# "Effective Well Diagnosis for Permanent Abandonment through Integrated Multi-Sensor Analysis and Use of Damped Charges for Cement Injection"

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## 1. Abstract

The permanent abandonment of the well XXX, located in Colombia, was carried out under high-temperature and high-pressure (HTHP) reservoir conditions and presented the additional challenge of sustained annular pressure (2,000 psi in the 9 5/8" casing).

This paper outlines the strategy and execution of the abandonment process, including the placement of cement barriers, the use of damped perforating charges, and verification of mechanical integrity and regulatory compliance. Although advanced diagnostics tools supported decision making, this study focuses on operational and technical aspects of abandonment execution.

The strategy successfully ensured integrity, avoided unnecessary re-entries, and followed with Resolution 40622 of 2023. This case provides a practical reference for well abandonment under complex subsurface and logistical conditions in mature fields.

## 2. Introduction

Well abandonment in high-pressure, high-temperature (HPHT) environments demand precise planning, strict regulatory alignment, and operational adaptability. Additional factors such as sustained annular pressures and limited local infrastructure further complicate the process. These challenges require not only technical rigor, but also strategic execution to ensure permanent isolation and environmental protection.

The well XXX exemplifies this complexity. Located in Colombia, its final abandonment required customized solutions to manage subsurface conditions and meet regulatory expectations within a defined time limit. This included cement placement in critical intervals, keeping casing integrity, and enabling safe annular access for zonal isolation.

This paper documents well abandonment plan and field execution, highlighting decisions made under operational constraints and lessons applicable to similar HPHT wells nearing end of life stages.

## 3. Well Overview & Challenges

The well XXX is located at Colombia. In this field there are 4 drilled wells, which are located within the field's Gas Plant. One of the this 4 wells currently supplies more than 81% of the gas in the area.

The well XXX, is an "A0" type development well, which started drilling on September 2022. The final depth was 12,865 feet MD / 12,030 feet TVD with a maximum inclination of 26.14° at 7,025 feet and with a bottomhole temperature of 327°F. Well temperature was a main consideration during the planning and execution of the intervention.

The well was constructed in 4 phases as follows (see Fig. 2):

- 26” hole with 20” casing, 133#/ft, K-55, BTC to 1,605 ft, with spacer returns at surface.
- 17 ½” hole with 13 3/8” casing, 72#/ft, P110 to 6,573 ft, with cement stop at 1,405 ft.
- 12 ¼” hole with 9 5/8” casing, 53.5#/ft, Q-125 to 12,804 ft, with TOC @ 6,560 ft.
- 8 ½” hole to 12,865 ft (final well depth), with 6 5/8" screens, TOL 7 in @ 12,606 ft.

