing capability ensures even cement distribution around the casing, thereby restoring integrity to previously compromised wells. The improved functionality of the MEP technology not only reduces lifecycle costs but also offers significant operational benefits by minimizing constraints and complexity in geothermal well interventions.

1 INTRODUCTION

Geothermal drilling operations face unique and persistent challenges that differentiate them from conventional hydrocarbon well construction and workovers, particularly in environments where subsurface conditions are both thermally and chemically aggressive (Visser et al., 2018). The long-term performance of wells in such fields is frequently undermined by accelerated material degradation driven by aggressive fluid chemistries (high chloride, CO_2, H_2S, low pH) and steep temperature–pressure gradients that promote both corrosion and scaling (Nogara, 2018).These hostile conditions demand thermally resilient tubulars and completion systems, careful selection of corrosion-resistant alloys or protective coatings, and active monitoring and mitigation to preserve integrity over the well's operational life (Penot et al., 2023).

In conventional geothermal systems, such as those commonly encountered across Southeast Asia including the Philippines, well failures are frequently linked to corrosive geochemistry and unstable geological formations, (Marbun, et al., 2019). These factors complicate both initial well construction and later-stage workover activities, significantly impacting operational efficiency and cost-effectiveness. Standard well construction and workover methods, largely derived from oil and gas technologies and practices, often fall short under these more extreme geothermal conditions, resulting in premature component failure and reduced asset longevity (Kruszewski and Wittig, 2018).

This study investigated well engineering strategies to address persistent failure modes, specifically with regards to cementing and relining of wells in aggressive geothermal systems with pH level of less than four. The study focused on improving well integrity and prolonging the lifespan of a well through optimized material and technology selection, and system design.

The paper presents case stories in four production and two injection wells in the Philippines that benefited from engineered solutions tailored specifically for geothermal wells which aimed to enhance reliability and economic viability in high-risk geothermal developments.

2 SCOPE AND DELIMITATION OF THE STUDY

This study focused on the relining activities conducted in the Leyte Geothermal Field operated by Energy Development Corporation (EDC). It covers wells that:

1. Exhibit acidic or low pH conditions (pH < 4.5) and mature wells at the time of relining, or
2. Are neutral wells with non-critical casing integrity, which are also included within the study scope.

The research aimed to evaluate the operational and economic advantages of using the Metal Expandable Packer (MEP) system compared to conventional relining methods under specific well conditions. Data were obtained from existing databases and Workover End-of-Well Reports (EOWR) of Energy Development Corporation (EDC), which provided relevant operational parameters, cost information, and performance results.

Despite efforts to ensure data accuracy and analytical reliability, the study is subject to certain limitations. The analysis was focused solely on wells relined from 2015 to the present, primarily due to data availability and completeness constraints. Differences in cementing practices, including the use of various cement slurry formulations, such as but not limited to acid-resistant and basic slurries, may affect the comparability of results between relining methods and performance over the life of the well.

Furthermore, the absence of post-relining cement bond log (CBL) limits the ability to directly assess cement homogeneity and bonding integrity across cases. Lastly, cost data were normalized to current rates to account for inflation and pricing changes over time. However, it is worth noting that these adjustments may not fully reflect historical cost conditions.

3 METHODOLOGY

3.1 Field and Wells Overview

The study areas are located within two geothermal fields operated by Energy Development Corporation (EDC), both characterized by complex subsurface geology consisting of interbedded volcanic, sedimentary, and intrusive rock formations. These varied lithologies contribute to differences in wellbore behavior, fluid movement, and casing performance over the life of the wells (Runcimann and Zahacy, 2021).

Within these sites, several wells exhibit acidic characteristics with measured fluid pH values below 4.5, indicating corrosive downhole environments that accelerate casing deterioration and scaling. Conversely, other wells maintain neutral conditions, reflecting more stable geochemical settings with reduced corrosion potential. This contrast in chemical environments provides a robust basis for comparative assessment.

