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RESEARCH ARTICLE

Comprehensive Analysis of Latex Additives for Zonal Isolation and Gas Migration Control

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Abstract

This paper evaluates the performance of latex additives in 7-inch production casing cementing, specifically addressing zonal isolation and gas migration control. The study utilizes data from Cement Hydration Analyzers (CHA), Static Gel Strength Analyzers (SGSA), Cement Bond Logs (CBL), and Ultrasonic Imaging Tools (USIT) to assess bond integrity. Latex additives improve the mechanical properties of cement slurries, creating resilient seals essential for well integrity and hydrocarbon production. Advanced monitoring via CHA and SGSA offers real-time insights into hydration and mechanical property development. Results indicate that latex additives, when combined with comprehensive simulations of displacement efficiency and static gel strength, significantly mitigate gas migration risks. Furthermore, the findings suggest that this rigorous approach may reduce costs by potentially eliminating the need for ultrasonic logging in future latex-enhanced operations.

Keywords: Cement Hydration Analyzer, Static Gel Strength Analyzer, Latex, Zonal Isolation

1. Introduction

In the oil and gas industry, the success of primary cementing practices is critical for the long-term integrity and productivity of wells. This is particularly important for production casings, where a strong cement sheath ensures effective zonal isolation and prevents fluid migration between formations. A good cement bond also provides essential support for the casing, enabling safe and efficient hydrocarbon extraction.

A primary cement fault job will lead to substantial costs for remedial work. This could lead to additional time, additional labor, and additional safety risk. To avoid this, the industry has explored various strategies to enhance cementing practices, including the incorporation of latex-based additives. These additives, designed to strengthen the bond between the casing and geological formations, offer a promising solution for improving zonal isolation and controlling gas migration. By enhancing the mechanical properties of cement slurries, latex additives create a more resilient seal capable of withstanding the dynamic conditions encountered during hydrocarbon production.

This paper focuses on analyzing the performance of the latex additive in a 7" production casing cementing operation carried out by PT COSL INDO. The study specifically investigates the effectiveness of latex additive in enhancing zonal isolation and preventing gas migration. Using data obtained from Cement Hydration Analysis (CHA), Static Gel Strength Analysis (SGSA), CEMPRO Simulator, Cement Bond Logs (CBL) and Ultrasonic Imaging Tools (USIT), the study evaluates the impact of Latex Additive on the quality and integrity of the cement bond. The findings from this study contribute to the understanding of how latex additives can be strategically employed to optimize hydrocarbon extraction, safeguard well integrity and to develop new methods to mitigate gas migration.

2. Background

A key objective in oil and gas well cementing is to achieve complete zonal isolation, which prevents the unwanted movement of fluids between formations. Effective zonal isolation is critical for well integrity, production optimization, and environmental protection. A successful cement job creates a strong bond between the casing and the wellbore, forming a durable seal that withstands the dynamic pressures and stresses encountered throughout the well's lifespan. A competent cement sheath prevents fluid migration, maintains reservoir pressure, protects freshwater aquifers, and ensures the well's structural integrity.

Industry-standard cementing techniques often rely on conventional cement systems, which can exhibit limitations in demanding wellbore conditions. Factors such as high formation pressures, the presence of reactive shales, or temperature variations can compromise the integrity of the cement sheath, leading to zonal isolation failures. One common issue is fluid loss, where water from the cement slurry migrates into the formation, weakening the cement structure and creating pathways for fluid migration.

Latex additives have emerged as valuable components in cementing operations, particularly for addressing fluid loss concerns and enhancing cement bonding. Latex additives act as fluid loss control agents, reducing the permeability of the cement slurry and limiting the migration of water into the formation. This improved fluid loss control contributes to a better cement structure and a stronger bond between the casing and the wellbore. By strengthening this interface, latex additives enhance zonal isolation, mitigating the risks of gas migration and other fluid flow issues.

Advanced technologies like the CHA and SGSA have revolutionized cement job evaluation. The CHA provides real-time monitoring of the cement hydration process, offering good estimations into the development of mechanical properties like compressive strength and bonding. This real-time data enables more accurate predictions of cement integrity and zonal isolation. The SGSA complements the CHA by measuring the static gel strength during the critical fluid-to-solid transition, helping to identify potential weaknesses and prevent fluid migration by leveraging these tools,

Evaluating the effectiveness of a cement job involves utilizing specialized well logging tools, such as CBL and USIT. CBL employs acoustic waves to assess the quality of the bond between the casing and the cement, providing estimations into potential areas of poor bonding or channeling. USIT utilizes ultrasonic technology to generate detailed images of the cement sheath, enabling a comprehensive evaluation of cement integrity, including identifying micro-annuli, cracks, or other imperfections that might compromise zonal isolation. These tools are essential for verifying cement bond quality and ensuring long-term well integrity.

This study presents a comprehensive analysis of the latex additive in a 7" casing cementing operation, focusing on its effectiveness in zonal isolation and gas migration control. By leveraging data from CBL, USIT evaluations, and advanced tools like CHA and SGSA.

3. Literature Study

Latex additives in cement improve zonal isolation by enhancing the cement's ability to resist gas migration. They achieve this by creating a flexible, low-permeability barrier that adapts to formation movements. Case studies highlight significant improvements in cementing performance and long-term well integrity (Abdul-Rahman & Chong, 1997). Latex additives provide excellent fluid-loss control, while still improving surface mixability (Pavlock et al., 2012). Latex additives enhance cement bonding and prevent gas migration. They create a low-permeability barrier, ensuring zonal isolation and reducing risks associated with gas migration during cementing operations. Field applications demonstrate significant improvements in cementing performance and cost-effectiveness (Jones & Carpenter, 1991). Research reports show that adding polymer latex and silica fumes improves the tensile strength, adhesion, and sulfate resistance of cement mortar and concrete (Vektaris et al., 2003). Adding latex will form an artificial barrier between the cementitious phases and the attacking fluid (Brandl et al., 2011).