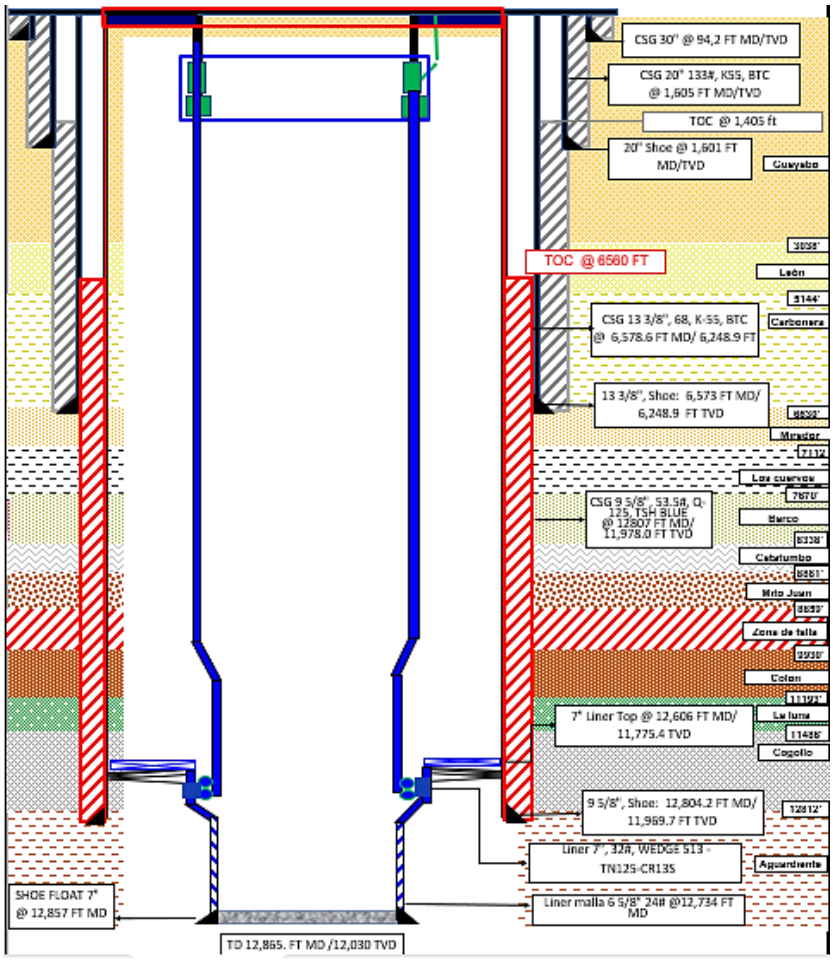



**Fig. 2**. Well schematic – Well XXX - drilling

The drilling and completion of the well XXX in January 2023 faced multiple challenges. The first production test in the Aguardiente formation did not confirm the presence of dry gas. In response, the uphole Anturio opportunity was assessed, with the intention of confirming commercial accumulations in La Luna Formation. However, test resulted in high production of associated water, which made its technical and economic exploitation unfeasible.

Therefore, it was decided to abandon the well. During the temporary abandonment, cement plugs were put in place, but bubbling was detected when the BOPs were removed, leading to the installation of production tree and pressure monitoring. During monitoring pressure increase up to 2,000 psi in the 9 5/8 in casing annulus.

After detecting the pressure anomaly in the well XXX (2000 psi in the annular of 9 5/8 in casing) during its temporary abandonment, the National Hydrocarbons Agency (ANH) demanded remediation within 3 months. Since other uses of the well were ruled out, it was decided to permanently abandon it, according to national regulations (Resolution 40622 of 2023) and Ecopetrol's internal guidelines

The main technical challenge to perform the definitive abandonment of the well is associated with the depth (12,860 ft MD), high temperature (327 °F) and high formation pressure (6,744 psi) of the field, taking into consideration the technology limitations available in Colombia for this type of well.

Also, part of the technical challenge was to identify if the accumulated pressure accumulated in the 9 5/8 in casing was related to loss integrity in the casing or in the mechanical and/or cement plugs installed during the temporary abandonment job.

## 4. Methodology & Technologies Applied

The abandonment of well XXX was planned under Ecopetrol S.A.'s "Resources to Production" RAP methodology, ensuring efficiency, integrity, environmental and safety compliance. Internal service company guidelines and instructions were also followed. This allowed for a successful operation, preventing any loss of fluid containment associated with the integrity of the well and guaranteeing effective barriers after abandonment. Each of these goals was addressed in developing the technical abandonment strategy.

### Initial well diagnosis

Although the primary focus of this work is the permanent abandonment of well XXX, it is relevant to briefly include the diagnostic basis that guided key operational decisions. Prior to the intervention, a rigless evaluation of casing and cement integrity was performed using electromagnetic induction and multi-finger caliper tools. These tools confirmed that the 9 5/8” casing was structurally sound, with no severe damage:

The multi-finger caliper detected a maximum internal radial loss of 16.79%, which did not compromise mechanical integrity. The electromagnetic induction tool estimated a maximum wall thickness loss of 3.76%.

Additionally, production logging tool found intermittent gas entry through the cement plug at 8,798 ft, based on spinner response at 8,645 ft during flowing conditions. No other anomalies were observed along the logged interval.

These findings enabled accurate placement of abandonment barriers and prevented unnecessary or misdirected remedial actions. The use of diagnostic tools prior a definitive well abandonment is required to accomplish Colombian Government Resolution 40622 of 2023 and ensure long-term well integrity.

### Abandonment strategy

As a part of planning and assurance of the well XXX abandonment, the PAC-7037-451C damped charges were designed and tested considering wellbore geometry and well environmental conditions. The main purpose of the casing puncher was to perforate two of three (2/3) casings without compromising the integrity of most external (20 in), establishing hydraulic communication of annular spaces to pump cement. Manufacturing and testing process of damped charges took two months, from project assignment until the charges were delivered to the well location.