3.2 Review of Casing Failure

Field data were collected from a set of geothermal wells across three fields in the Philippines, selected based on their exposure to extreme downhole conditions specifically, fluid pH levels of less than three and formation temperatures exceeding 250 °C.

End-of-Well Reports, and failure analyses were reviewed in conjunction with historical workover logs to identify trends and failure modes correlated with operational and environmental impact. Only wells with complete construction and workover datasets post-2012 were included to ensure compatibility with current material and operational standards.

Persistent operational challenges observed in high-temperature, corrosive geothermal wells were investigated to address the casing failures and mitigate the premature failure thereafter. These include accelerated degradation of casing materials, the development of wellbore irregularities resulting from corrosion and annular pressure build-up, and frequent integrity failures that lead to repeated and costly workovers. The analysis further considers the current limitations in available drilling technologies, particularly the lack of thermally and chemically robust systems capable of sustaining long-term well integrity under extreme geothermal conditions.

Detailed in Figure 1 is the downhole image of the casing failure that occurred in one of the wells that resulted in an urgent need for a workover.

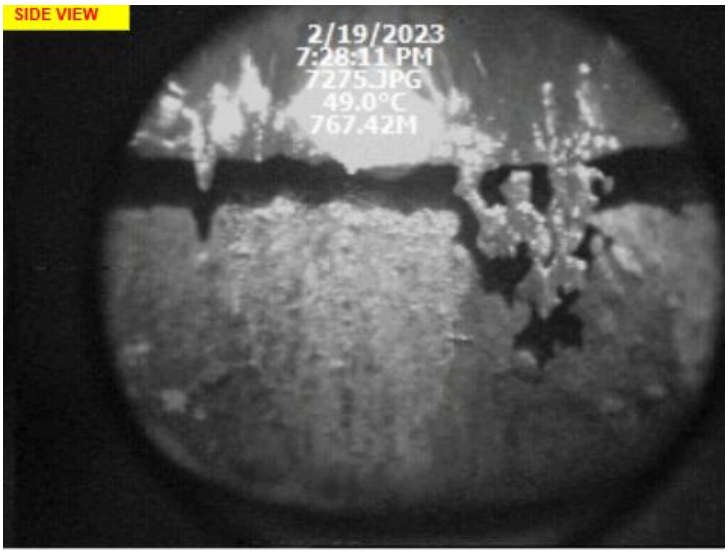


Figure 1. Downhole image of a well that exhibited premature failure

The subject well was drilled in 2021 and subsequently cut-in in a year after following the completion of drilling activities for its adjacent well. Initial discharge operations were delayed due to leak incidents encountered during early flow attempts, necessitating temporary shutdown and corrective repairs.

Within four days after the initial cut-in, the well exhibited elevated total suspended solids (TSS), indicative of possible scaling, corrosion product mobilization, or liner deterioration. The well was re-cut in approximately two weeks later, but was again cut out after recurrent leak incidents were detected at multiple locations, including branchline connections and stub-in points, suggesting systemic integrity issues.

A subsequent go-devil survey conducted in May 2022 identified anomalies between 768 mMD to 792 mMD, accompanied by carbon steel debris lodged in the top valve assembly. These findings confirm the onset of casing damage as early as one month after the initial production cut-in of the well. Based on the preliminary assessment conducted, the early casing degradation is attributed to the absence of a comprehensive hazard analysis and mitigation plan for the well's high output, low water fraction, and the low-pH nature of the produced fluids.