Primary cementing is a critical procedure in the oil and gas industry, involving the placement of cement slurries in the annular space between the casing and the borehole. This process is vital for numerous reasons. The hardened cement forms a hydraulic seal, preventing the migration of formation fluids within the annulus. This ensures the isolation of different geological formations, protecting freshwater aquifers from contamination and enabling the safe and efficient extraction of hydrocarbons. A well-constructed cement sheath anchors and supports the casing string. This structural integrity protects the casing from collapse due to formation sloughing or caving. It helps distribute the load on the casing more evenly, reducing stress concentrations and preventing buckling or collapse under lateral forces. The cement sheath safeguards the casing string from the corrosive effects of formation fluids, particularly hot brine and hydrogen sulfide. This protection extends the operational lifespan of the well and reduces maintenance costs. Properly cemented casing resists erosion caused by the high-velocity flow of produced fluids, especially when these fluids carry abrasive particles like formation sand. The fundamental principles of primary cementing remain consistent across different well types. Typically, the cement slurry is pumped down the inside of the casing, exits through the shoe at the bottom, and displaces the drilling mud as it rises in the annulus. While the basic principles remain the same, the specifics of the placement technique may vary depending on the type of casing string and the well's conditions. The casing is designed to endure the mechanical and chemical stress encountered in the well (Rodriguez et al., 2003). Diaz et al. (2004) present a method for estimating friction losses and equivalent circulating density during casing drilling cementing operations. Effective primary cementing requires planning and careful execution. Key operational considerations are important. Accurate calculations of slurry volume and displacement volumes are essential for successful cement placement. Knowledge of the bottomhole circulating temperature (BHCT) is essential for optimizing cement slurry properties and predicting setting times. Temperature simulators can be used to model the temperature profile during cementing operations. Mitchell and Wedelich (1989) and Beirute (1991) describe early temperature simulators, while Guillot et al. (1993) introduce a more advanced simulator validated with field measurements by Merlo et al. (1994) and Davies et al. (1994). Accurate knowledge of downhole pressures is essential for maintaining control during cementing. A minimum slurry density is required to balance formation pressures, and slurry rheology affects friction losses during placement. Excessive slurry density or displacement rates can induce formation fracturing and lead to lost circulation. Implementing a quality control program is crucial for ensuring the performance of cementing materials. This includes testing all materials, including cement, additives, and mix water, under laboratory conditions that simulate the anticipated wellbore environment. Additional testing beyond standard specifications may be necessary when cement quality is questionable. Real-time monitoring of critical parameters, such as pressure, slurry rate, density, and volume, is essential for evaluating cement placement and identifying potential problems. Modern cementing units incorporate sophisticated monitoring systems, including electronic pressure transducers and mass-flow meters, to provide accurate data recording. Vigneaux et al. (2003) introduce a cement monitoring and control system based on slurry volumetric balance, ensuring consistent slurry quality by monitoring the quantity of cementitious solids.

Defoamers or antifoams are effective in controlling foam formation during slurry mixing, enhancing fluid density and placement accuracy (Tao et al., 2021). Fluid loss control is essential for maintaining the slurry's consistency and preventing premature dehydration, which can compromise wellbore integrity. Research shows that effective fluid loss additives reduce the cement cake thickness and help maintain wellbore pressure during placement (Daccord & Baret, 1994). A major concern during cementing is gas migration, which compromises zonal isolation. Novel polymeric anti-gas migration additives have demonstrated significant improvements in reducing gas transition time and preventing leakage (Mohamed et al., 2022). Expansion additives in cement are used to counteract the natural shrinkage that occurs during the setting process. This shrinkage can create pathways for fluid migration, leading to issues such as sustained casing pressure (SCP) in oil wells. The goal of expansion additives is to create a tight seal between the cement and surrounding formations, ensuring zonal isolation (Murtaza et al., 2021). Retarders are essential chemical additives used in oil well cementing to slow down the hydration process of cement. The hydration process is the chemical reaction between cement and water, which leads to the setting and hardening of the cement. By delaying the setting time, retarders ensure sufficient time for proper placement of the cement slurry in deep and hot wells where higher temperatures accelerate the hydration process (Broni-Bediako et al., 2016). Fibers act as reinforcement agents within the cement matrix, enhancing its mechanical properties and durability. Lost circulation is a significant issue in oil well drilling and cementing. It happens when drilling fluids or cement leak into the surrounding rock. This can be very costly and lead to problems like increased well costs, longer drilling time, damaged formations, incomplete zonal isolation, blowouts, and even losing the well. To prevent this, lost circulation materials (LCM) are added to drilling fluids and cement slurries. Fibers are a particularly effective type of LCM for cementing (Low et al., 2003). Micro-silica in anti-gas migration material helps prevent cement strength loss by creating additional C-S-H gel, which strengthens the cement. It also lowers the CaO/SiO2 ratio, promoting the formation of stronger, less permeable minerals like tobermorite and xonotlite. These improvements can help prevent gas migration (Gaurina-Međimurec et al., 2017). Hollow, fused, pressure-resistant mineral spheres are used in ultra-lightweight cement slurries for well cementing. These spheres, also known as hollow spheres or glass bubbles, help reduce slurry density, improve compressive strength, prevent lost circulation, provide thermal insulation, and increase slurry volume. They are especially useful in formations with low fracture gradients and in wells with high temperatures (Nabi et al., 2010).

Quantitative measurements of good zonal isolation include cement compressive strength and permeability, static gel strength, and acoustic impedance. The industry uses the upper end of the range, 500 lbf/100 ft^2, as the accepted limit. A CSGS considerably lower than 500 lbf/100 ft^2 indicates a high potential for formation fluid to enter the wellbore during cement hydration. A CSGS approaching 500 lbf/100 ft^2 means a relatively low probability of fluid influx during cement hydration. Individual process elements such as slurry design, testing, applied engineering, and job execution impact the ability to install a cement barrier. Conditions in the well at the time of cementing also impact the ability to install a cement barrier. Operators should attempt to identify and analyze potential flow zones before drilling a well. Properly isolating potential flow zones requires proper cementing planning and execution. The Minerals Management Service (MMS) presented safety concerns on uncontrolled annular flows to an API workgroup in 2000. The workgroup, including government and industry representatives, documented industry best practices to improve zonal isolation, reduce sustained casing pressure occurrence, and prevent annular flow incidents. API published a series of API RP 65 documents to mitigate and prevent annular flows (American Petroleum Institute, 2010b).