***Design of cementing barriers (Location and justification).***

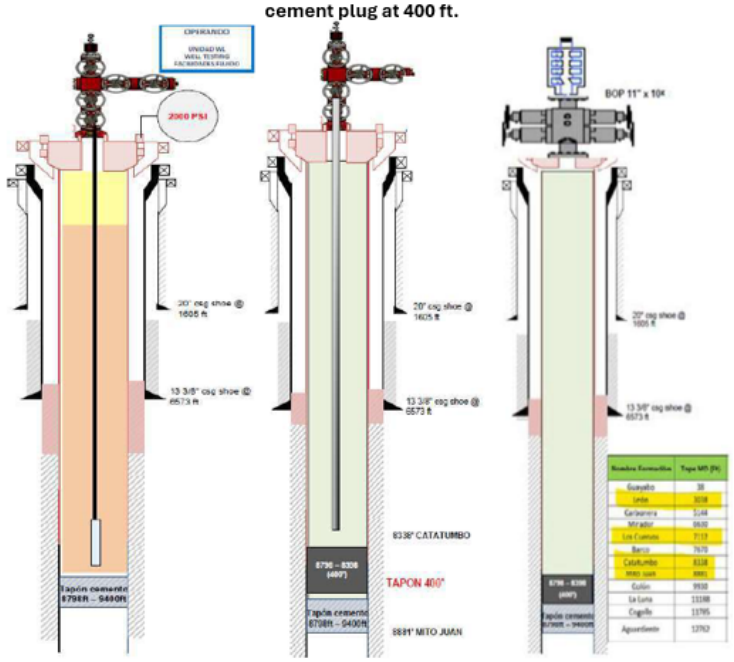
The well abandonment program approved by ANH regulatory, was designed by Ecopetrol S.A. to guarantee compliance of Colombia Government Resolution 40622 of 2023. The barriers were defined to prevent the flow of fluids to the surface after the definitive abandonment.

Based on this input and the approval of the well XXX definitive abandonment program by the ANH, a multi-phase intervention strategy was developed as follows:

1. Wireline production logging program to identify the zone with gas contribution

2. Preparation and pumping of fluid with coiled tubing, followed by the pumping of a cement plug at 400 ft.

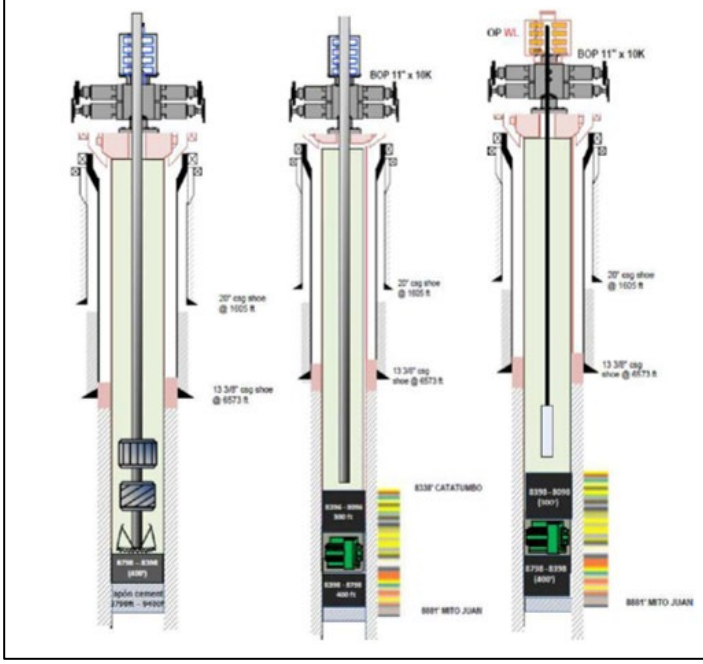
3. Dismantling of Xmas Tree, installation and testing of 11" – 10k BOP