3.3 Conventional and Optimized Workover Strategies

The conventional workover design previously being utilized for addressing casing integrity issues that require relining involves the use of a cemented reline casing or tieback string. These compromised casings are particularly seen in the 9-⅝" production casing for regular wells and the 13-⅜" casing in big-hole configurations

This method of workover detailed in Figure 2 typically employs a drillable bridge plug, set just above or near the top of the existing liner, to serve as a temporary mechanical barrier during the relining and cementing operation. Once cement placement is complete, the cement and the plug must be drilled out to regain access to the production interval. While this technique has been widely adopted in Southeast Asia, it presents inherent risks, especially in wells exposed to harsh geothermal conditions such as corrosive fluids, high thermal gradients, and mechanical fatigue. The non-retrievable nature of the bridge plug, combined with the need for debris removal following drill-out, increases the potential for damaging already compromised liner sections. Additionally, incomplete debris clearance or mechanical interference with the liner can lead to inefficient production and/or injection, extended non-productive time (NPT), and increased likelihood of subsequent well failure. Despite its widespread use, this conventional method may be suboptimal in environments where casing and liner integrity are already severely degraded.

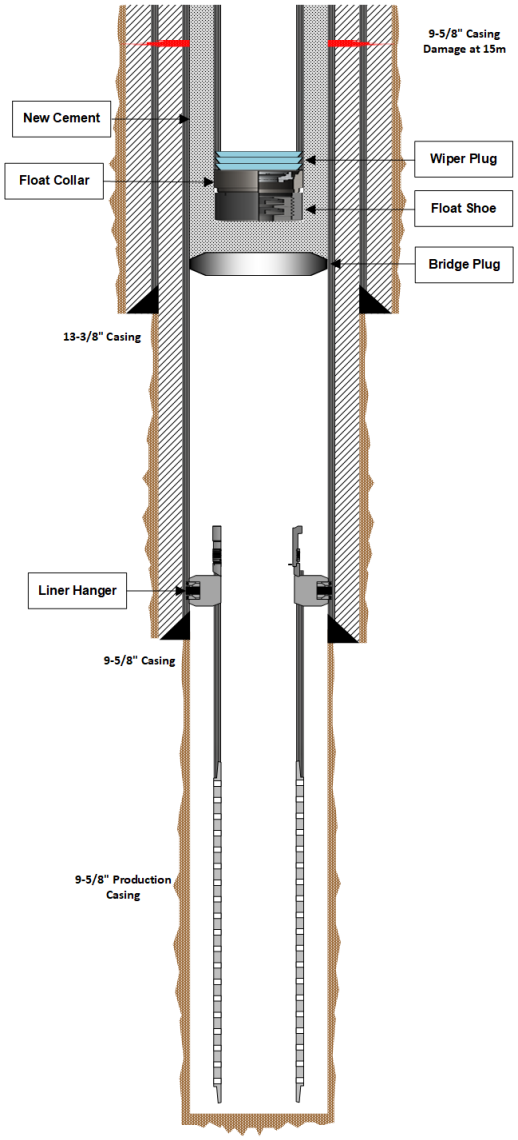


Figure 2. Relining damaged 9-⅝" production casing using drillable bridge plug

The wells were designed to have a 9-⅝" reline casing with the shoe set at either on top or inside the top of liner to regain the integrity of the wells which were compromised due to severe casing corrosion and degradation. Each well utilized a Metal Expandable Packer (MEP) technology shown in Figure 3 specifically designed for geothermal conditions.

In contrast to conventional isolation barriers, such as bridge plugs, the MEP utilizes a hydraulically activated metal sleeve that is integrated with the casing or liner, enabling the formation of instantaneous permanent annular seal upon activation. Its design permits full rotation and circulation during deployment, thereby accommodating one of the challenges in relining the geothermal wells where casing oftentimes had to be rotated to align with the wellbore and allow passage to casing bulge or entry to parted casing. This capability facilitated precise placement and extended reach without the risk of unintentional setting which was deemed as an essential feature for complex well trajectories and re-entry operations.

Taking into account the life of the wells of EDC, the MEPs were tested and qualified in accordance to ISO14310 qualification criteria to ensure that the packer will be able to handle the thermal swings and annular pressure build-up in the event that a trapped fluid is present in casing-to-casing annulus.