The CHA, first described in a 1997 API Technical Report (TR) 10TR2 (American Petroleum Institute, 1997), measures critical parameters during cement hydration to understand gas entry mechanisms downhole. This bench-scale device operates under fixed-pressure conditions to assess hydration rate, shrinkage (due to chemical contraction or porosity development as the slurry hydrates), and mechanical properties. The gas migration cell, an 8-inch long, 2-inch diameter disposable cylinder, has a closed top with a pressure transducer and temperature probe. A sliding piston at the bottom, connected to a gas source, pressurizes the slurry. The CHA monitors the gas entry rate and the water pushing the piston as shrinkage develops. Placed in a thermostatic oven, the cell reaches thermal equilibrium. While the slurry remains liquid, the top pressure stays constant, with the piston compensating for shrinkage. As hydration progresses, temperature increases, and shrinkage continues until the piston halts due to increased wall shear stress, reducing pressure. When pressure drops to a set value, the gas valve opens, allowing gas to enter, driven by the pressure decrease and ongoing shrinkage. The slurry's gas permeability is determined by analyzing pressure and gas flow rate. If permeable, cell pressure equilibrates with the gas-inlet pressure, and gas flow is measured. The amount of gas entering indicates shrinkage, and visual observation post-test reveals gas migration patterns, such as bubbles, micro-percolation, or fractures. If impermeable, pressure decreases with no observed gas flow.

SGSA utilize techniques that analyze the acoustic waveform transmitted through cement to evaluate static gel strength (SGS) under downhole conditions of pressure and temperature. Proprietary algorithms convert these acoustic waveforms into evaluations of SGS, which is crucial for understanding annular fluid migration. As cement develops SGS, the amplitude of the acoustic signal passing through the sample increases. By establishing correlations between the change in signal amplitude and SGS, precise measurements can be obtained. Sabins and Maki (1999) developed a device, akin to the ultrasonic cement analyzer, capable of measuring SGS. This method has the advantage of not mechanically shearing the slurry, allowing SGS to be measured at a zero shear rate. This measurement technique ensures accurate assessment of SGS, directly impacting the understanding of fluid migration and cement integrity in wellbores. This non-destructive method also enhances the reliability of data, enabling better prediction and management of wellbore conditions, ultimately contributing to safer and more efficient oil and gas operations. Further research and development in this area promise continued improvements in the accuracy and application of SGS measurements, highlighting the importance of acoustic analysis in modern cement evaluation practices(Sabins & Maki, 1999).

A representative computer simulation significantly enhances cement job design by aiding the development of centralization programs and mud removal strategies. This simulation helps create temperature and pressure schedules for cement lab tests, providing a reliable framework before the actual job. Hydraulics simulations determine the expected pressures during the operation, ensuring effective well control and fluid displacement in the annulus. Furthermore, the simulation calculates the critical static gel strength along the entire wellbore, assessing the risk of gas migration. The primary goal of a cement program is to prevent operational problems, and adhering to the planned program ensures success. Well site execution involves mixing fluids to the correct density, pumping them at the programmed rate, and using the programmed volumes of spacers, lead slurry, tail slurry, and displacement fluids. Built-in tolerances and contingency plans within the cement program allow job objectives to be met even if operational issues arise. The simulation provides important estimate into wellbore conditions, enabling professionals to make informed decisions and reduce the risk of fluid migration. Assessing hole conditions using caliper logs, temperature knowledge through simulators validated by field measurements, and pressure management to balance formation pressures and prevent fracturing are crucial steps. This approach highlights the importance of accurate planning, execution, and monitoring in cementing operations, ultimately contributing to the longevity and integrity of the wellbore (Liu, 2021).

The core concept behind the ultrasonic technique is to make a small area of the casing resonate through its thickness. The transducer emits a short ultrasound pulse and listens to the echo containing the resonance. When fluid is present behind the casing, it causes the area to resonate or "ring," whereas solid cement behind the casing dampens the resonance. This resonance is then analyzed to determine the acoustic impedance of the cement. By assessing the resonance, one can infer the type and quality of the material behind the casing. This method provides a reliable means of evaluating cement integrity, ensuring wellbore stability, and preventing fluid migration. The differentiation between fluid and solid cement based on resonance characteristics is crucial for maintaining the structural integrity of the well and ensuring safe operation. Accurate measurement of acoustic impedance helps in making informed decisions about wellbore conditions and necessary interventions. This technique is essential for the oil and gas industry to monitor and maintain wellbore health effectively. Understanding the acoustic properties of the materials behind the casing allows for precise evaluation and timely corrective actions, ensuring the longevity and safety of the wellbore. This method's non-intrusive nature makes it an invaluable tool in the continuous assessment and management of wellbore integrity (Shaposhnikov et al., 2017).

CBL evaluates cement jobs in oil and gas wells, developed in the late 1950s and is still widely used. Cementing involves placing cement in the annulus between the casing and the wellbore to support the casing and prevent fluid migration. CBL relies on the principle that the strength of an acoustic signal traveling along the casing is influenced by the surrounding material. The acoustic transmitter sends a signal along the casing, with receivers measuring the signal's amplitude and transit time. A well-bonded cement sheath attenuates the acoustic signal more than a poorly bonded or free pipe. A good bond transfers sonic energy from the casing to the cement, resulting in low amplitude casing waves. A poor bond or free pipe, filled with fluid, results in less attenuation and high amplitude casing waves. The CBL attenuation rate measures how much the acoustic signal weakens as it travels along the casing, with a higher rate indicating a better bond between the casing and cement. Several factors affect the CBL attenuation rate, including cement properties (acoustic impedance and density), casing properties (thickness and diameter), wellbore fluid properties, temperature, and pressure. Understanding these variables is crucial for accurate cement bond evaluation and ensuring wellbore integrity. CBL is vital for maintaining the safety and efficiency of oil and gas operations, providing knowledge into the condition and quality of the cement bond. Identifying potential issues with the cement job allows for timely corrective actions to maintain wellbore integrity and prevent fluid migration (Wang et al., 2016).

4. Methodology

Below are several methodologies relating to engineering aspect of the study. This includes the common lab tests, CHA test, SGSA test, latex additive, primary cementing, and cement evaluation.

Lab tests involve analyzing cement samples under simulated conditions to predict performance in real wellbores. The CHA (**Figure 1**) evaluates the degree of hydration and susceptibility to gas migration. The SGSA (**Figure 2**) measures the static gel strength development of cement slurries, which is crucial for wellbore integrity. Latex in cement slurries prevent gas migration by enhancing bonding strength and reducing permeability. Primary cementing methods ensure effective zonal isolation by selecting appropriate materials, equipment setup, and monitoring parameters. Cement evaluation involves using specialized tools like CBL and ultrasonic imaging to assess the quality and integrity of the cement sheath. These methodologies combine to ensure cement's effectiveness in sealing wellbores, preventing fluid migration, and maintaining structural integrity throughout the well's lifecycle.