4. Coiled tubing calibration for 9-5/8" casing

5. Bridge Plug setting with WL and 300 ft cement plug pumping .

6. Flexural attenuation logging run .



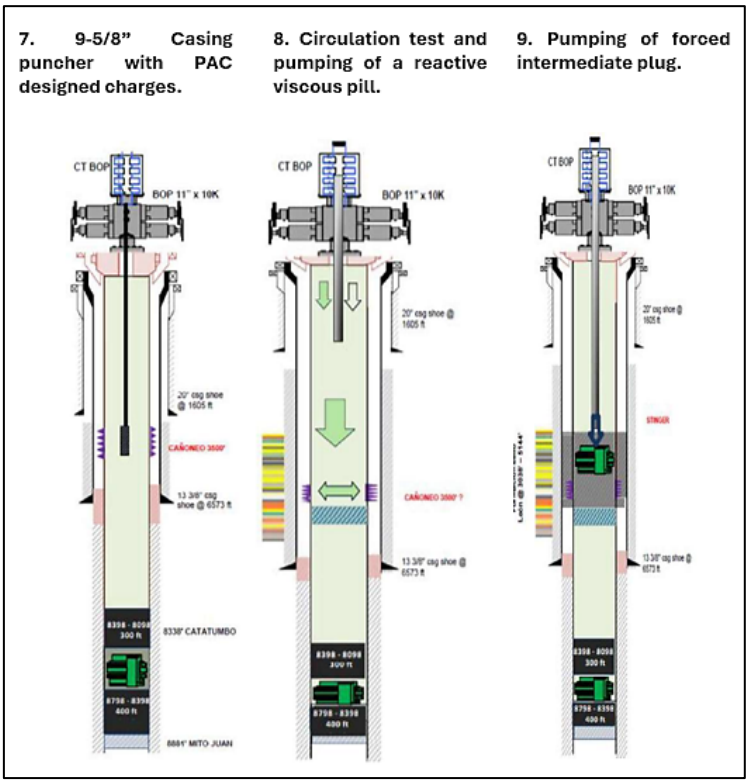



**Fig. 3**. Final well abandonment strategy for well XXX.

## Design and development of dampened gun charges

As part of the final abandonment strategy, a set of specially engineered dampened charges PAC-7037-451C were designed, tested and developed to establish communication between annular spaces enabling subsequent cement injection for zonal isolation. The charges were specifically designed to perforate the 9.625" casing (53.5# Q-125) and the 13.375" casing (72# P-110), while preserving the integrity of the 20" conductor casing (133# K-55). This selective targeting was critical to avoid compromising the outermost transverse barrier and ensure regulatory compliance with ANH standards. The strategy represents a tailored solution for complex abandonment scenarios, restricting controlled fluid migration and long-term well integrity. The test design and its purpose are outlined in detail in Figure 4, which illustrates the simulated wellbore configuration used to confirm the dampened perforation charge effectiveness under realistic conditions.