To optimize cement placement and ensure address cementing uncertainties, a two-stage cementing port collar is integrated into the reline casing and strategically placed above the MEP. This configuration improves displacement efficiency and facilitates staged cement injection in complex well geometries. With the capability of MEP to provide a V0 seal in cased hole, the risk of cement contamination from reservoir fluids was eliminated.

However, simulations conducted during the design phase identified a critical risk of annular fluid entrapment between the cement port collar and the MEP. Under geothermal operating conditions characterized by high thermal gradients, thermal expansion of this trapped fluid can generate significant annular pressure, potentially imposing mechanical loads on the reline casing that exceed safe operating limits.

To address this risk, pressure-activated rupture disks are installed in the annular section between the MEP and the cement port collar as well as in the valve itself of the MEP. These devices function as engineered pressure relief mechanisms, designed to activate at predefined thresholds, thereby maintaining annular pressure equilibrium during thermal transients. This design enhancement mitigates the risk of casing deformation or failure and enhances the overall integrity and reliability of the relining system under cyclic geothermal loading conditions.

This approach, intended for deployment, also eliminates the reliance on extended liner laps, which were previously employed primarily to limit reline depths to what was considered the practical minimum at 700m to 800m. The integrated pressure compensation system of the MEP enables it to accommodate high differential pressure loads across a broad depth range from 1,000mTVD to 2,200mTVD. This capability ensures reliable sealing performance under elevated geothermal pressure regimes, where conventional packer systems may be prone to failure due to pressure imbalance or thermal expansion effects, all while maintaining its temperature rating of up to 330°C.

Detailed in Figure 3 is the optimized well design for relining 13-⅜” production casing using 9-⅝” reline.

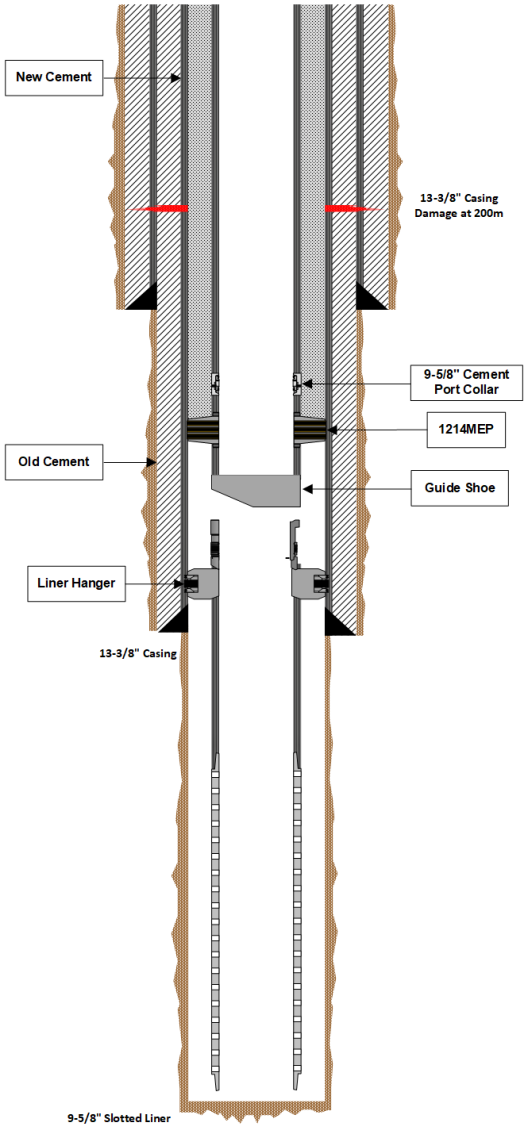


Figure 3. Relining damaged 13-⅜" production casing utilizing bespoke Metal Expandable Packer (MEP) for geothermal wells

3.4 Pre-Intervention Diagnostics and Well Integrity Assessment

For wells with prolonged exposure to aggressive downhole chemistries such as high-chloride geothermal fluids, elevated temperatures, abrasive formation fluid fluids, and acidic or low pH conditions, comprehensive well integrity diagnostics were performed to assess the suitability of deploying MEP as a relining solution.