The evaluation of well cement was conducted according to the API RP 10B-2 standard. This standard outlines methodologies for testing cement performance under simulated well conditions. Samples of cement, additives, and mixing water were collected as per the guidelines. Subsequently, cement slurries were prepared using specified mixing methods that accounted for temperature adjustments. Non-destructive sonic testing was employed to assess strength development using ultrasonic signals. Additionally, thickening time tests simulated well conditions to evaluate the pumpability of cement slurries under defined temperatures and pressures. Fluid loss from the slurries was measured under both atmospheric and pressurized conditions. A rotational viscometer was used to characterize the rheological behavior of the slurries. Using the resulting data, pressure drop and flow regimes in pipes and annuli were calculated via different rheological models. Finally, the slurries were assessed for free fluid separation and sedimentation. Each procedure followed API RP 10B-2 to accurately simulate well conditions and ensure a thorough evaluation of the cement's performance (American Petroleum Institute, 2010a).

The CHA evaluates oil-well cement formulations for gas migration and hydration. This closed system simulates wellbore conditions by injecting nitrogen gas into a cement slurry sample. The system monitors pore pressure, confining pressure, gas injection pressure, and cement temperature. It also tracks water and nitrogen gas flow rates. In a closed cell test with no gas injection, the system measures pore pressure at the top of the cement sample. A decrease in pressure indicates cement shrinkage, which depends on the slurry's compressibility. In the open-cell test, a constant water confining pressure is applied to the cement sample until gas injection begins. During this phase, the gas injection pressure remains lower than the confining pressure. Once the pore pressure reaches the preset gas injection pressure, the confining valve closes, and the gas injection valve opens. The volume of gas entering the cell is measured by a flow meter to estimate cement shrinkage and assess gas migration. Interpreting the results involves analyzing the pore pressure response. An increase in pore pressure, especially if it reaches the gas injection pressure, indicates gas migration. Conversely, a continuous decrease in pore pressure suggests no gas migration. Flow rates provide insights into the cement's shrinkage or expansion and the volume of gas entering the sample. This methodology simulates downhole conditions in a lab to understand cement behavior during hydration and under pressure. Ultimately, it evaluates the cement's effectiveness in preventing gas migration (Chandler Engineering Company, LLC, 2021).

The SGSA measures the static gel strength of cement slurries under simulated wellbore conditions using ultrasonic technology. The instrument includes an autoclave with an internal processor, pressure and temperature control systems, and ultrasonic transducers. Sample preparation follows API Spec 10 procedures. The cement slurry is carefully poured into a specialized test cell. This test cell, assembled with ultrasonic transducers in the top and bottom plugs, generates and receives ultrasonic signals through the cement sample. The autoclave controls the temperature and pressure within the test cell to simulate wellbore conditions. The instrument captures ultrasonic signals transmitted through the cement sample and processes the data using proprietary algorithms. These algorithms analyze changes in the ultrasonic signal characteristics as the cement hydrates and sets. This process provides real-time measurements of static gel strength development. The methodology focuses on simulating downhole conditions to accurately assess static gel strength and compressive strength development of cement slurries. Real-time measurements provide insights into the cement's ability to prevent gas migration and support wellbore integrity (Chandler Engineering Company, LLC, 2016).

Adding latex to the cement slurry creates a seal between the casing and formation. The slurry is a mix of cement, water, and additives. Latex particles are smaller than cement particles. They fill spaces between the larger particles, increasing the solid volume and reducing void space. Consequently, this decreases permeability. Lower permeability prevents gas from penetrating and migrating through the cement sheath, which reduces gas leakage risks. The cohesive nature of latex enhances bond strength between the cement, casing, and formation. This creates a secure barrier that inhibits gas migration. Improved adhesion ensures a tight seal, minimizing potential gas pathways. Latex's film-forming ability integrates into the cement hydration product, forming an impermeable barrier within the cement matrix. Latex also improves slurry rheological properties, making it easier to pump and place in the wellbore. It contributes to fluid-loss control by plugging pores and preventing excessive water loss. Finally, latex's shrinkage-compensating properties maintain the integrity and dimensional stability of the cement sheath over time.

CEMPRO evaluates and mitigates gas migration risks while ensuring zonal isolation during cementing operations. The software models hydrostatic pressure imbalances between the casing and annulus during cement placement. It simulates U-tubing effects to predict fluid flow behavior and identify gas migration pathways. This helps prevent low-pressure zones in the casing. Effective mud removal is essential for zonal isolation and preventing gas

Fig 1. Cement Hydration Analyzer (CHA)
(Chandler Engineering Company, LLC, 2021)

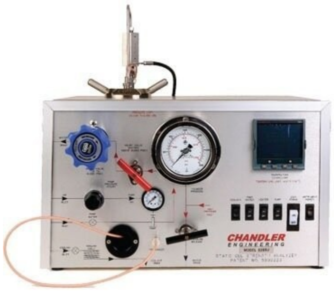


Fig 2. Static Gel Strength Analyzer (SGSA)
(Chandler Engineering Company, LLC, 2016)

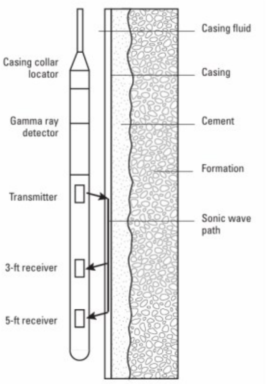


Fig 3. Cement Bond Log Tool (Allouche et al., 2006)

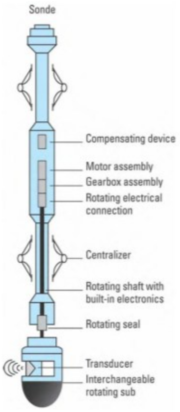


Fig 4. Ultrasonic Imaging Tools (Allouche et al., 2006)

migration. Therefore, CEMPRO simulates the displacement process to optimize fluid designs, pumping schedules, and operational parameters. Accurate temperature prediction ensures proper cement hydration and a competent cement sheath for long-term zonal isolation. This capability aids in selecting cement formulations and operational parameters. Additionally, the software predicts casing standoff profiles to ensure uniform cement sheath placement and prevent gas migration, which optimizes centralizer placement. CEMPRO calculates gas flow potential to assess gas migration likelihood. This allows for modifications to cement designs or parameters. Finally, the software simulates static gel strength development. It compares critical static gel strength with calculated gas flow potential to evaluate gas migration risk and select appropriate cement formulations.