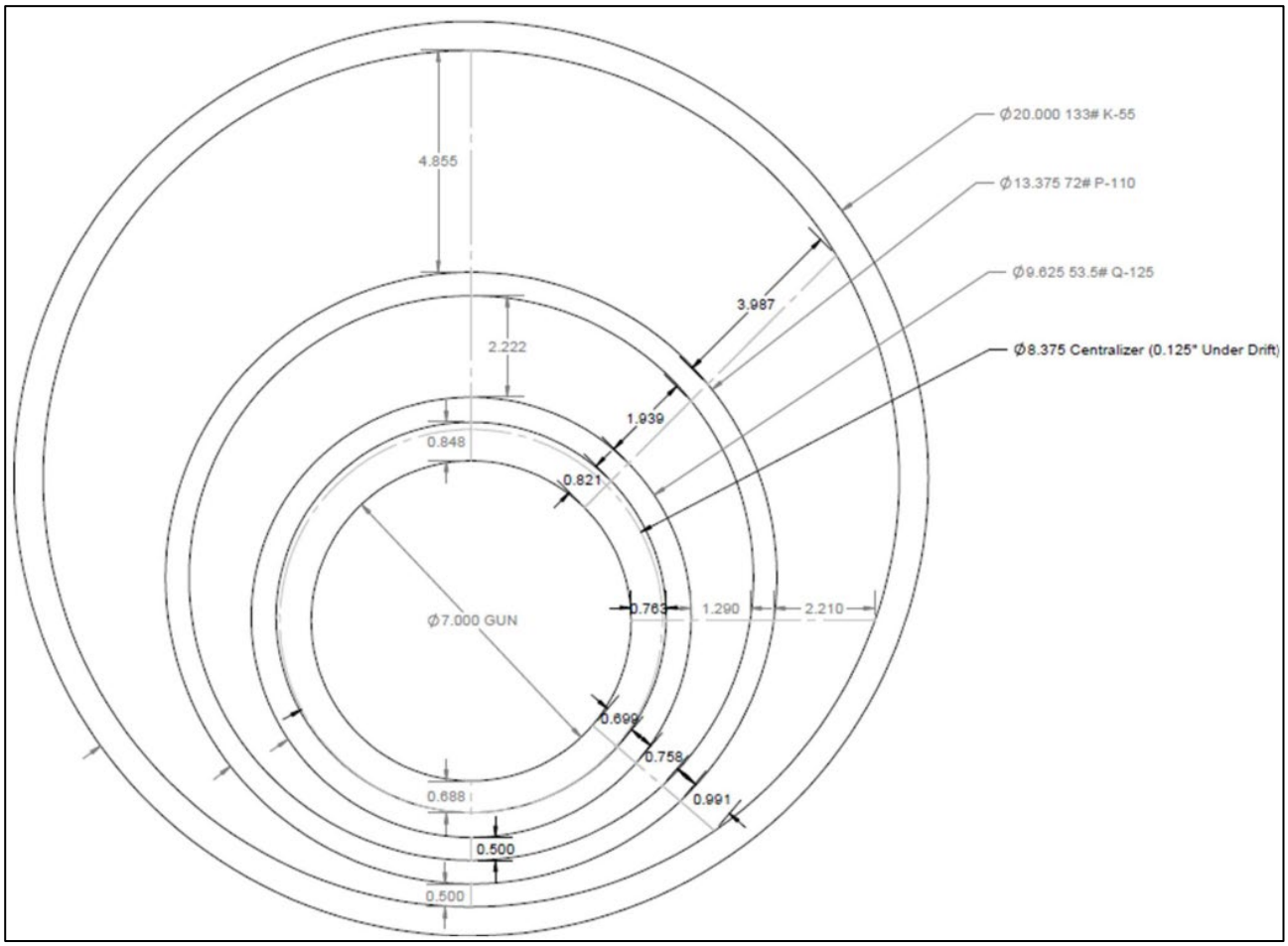


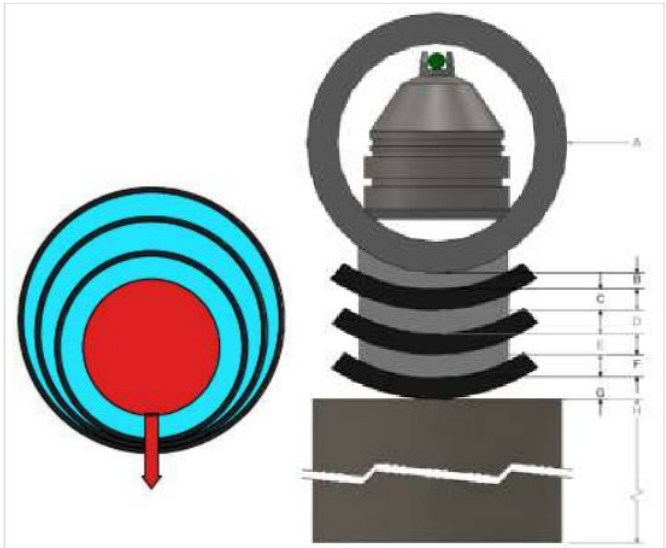

**Fig. 4**. Schematic representation of the wellbore scenario for well XXX abandonment tests.
*Depicts the casing configuration (20", 13.375", and 9.625") and targeted perforation zones for selective communication.*

## Charge Design and Test Methodology

The PAC-7037-451C charges were designed with dampening features to reduce shock transmission while delivering sufficient energy for selective perforation. Laboratory tests simulated the downhole environment using a series of single-shot experiments, with shots fired at various phases including low-side orientation to assess maximum casing damage and optimize circumferential perforation. A worst-case test was also included, involving no collar offset to simulate potential deviated pipe contact scenarios. The configuration and expected outcomes of each shot are detailed in the test results section, with supporting data presented in the corresponding figures and tables. These results proved that, when the gun is centralized within 1/8" of the drift diameter, the system achieved full inner casing perforation coverage without compromising the outer casing. The graphical data confirms consistent performance, with penetration profiles and casing response matching predicted behavior.

### *Test Results*

Test results will be summarized in the tables and figures below. The individual shot details will be listed just prior to the relevant results for clarity.