Multi-arm caliper logging was conducted to generate high-resolution profiles of the internal casing geometry. This included detection and quantification of casing ovality, internal diameter restrictions, wall thinning, and scale deposition to determine the minimum setting pressure and accurately pinpoint the ideal setting depth of the MEP to avoid any potential risk of channeling behind the host casing, bypassing the sealing element. A retrievable packer was also deployed during pre-relining operations to facilitate pressure testing for potential casing leaks and to enable targeted squeeze cementing, where necessary. This proactive isolation and remediation approach ensured restoration of pressure integrity prior to the relining phase, thereby eliminating the need for a top job following liner installation. By addressing potential leak paths in advance, this method optimized cement placement efficiency during reline cementing and minimized the risk of post-job remedial interventions.

These diagnostics were critical in confirming the mechanical integrity of the host casing and in determining optimal setting depths for MEP installation. This process was applied across both regular(9-5/8") and large-diameter (13-3/8") production casing strings to ensure that the relining solution could be effectively integrated within legacy well architectures.

It is important to note, however, that the MEP design allows it to compensate for ovality and out-of-gauge sections, restoring annular isolation without the need for extensive cement remediation. In addition, its ability to seal across irregular profiles enables effective isolation and sealing while maintaining full bore internal diameter (ID).

3.5 Deployment of 1214MEP and 812MEP in Production and Injection Wells

Following several months of technical reviews and detailed operational planning, the first deployment of the reline and expandable packer system commenced in the Philippines. Since initiation, a total of six wells comprising four production and two injection wells have been successfully worked over. All production wells are located in the Mahanagdong Sector in Leyte Island, while the two injection wells are distributed across two separate geothermal fields on different islands within the Philippines.

The production wells employed the 1214MEP configuration, wherein the 1214MEP was mounted on a 9-⅝" casing and set inside a 13-⅜" host casing. This design also allows deployment in 12-¼" open hole sections, providing operational flexibility. For the injection wells, the 812MEP used was mounted on a 7" casing and set inside a 9-5/8" casing. This has the capability to be deployed in an 8-½" open hole when required. These configurations were selected to match the specific geometries, deterioration profiles, and operational objectives of each well.

All wells exhibited significant casing degradation based on the casing diagnostics performed, including advanced internal corrosion, erosion, parted tubulars, and localized collapses. To address these complex failure modes, each MEP sub-assembly included handling pups, a two-stage cement port collar, and the MEP itself. Each component was carefully measured and spaced out to ensure accurate placement at the designated setting depth. Precision in depth placement was critical, as minor deviations could result in ineffective sealing, especially in highly damaged sections where crossflow or fluid migration across the 13-3/8" and 9-5/8" annuli posed major integrity risks.

Once the target setting depth was reached, a cup tool was deployed to hydraulically activate the MEP and execute stage cementing via the integrated port collar, all in a single trip. Prior to cement job, the annular space between the host casing and reline casing was pressure tested up to 1,000 psi to confirm complete radial expansion and pressure-tight sealing of the MEP. This pre-cement validation step ensured that the system could withstand the hydrostatic pressure of the slurry during displacement and curing, thereby confirming annular isolation and eliminating the risk of interzonal fluid migration or cement fallback during thermal cycling.

Performing proper spaceout ensured that mechanically activated cement collars were accurately latched to conduct the cement job. Following the cementing, the cup tool was pulled out of the hole, rendering the well immediately available for production or injection without the need for a subsequent drill-out run and chasing of plug to bottom. This eliminated a conventional step in the workover process, significantly reducing rig time and associated operational costs while addressing well integrity issues. The successful deployment of expandable packer technology within the workover workflow exemplifies a transition from reactive remediation practices toward a proactive, design-driven approach to geothermal well integrity management, emphasizing long-term reliability, efficiency, and reduced lifecycle intervention requirements.