In primary cementing, a thorough assessment of the wellbore is crucial before cementing. Engineers review drilling reports and caliper logs to identify irregularities. These include washouts, tight spots, or lost circulation zones. Operators condition the drilling mud by adjusting its properties to ensure effective displacement by the cement slurry. The cement type and additives are chosen based on wellbore conditions. Portland cement is blended with dry additives in a controlled environment. This ensures proper proportions and homogeneity. Metered water is mixed with the dry cement and additives using a jet mixer to create the slurry. Cement placement procedures depend on wellbore characteristics and pressure limitations. Equipment includes cementing units, pumps, and plug containers. All equipment must be in working order before starting to avoid delays. Centralizers are positioned along the casing string to maintain standoff. This ensures uniform cement sheath placement. Casing movement through rotation or reciprocation enhances mud displacement. It also improves cement bond quality. Continuous monitoring of pressure, flow rate, density, and volume ensures proper job execution. Post-job analysis of recorded data allows for the evaluation and optimization of future cementing operations. After placing the cement slurry, a waiting period is observed for the cement to set and develop strength. This duration is based on the type of cement, downhole temperature, and desired compressive strength. This systematic methodology for land-based primary cementing operations emphasizes proper planning, execution, and monitoring. This achieves successful cement placement, zonal isolation, and wellbore integrity. Consequently, operators can seal formations and prevent fluid migration. This establishes a foundation for subsequent well completion and production activities.

The CBL (**Figure 3**) uses acoustic waves to evaluate the bond between casing, cement, and formation. The tool consists of an acoustic transmitter and one or two receivers. These components are housed in a sonde that is lowered into the wellbore. The transmitter emits pulses that travel through the borehole fluid. These pulses interact with the casing, cement, and formation. Receivers detect the reflected acoustic signals. These signals are then analyzed to evaluate cement bond quality. The tool is typically centralized in the casing to ensure accurate measurements.

The CBL measures the amplitude and attenuation of the acoustic signal along the casing. A well-cemented section shows lower amplitude signals due to attenuation. Conversely, poorly cemented sections show high amplitude. The attenuation rate, expressed in decibels per foot (dB/ft), indicates bonding quality. The Variable Density Log (VDL) provides views into bond quality. Well-bonded casings show clear formation signals. In contrast, poorly bonded casings show strong casing signals and weak formation arrivals.

Quality control ensures reliability. This includes running repeat sections to verify consistency. It also involves analyzing transit time curves to check tool centralization. Factors like micro annulus, fast formations, and cement curing time can influence CBL response. Therefore, these factors require careful interpretation. By following this methodology, operators can effectively use the CBL tool to evaluate cement bond quality. They can make informed decisions about zonal isolation and well integrity. Ultimately, this ensures the long-term success of oil and gas production operations.

The methodology for using the USIT (**Figure 4**) in evaluating cementing in oil and gas wells involves several key steps. The USIT uses a rotating transducer to emit high-frequency ultrasonic pulses ranging from 200 kHz to 700 kHz. These pulses interact with the casing and surrounding material to generate echoes that assess cement sheath quality. The USIT induces casing resonance. Liquid behind the casing results in strong resonance, while solid cement dampens the resonance. This difference indicates bonding quality. The tool calculates acoustic impedances to determine material density and elastic properties. Additionally, it measures casing thickness and internal radius for integrity assessment. The USIT generates a color-coded acoustic impedance image that differentiates gas, liquids, and solids. Statistical image processing techniques, such as the micro-debonding algorithm, enhance the identification of cement presence and bonding quality. Quality control involves verifying fluid properties, ensuring repeatability through repeated log sections, and monitoring tool eccentricity. Limitations include potential micro annulus effects, interference from fast formations, and the impact of casing condition on measurements. Integrating USIT data with CBL and Variable Density Log (VDL) data provides a comprehensive view of cement bond quality. Combining wellbore geometry, casing properties, cement slurry design, and placement procedures further aids interpretation. This methodology ensures effective use of the USIT tool. It enables accurate assessment of cement bond integrity, zonal isolation, and long-term well success.

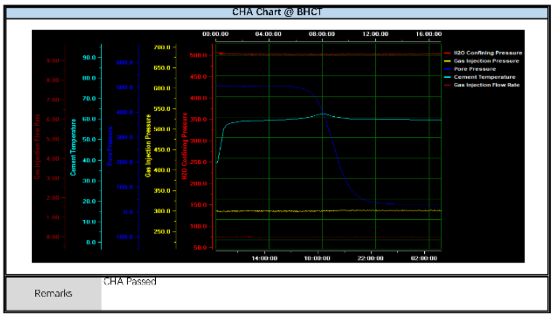
5. Data Analysis

The 7-inch casing had a weight of 26 lbs/ft, K-55 grade, BTC threading, an outer diameter (OD) of 7 inches, an inner diameter (ID) of 6.276 inches, and had reached a measured depth (MD) of 1550.40 meters. The 8.5-inch open hole had an OD of 8.5 inches and had extended to an MD of 1552.00 meters. The 9-5/8-inch casing, with a weight of 40 lbs/ft, also used K-55 grade and BTC threading, had an OD of 9.625 inches, an ID of 8.835 inches, and had an MD of 598.48 meters. The top of tail cement had been designed at 1000 meters, and the top of lead cement at the surface. The deviation showing gradual changes in inclination and azimuth to shape the well's trajectory. Inclinations start near zero, rising steadily to around 40° between 523 and 752 meters, while azimuths remain mostly within the 70° to 75° range. Toward the final depths, inclination stabilizes around 38°, with azimuths between 72° and 74°, this can be seen at **Figure 9** from the schematic of deviation of the well.