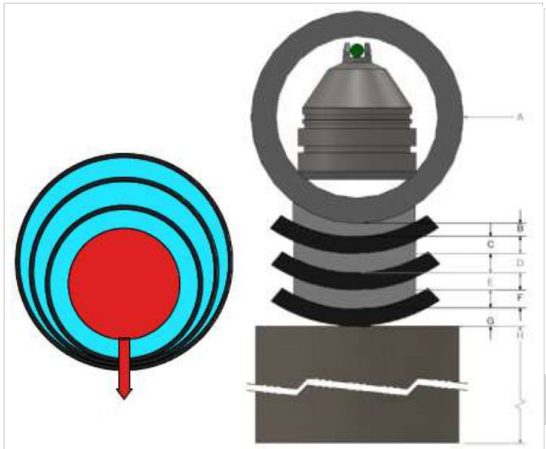

| Location on Graphic | Value (in.) | Material |
|---|---|---|
| PAC-7037-451C | | 1.265" Internal Charge Standoff |
| A | N/A | 7" Gun Section |
| B | 0.688 | Fresh Water |
| C | 0.545 | 9.625" 53.5# Q-125 |
| D | 0 | Fresh Water |
| E | 0.514 | 13.375" 72# P-110 |
| F | 0 | Fresh Water |
| G | 0.635 | 20" 133# K-55 |

| Shot number | Casing | Results | | | | Notes |
|---|---|---|---|---|---|---|
| | | Hole Size min Axis (in.) | Hole Size max Axis (in.) | Average Hole Size (in.) | Penetration | |
| | 9.625 | 0.48 | 0.49 | 0.49 | THRU | |
| | 13.375 | 0.47 | 0.48 | 0.48 | THRU | |
| 1 | 20 | N/A | N/A | **N/A** | 0.335 | 47% Remaining Casing Wall |

**Table 1:** Worse case

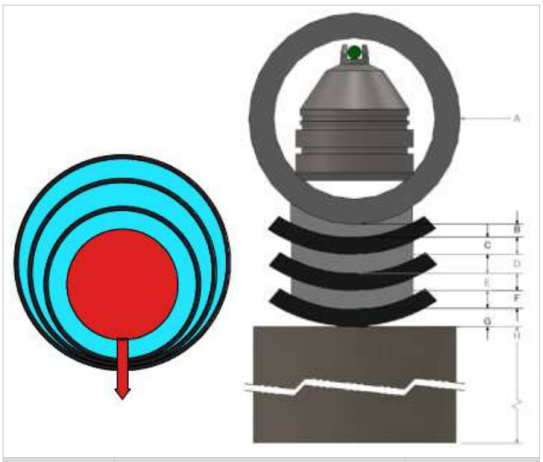
low-side test setups (with NO collar offsets) – left side

low-side test results (with NO collar offsets) right side




| Location on Graphic | Value (in.) | Material |
|---|---|---|
| PAC-7037-451C | | 1.265" Internal Charge Standoff |
| A | N/A | 7" Gun Section |
| B | 0.688 | Fresh Water |
| C | 0.545 | 9.625" 53.5# Q-125 |
| D | 0.5 | Fresh Water |
| E | 0.514 | 13.375" 72# P-110 |
| F | 0.5 | Fresh Water |
| G | 0.635 | 20" 133# K-55 |

| Shot number | Casing | Results | | | | Notes |
|---|---|---|---|---|---|---|
| | | Hole Size min Axis (in.) | Hole Size max Axis (in.) | Average Hole Size (in.) | Penetration | |
| | 9.625 | 0.46 | 0.46 | 0.46 | THRU | |
| | 13.375 | 0.46 | 0.47 | 0.47 | THRU | |
| 1 | 20 | N/A | N/A | **N/A** | 0.089 | 86% Remaining Wall |
| | 9.625 | 0.46 | 0.47 | **0.47** | THRU | |
| | 13.375 | 0.44 | 0.48 | **0.46** | THRU | |
| 2 | 20 | N/A | N/A | **N/A** | 0.077 | |
| | 9.625 | 0.46 | 0.47 | **0.47** | THRU | |
| | 13.375 | 0.48 | 0.51 | **0.50** | THRU | |
| 3 | 20 | N/A | N/A | **N/A** | 0.059 | |
| | **9.625** | **0.46** | **0.47** | **0.47** | **THRU** | |
| | **13.375** | **0.47** | **0.49** | **0.48** | **THRU** | |
| **Average** | **20** | **N/A** | **N/A** | **N/A** | **0.075** | |