3.6 Field Performance Evaluation and Benefits Over Conventional Methods

A total of eight wells were relined utilizing the bespoke MEP for geothermal wells to eliminate the dedicated drillout run after the cementing operations.

The MEP solution was now predominantly being adapted to be used in low pH environments, where casing integrity is critical due to corrosion risks. Furthermore, the solution also showed that the design can be successfully deployed across a wide well age bracket ranging from one year to approximately 30 years, demonstrating suitability and the ability to reline wells without damaging the perforated liners due to the elimination of drillout run.

The data from this study demonstrates the superior performance of MEP and port collar systems compared to conventional relining methods, specifically focusing on operational efficiency, well integrity, and overall cost-effectiveness. The wells selected for this analysis, as detailed in Table 1, span a variety of conditions, including

differing well ages, casing sizes, metallurgy, and pH environments, providing a broad overview of the optimized solution performance in diverse settings.

Table 1. Relined well data utilizing MEP and conventional methods

Well Name	Age Category at the Time of Reline	Reline Length (meters)	Reline Casing Size	Reline Casing Metallurgy	Relining Strategy	pH
Well A	4-7	<650	7"	Corrosion Resistant Alloy	MEP without drillout	Low pH
Well B	1-3	<800	9-5/8"	Corrosion Resistant Alloy	MEP without drillout	Low pH
Well C	4-7	<800	9-5/8"	Corrosion Resistant Alloy	MEP without drillout	Low pH
Well D	4-7	<700	9-5/8"	Corrosion Resistant Alloy	MEP without drillout	Low pH
Well E	8-10	<700	9-5/8"	Carbon Steel	MEP without drillout	Low pH
Well F	4-7	<900	9-5/8"	Corrosion Resistant Alloy	MEP without drillout	Low pH
Well G	1-3	<1000	7"	Corrosion Resistant Alloy	Conventional with drillout	Low pH
Well H	25-30	<1100	9-5/8"	Carbon Steel	MEP without drillout	Neutral
Well I	15-20	<500	7"	Carbon Steel	MEP without drillout	Neutral
Well J	15-20	<800	9-5/8"	Carbon Steel	Conventional with drillout	Neutral
Well K	1-3	<200	7"	Carbon Steel	Conventional with drillout	Neutral
Well L	30-35	<550	7"	Carbon Steel	Conventional with drillout	Neutral
Well M	30-35	<750	7"	Carbon Steel	Conventional with drillout	Neutral
Well N	15-20	<1000	7"	Carbon Steel	Conventional with drillout	Neutral

One of the primary advantages of the aforementioned solution design was the standardization it offers over conventional relining methods. Traditional approaches, which often involve the use of heterogeneous materials

such as rubber plugs, cast iron, or composite bridge plugs, can lead to variability in installation and reliability. In contrast, the MEP, while eliminating the dedicated drillout run, provided a more uniform and predictable installation process, which enhances both installation accuracy and long-term wellbore integrity. This standardization is particularly beneficial in wells such as Well A, Well B, and Well F, where corrosion-resistant alloys (CRA) were employed and the operating environment is low pH. By removing the variability introduced by more traditional plug systems, it ensured more consistent performance, which is a critical factor for both short-term operational success and long-term well integrity.

Another key benefit of the design was its ability to completely eliminate the need for drillout runs, a common requirement in many conventional relining strategies. Wells, such as Well G, Well J, Well K, Well L, Well M, and Well N, increase the risk of mechanical damage to the wellbore or the existing liner during cleanup procedures, often leading to unplanned delays and potential integrity concerns. By bypassing the aforementioned step, the MEP streamlined the operations and reduced the risks to liners, and enabled effective relining of older wells, improving both efficiency and long-term well integrity.