The well had a bottom hole pressure (BHP) of 2400 psi, a surface temperature of 39°F, bottom hole static temperature (BHST) of 185°F, bottom hole circulating temperature (BHCT) of 139°F. The tail slurry had a density of 15.80 ppg, a yield of 11.98 cu ft/sk, and a mix fluid of

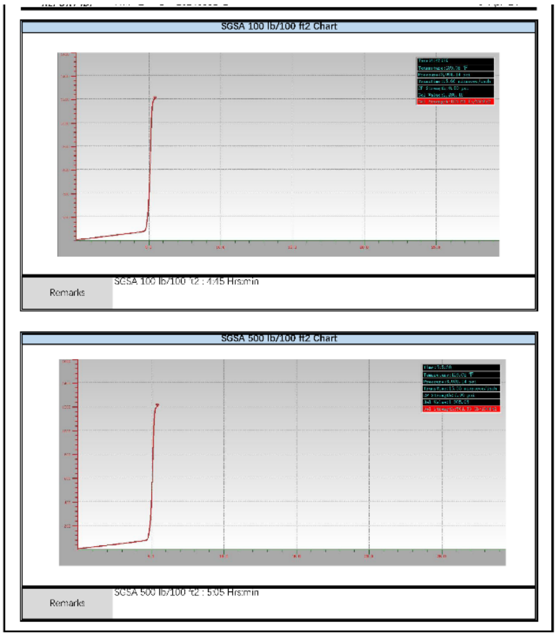
5.422 gps. The composition included fresh water (3.646 gps), various additives such as defoamers (PC-X60L at 0.128 gps and PC-X66L at 0.113 gps), fluid loss control agent (PC-G80L at 0.309 gps), anti-migration gas additive (PC-GS2L at 0.405 gps), dispersant (PC-F41L at 0.108 gps), latex (PC-GR1 at 0.153 gps), and cement retarder (PC-H21L at 0.090 gps). The expanding agent (PC-B20S) was added at 3.000 %BWOC, with cement class G as 100.00 %BWOC. At a temperature of 139°F and 0 psi pressure, the rheology measurements over a conditioning time of 30 minutes showed: 300 (205), 200 (163), 100 (123), 60 (89), 30 (48), 6 (12), and 3 (9) respectively. The viscosity was 174.0 cP, and the yield point was 31.00 lbf/100 ft^2. The API fluid loss was 32 ml in 30 minutes at 139°F and 1000 psi, indicating efficient fluid loss control. The thickening time (elapsed time is expressed as h:mm.) results showed 50 BC at 3:17, 70 BC at 3:23, and 100 BC at 3:27, defining the timeline for slurry hardening. The Ultra Sonic Cement Analyzer (UCA) results indicated a compressive strength (CS) of 50 psi at 3:49, 500 psi at 4:37, and 3250 psi at 24:00. The SGSA results revealed 100 lbf/100 ft^2 at 4:10 and 500 lbf/100 ft^2 at 4:25, with a transition time of 15 minutes, signifying the slurry's ability to resist gas migration during setting. Overall, it reflects a well-prepared cement slurry with controlled fluid loss, consistent rheology, and adequate thickening time and compressive strength.

For the lead slurry, the density is 13.80 ppg, with a mix fluid of 6.821 gps and a yield of 1.548 cu.ft/sk. The composition includes fresh water at 5.641 gps, defoamer liquid PC-X60L at 0.013 gps, high-temperature fluid loss cement PC-G80L at 0.618 gps, anti-migration gas additive PC-GS2L at 0.486 gps, cement retarder PC-H21L at 0.064



CHA Passed

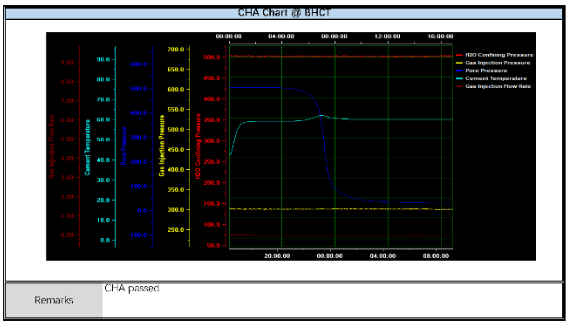
Fig 5. CHA Result for 13.8 ppg cement slurry



SGSA 100 lb/100 ft2 : 4:45 Hrs:min

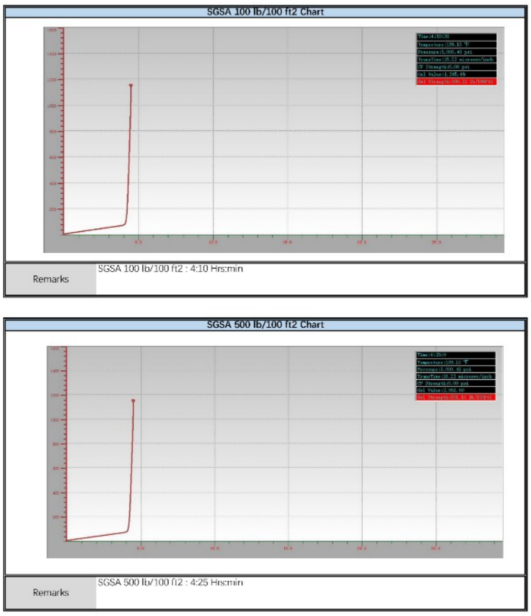
SGSA 500 lb/100 ft2 : 5:05 Hrs:min

Fig 6. SGSA Result for 13.8 ppg cement slurry



CHA passed

Fig 7. CHA Result for 15.8 ppg cement slurry



SGSA 100 lb/100 ft2 : 4:10 Hrs:min

SGSA 500 lb/100 ft2 : 4:25 Hrs:min

Fig 8. SGSA Result for 15.8 ppg cement slurry gps, and cement class G at 100.00 %BWOC. Additional components are cenosphere PC-P61S at 6.00 %BWOC, strength enhancer PC-GS12S at 2.00 %BWOC, and fiber PC-Seal at 0.10 %BWOC. At a temperature of 139°F and 0 psi pressure, rheology measurements over a conditioning time of 30 minutes show: 300 (198), 200 (150), 100 (84), 60 (52), 30 (28), 6 (10), 3 (8). The viscosity is 171.0 cP, and the yield point is 27.00 lbf/100 ft^2. The API fluid loss is 40 ml in 30 minutes at 139°F and 1000 psi, indicating efficient fluid loss control. The thickening time (elapsed time is expressed as h:mm.) results show 50 BC at 4:17, 70 BC at 4:22, and 100 BC at 4:26, defining the timeline for slurry thickening. UCA results indicate a compressive strength (CS) of 50 psi at 4:35, 500 psi at 6:08, and 2182 psi at 24:00, demonstrating rapid development of mechanical strength. SGSA results reveal a gel strength of 100 lbf/100 ft^2 at 4:45 and 500 lbf/100 ft^2 at 5:05, with a transition time of 20 minutes, indicating the slurry's ability to resist gas migration during setting. The report reflects a well-prepared cement slurry with controlled fluid loss, consistent rheology, and adequate thickening time and compressive strength. Efficient fluid loss control, demonstrated by 40 ml API fluid loss, maintains slurry stability and prevents formation damage. The thickening time and rapid development of compressive strength, shown by UCA results, indicate the slurry's ability to support the casing and maintain structural integrity. SGSA results highlight the slurry's capability to resist gas migration, ensuring effective zonal isolation. On the CHA both shows the pore pressure continues to decrease (approaching 0 psig), which indicates no gas migration has occurred.