| Location on Graphic | Value (in.) | Material |
|---|---|---|
| PAC-7037-451C | 1.265" Internal Charge Standoff | |
| A | N/A | 7" Gun Section |
| B | 45° (0.711), 90° (0.767), 135° (0.824), 180° (0.848) | Fresh Water |
| C | 0.545 | 9.625" 53.5# Q-125 |
| D | 45° (0.717), 90° (1.290), 135° (1.934), 180° (2.222) | Fresh Water |
| E | 0.514 | 13.375" 72# P-110 |
| F | 45° (0.908), 90° (2.210), 135° (3.987), 180° (4.855) | Fresh Water |
| G | 0.635 | 20" 133# K-55 |

*Left to Right_45°, 90°, 135°, 180°

| Phase | Casing | Results | | | | Notes |
|---|---|---|---|---|---|---|
| | | Hole Size min Axis (in.) | Hole Size max Axis (in.) | Average Hole Size (in.) | Penetration | |
| 45° | 9.625 | 0.47 | 0.48 | **0.48** | THRU | |
| | 13.375 | 0.51 | 0.57 | **0.54** | THRU | |
| | 20 | N/A | N/A | **N/A** | 0.094 | 85% Remaining Wall |
| 90° | 9.625 | 0.46 | 0.50 | **0.48** | THRU | |
| | 13.375 | 0.52 | 0.52 | **0.52** | THRU | |
| | 20 | N/A | N/A | **N/A** | 0.068 | 89% Remaining Wall |
| 135° | 9.625 | 0.46 | 0.49 | **0.48** | THRU | |
| | 13.375 | 0.53 | 0.57 | **0.55** | THRU | |
| | 20 | N/A | N/A | **N/A** | 0.050 | 92% Remaining Wall |
| 180° | 9.625 | 0.44 | 0.46 | **0.45** | THRU | |
| | 13.375 | 0.48 | 0.51 | **0.50** | THRU | |
| | 20 | N/A | N/A | **N/A** | SPLASH | ~ 100% Remaining |

**Table 2:** Low-side test setups (with collar offsets) – Upper left side

Low-side test setups (with collar offsets) – Upper right side

Phased coverage test setup – Lower left side

Phased coverage test results – Lower right side

### *Results, Interpretation, and Operational Considerations*

The test results confirm that the PAC-7037-451C charges are a robust and safe option for multi-string perforation in abandonment operations. In mildly deviated well sections, casing offset led to outer casing damage below 15% of wall thickness, while in highly deviated zones, maximum penetration reached 53%. However, damage was primarily due to residual jet energy causing deformation rather than full perforation. This distinction is visually supported in the graphical results, which show casing wall deflection rather than complete penetration. Metal extrusion effects, quantified between 0.050" and 0.100", suggest that actual remaining wall thickness could be between 92% and 84%, as indicated in the summary tables. Additionally, graphical comparisons between coupon tests and full-system tests demonstrate a reduction in penetration due to wellbore pressure and fluid density. The recommended operational deployment is the gun just below a casing collar identified with a CCL tool, as it creates clearance between casing strings and further reduces potential for outer casing damage and reinforces the system's reliability under challenging well conditions.

## 5. Results & Discussion

### *Evaluation of well integrity before and after the intervention*

One of the main achievements of the technical abandonment of the well XXX was to ensure its integrity, with effective barriers that prevented fluid leaks. The integrity barrier analysis showed the barriers are effective in mitigating any fluids to surface. The operation followed resolution 40622 of 2023 and Ecopetrol's internal guidelines for well integrity and asset divestment.