Although cementing remains a critical component of the solution, the approach mitigated several common risks typically associated with conventional cementing practices. Traditional relining methods often rely on cement to achieve pressure integrity and isolation, but issues such as poor placement, inadequate coverage, channeling, micro-annuli, and challenges in ensuring there is no trapped water from top down cement job, especially in older or deviated wells, can compromise the whole conventional strategy.

In contrast, the MEP system improved the reliability of cementing by providing a more stable base and ensuring a more effective seal during the whole relining operations. Moreover, the design provided improved sealing capability in wells completed with either corrosion-resistant alloys or carbon steel casing, such as Well A, Well F, and Well E, especially in environments with low pH conditions. By stabilizing the cement placement process and the incorporation of specialized valve block assembly, the aforementioned optimized solution reduced the risks typically associated with cementing, ensuring a more reliable, long-term seal.

It is also important to note that though the MEP solution may require additional rig time upfront due to more precise and careful installation, as well as the learning curve for the rig crew who may not yet be familiar with the new technology, the long-term cost benefits are substantial. The reduction in future interventions, the ability to avoid drillouts, and the improved effectiveness of cementing all contribute to lowering overall operational expenditures over the life of the well.

4 CONCLUSIONS AND RECOMMENDATIONS

The study highlights that casing degradation in geothermal wells is significantly accelerated in low pH environments, with wells exposed to downhole fluid pH values below 4.5 experiencing premature casing failures within as little as one to two months post-production. This is primarily due to corrosion, scaling, and erosion. Traditional workover methods that relied on cemented bridge plugs and subsequent drillout operations were found to introduce substantial mechanical risk and increase operational costs, as observed in wells such as Well G, J, K, L, M, and N, where drilling and mechanical damage during cleanup resulted in longer non-productive times and higher intervention costs. Conversely, the deployment of the Metal Expandable Packer (MEP) technology provided significant improvements in well integrity, with the MEP system achieving 100% success in eliminating the need for drillouts and ensuring a reliable annular seal in geothermal environments. The design of MEP, including its V0-rated seal and integration with a two-stage cementing port collar, enabled a reliable, pressure-tight seal under high thermal gradients and extreme geothermal conditions, significantly reducing risks associated with traditional cementing methods.

Furthermore, the ability of the MEP to accommodate challenging well conditions, such as severe casing ovality or parted tubulars, demonstrated its broad applicability for geothermal wells of varying ages, from 1 to 34 years, without compromising the integrity of the wellbore. The standardization over conventional methods also improved installation accuracy and long-term well integrity by removing variability introduced by other plug and liner systems. Additionally, the incorporation of engineered pressure relief devices, such as rupture disks, mitigated the risk of casing deformation due to annular fluid entrapment under thermal cycling, further enhancing the system's reliability.

Given these benefits, it is recommended that MEP-based relining systems be adopted as the standard solution for geothermal wells exposed to corrosive or low pH environments (pH < 4.5) and temperatures exceeding 250°C, as well as old geothermal wells with compromised casing or liners. To ensure maximum effectiveness, pre-intervention diagnostics, including multi-arm caliper logging and pressure testing, should be mandated to confirm casing integrity and identify optimal setting depths for the MEP. The elimination of drillout operations in favor of MEP will streamline well workovers, reduce mechanical risks, and lower operational costs over the life of the well. Additionally, a focus on training rig crews on the installation and handling of MEP systems will help mitigate any learning curve-related delays and enhance efficiency. Long-term performance tracking over 24 months is recommended to monitor the effectiveness of the MEP solution and ensure continued well integrity. Finally, the internal geothermal well integrity protocols should be updated to include the MEP system as an ISO14310-compliant alternative to conventional methods, positioning it as a more reliable, cost-effective solution for geothermal well management.

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