Simulation was done using CEMPRO Cementing Simulator. All the data of rheology is become the input for the simulation. The job simulation shows key aspects of the operation, covering pump rates, displacement efficiency, ECD, and centralization. The cementing job followed a strict pumping schedule with varying rates for each fluid. Lovis Mud was pumped at 4 bpm for 100 bbl, followed by Pre-flush at 5 bpm for 20 bbl, Spacer at 6 bpm for 100 bbl, Lead Slurry at 6 bpm for 121 bbl, and Tail Slurry at 5 bpm for 65 bbl. The overall pump rates were controlled to avoid high pressure spikes.

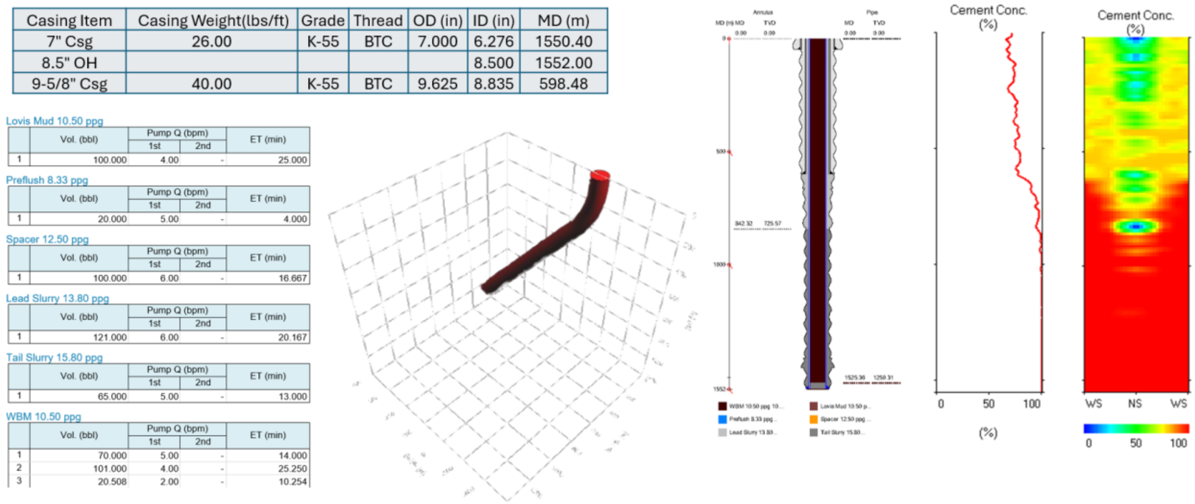
From the cement concentration line chart, with shallow zones at 90%-95%, mid-depth zones (900-1000m) at 98%-100%, and critical deeper sections reaching up to 100%. The cement concentration color chart shows an uneven distribution, with low cement concentrations (blue-green zones) along the narrow side (NS), indicating possible channeling and areas where fluid migration might occur. The higher concentrations on the wide side (WS) suggest asymmetric placement, likely due to poor centralization or flow restrictions. This asymmetry, with pockets of low cement concentration, poses a risk to zonal isolation by allowing potential flow paths. This can be seen in Figure 9.

As shown in **Figure 10**, ECD (Equivalent Circulating Density) readings increased with depth. ECD started at 11.33 ppg at the surface and rose steadily, reaching 16.66 ppg at the end of the job. The ECD remained below the fracture gradient, indicating no lost circulation due to weak formations. Hydrostatic pressure also increased with depth, starting at 10.5 ppg at the surface and rising to 14.7 ppg. The hydrostatic pressure consistently remained above the pore pressure, indicating no flow, as the pore pressure is lower than the hydrostatic pressure. There is minor flow potential, and the Critical Static Gel Strength is still above 100 lb/100 ft^2, so the result of SGSA test from 100 to 500 lb/100 ft^2 can still be safe to be used.

For the execution of the job, cementing operation for the 7” Production casing was performed. The operation reached a measured depth (mMD) of 1552 meters and a true vertical depth (TVD) of 1271.17 meters. A KCL polymer-based drilling fluid with a specific gravity (SG) of 1.26 was employed throughout the process. The operational timeline spanned from April 19 to April 20, 2024. The primary objective was to install and cement a 7-inch casing, securing the wellbore and preparing it for the subsequent drilling phase. This involved cementing operations, fluid displacement, pressure testing, and other preparatory tasks for further casing work. During preparation and Casing Installation (00:00 - 05:00), the 7-inch casing string (K-55, 26 ppf, BTC, Range 3) was lowered from a depth of 1443 mMD to 1550.60 mMD, with the shoe positioned at the bottom. A wash-down operation was conducted between 1443 mMD and 1550.60 mMD, utilizing a flow rate of 250-300 gallons per minute (gpm) and surface pump pressure (SPP) ranging from 320 to 620 psi. This ensured smooth casing placement and clearance of potential obstructions. The activity is continued with cementing execution at 05:00. Before cement pumping, pre-cementing activities included flushing and testing the cementing line at 3000 psi for 10 minutes to confirm no leaks. A total of 100 bbls of low-viscosity mud and 20 bbls of pre-flush were pumped to displace remaining drilling fluids, followed by 100 bbls of spacer (SG: 1.50) to ensure separation from the cement slurry. The lead slurry was mixed and pumped at a volume of 121 bbls with a density of 1.65 SG, followed by a tail slurry of 64 bbls at a density of 1.90 SG, During displacement, the bottom plug was dropped, and a mud of 1.26 SG was used. Displacement required 193.1 bbls, bumping of top plug at 1950 psi, with a 10-minute hold period to confirm placement. A pressure bleed-off of 1.9 bbls was observed, with spacer contaminant (SG: 1.42) noted at 13.1 bbls during displacement. After the waiting period for cement curing (waiting on cement), the cement line was released, and a circulating head was installed. Cement hardness was monitored in a water bath, with the lead slurry reaching 50% and the tail 60% hardness by 15:00 on April 19. A follow-up test on April 20 confirmed that both lead and tail slurries achieved 100% hardness, indicating solidification. The cement hardening process achieved satisfactory results, with lead and tail slurries solidifying within expected timelines, indicating successful zonal isolation. Pressure tests and bleed-offs were completed effectively, confirming the integrity of the cementing and casing system. Overall, the cementing operations were completed in adherence to planned procedures.

Based on the available CBL and USIT logs in Figure 10 and **Figure 11**, the analysis combines CBL amplitude, VDL signature, and USIT acoustic impedance to evaluate cement integrity. In the 1000-1100 m interval, the CBL amplitude ranges from 2.84 to 17.14 mV, indicating a generally low amplitude with a small indication of casing arrival. Some disturbance is observed in the VDL near the casing collar, and there is a clear formation arrival, which suggests adequate bonding between the casing and cement.

At the 1100-1200 m interval, the CBL amplitude varies from 0.85 to 29.84 mV, with small indications of casing arrival in some areas and a lack of casing arrival in others. Disturbances in the VDL near the casing collar and a good formation arrival are observed, confirming strong bonding with minor inconsistencies in casing arrival. At the 1200-1300 m interval, the CBL amplitude ranges from 0.63 to 12.89 mV, showing no casing arrival or chevron patterns



Casing Item	Casing Weight(lbs/ft)	Grade	Thread	OD (in)	ID (in)	MD (m)
7" Csg	26.00	K-55	BTC	7.000	6.276	1550.40
8.5" OH					8.500	1552.00
9-5/8" Csg	40.00	K-55	BTC	9.625	8.835	598.48

Lovis Mud 10.50 ppg

	Vol. (bbl)	Pump Q (bpm)		ET (min)
		1st	2nd	
1	100.000	4.00	-	25.000

Preflush 8.33 ppg

	Vol. (bbl)	Pump Q (bpm)		ET (min)
		1st	2nd	
1	20.000	5.00	-	4.000

Spacer 12.50 ppg

	Vol. (bbl)	Pump Q (bpm)		ET (min)
		1st	2nd	
1	100.000	6.00	-	16.667

Lead Slurry 13.80 ppg

	Vol. (bbl)	Pump Q (bpm)		ET (min)
		1st	2nd	
1	121.000	6.00	-	20.167

Tail Slurry 15.80 ppg

	Vol. (bbl)	Pump Q (bpm)		ET (min)
		1st	2nd	
1	65.000	5.00	-	13.000

WBM 10.50 ppg

	Vol. (bbl)	Pump Q (bpm)		ET (min)
		1st	2nd	
1	70.000	5.00	-	14.000
2	101.000	4.00	-	25.250
3	20.508	2.00	-	10.254

Fig 9. Simulation of Pump Schedule, Deviation, Fluid Position, and Cement Concentration

but displaying a clear formation arrival. This suggests effective bonding without significant casing interference. At the 1400-1535.5 m interval, the CBL amplitude remains low at 0.3 to 22 mV, with no casing arrival or chevron pattern detected. The consistent formation arrival supports strong cement bonding, which effectively isolates the zone down to the total depth of 1537.84 m.

In the 1000–1200 m interval, there is no sign of channeling. Although there is a trace of low impedance material with a lighter color, there is no significant gas presence except at 1004 m and 1076 m, where a small trace of gas is detected (indicated by red color). Most of the readings indicate a bonded state. There are traces of liquid at 1017–1019 m, 1063–1068 m, 1132–1139 m, and 1185 m, marked by light blue color. Overall, the majority of readings indicate bonding. The acoustic impedance values display high deviation with "noisy" readings, suggesting the presence of solid material cement behind the casing. In the 1200–1300 m interval, the impedance map at 1215–1227 m shows predominantly high impedance values, indicating cement presence in this section. From 1227–1245 m, there is a minor trace of liquid, but it is not interconnected, showing no signs of channeling. Overall, the cement map predominantly indicates bonding. For the 1300–1400 m interval, the readings display relatively darker colors, suggesting better cement. The lighter colors are isolated and do not indicate channeling. Finally, from 1400 m to the total depth, liquid is detected at 1435 m, potentially suggesting gas entry that might be isolated by a latex additive. There are indications of liquid and gas (notably at 1450 m) in what could be a pay zone, though these are also not interconnected. In summary, the overall readings indicate no channeling and good bonding.

6. Discussion

The job followed standard engineering procedures and execution. The use of latex, application of Flow Potential, and Static Gel Strength Analysis significantly enhanced cementing operations. The strong bonding detected by the CBL suggests that the USIT, designed for channeling determination, may be excluded in future jobs. This would make ultrasonic logging unnecessary and reduce costs. Even though simulations showed minor flow potential, latex was used to ensure good bonding and prevent gas migration. The CHA proved superior to the SGSA. It measured both the ability to prevent flow through the cement and the micro annulus. If either event occurs, gas migration prevention will fail. The SGSA detects long transition times, indicating flow through the cement. However, it cannot detect flow due to cement shrinkage. Despite this, both devices are recommended because the SGSA is directly related to the Critical Gel Strength Period (CSGP). Minimizing the critical gel strength period is essential. A maximum period of 45 minutes, measured at the temperature of the potentially flowing zone, is commonly accepted. This comprehensive approach ensures optimal well integrity, effective zonal isolation, and prevention of gas migration. Ultimately, it contributes to overall operational success and safety.

Comprehensive data analysis has been performed on lab tests, simulations, job execution, and sonic and ultrasonic data. It is concluded that latex is effective for zonal isolation and gas migration control. Using simulations for displacement efficiency, flow potential, and critical static gel strength covers all potential gas migration scenarios. Displacement efficiency simulation will analyze potential gas flow through mud channels. Flow potential simulation will analyze potential gas flow due to the design. Critical static gel strength will integrate readings from the SGSA with actual well parameters, such as cement length, pore pressure, and wellbore diameter. Potential savings from excluding ultrasonic logging and costly remediation can be achieved with this method.

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