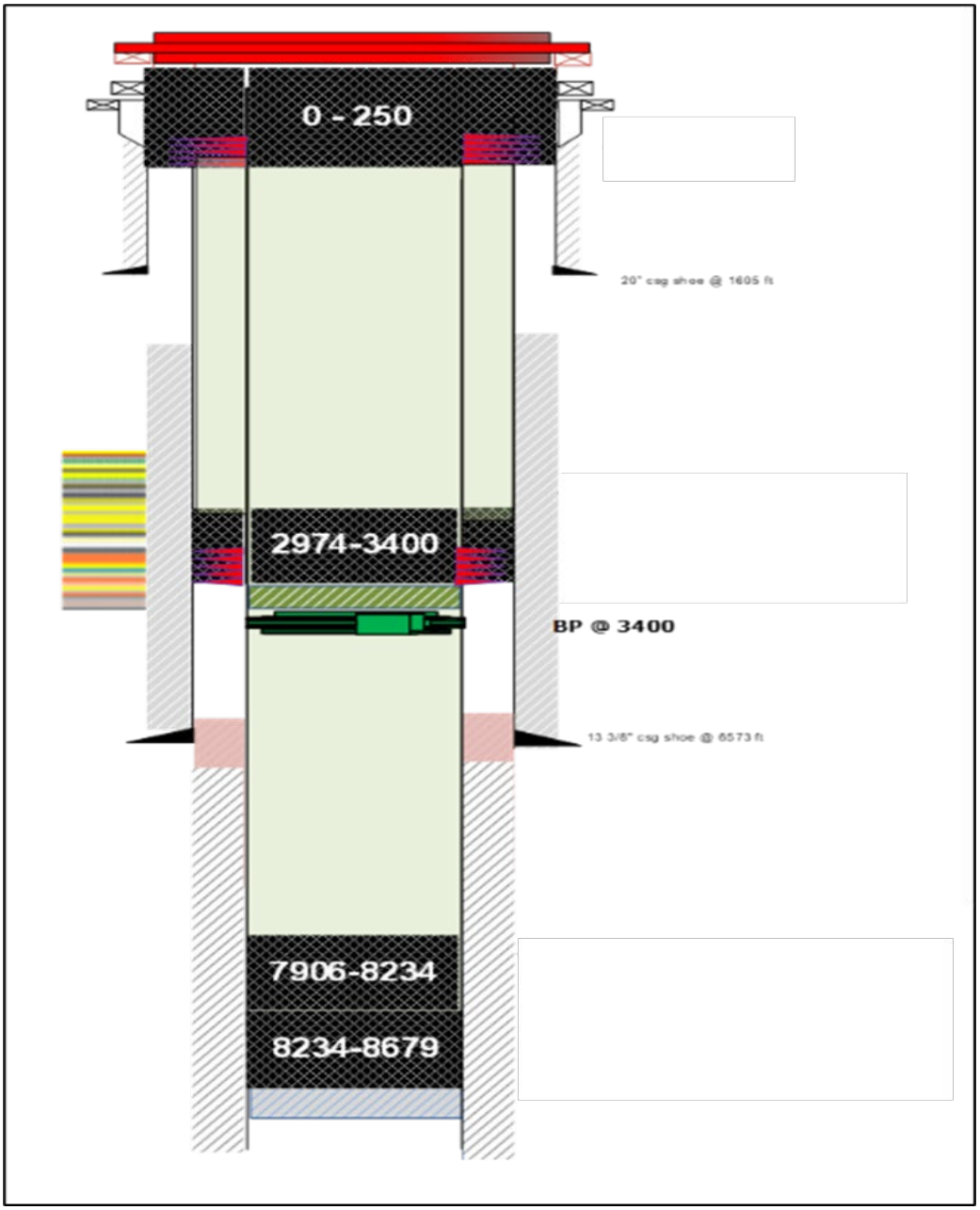



**Fig. 5.** Mechanical condition of the abandoned well XXX with effective barrier elements.

The use of PAC charges for perforation proved to be an effective technique for well abandonment, as it allowed access to the B and C annuli for subsequent cement placement and the required zonal isolation. Given that the casing metallurgy was harder than that of conventional casings, this challenge was addressed by designing custom PAC charges specifically for the well XXX. These were assessed and the necessary planning coordinated to ensure their timely delivery for use during the definitive abandonment operation.

The planning of the well XXX definitive abandonment, conducted in close coordination with regulatory authorities, technical leaders, and completion teams, proved to be a successful strategy. This collaborative approach ensured operational efficiency, minimized unplanned delays, and reduced the risk of undesired events.

## 6. Conclusions & Recommendations

The integrated results from the casing integrity sensors (electromagnetic induction tool and multi-finger imaging tool) and production logging tool confirmed that the 9-5/8" casing was in good condition and was not damaged. It was established that fluid entry occurred downhole, coincident with the location of the plug at 8,798 ft MD, as indicated by the production logging tool.

***Impact of the technologies used.:***

The success of the interventions for the abandonment operation of the well XXX was based on the thorough planning of each activity; carried from the implementation of the design and testing of the dampened charges to the synergy between the operator's multidisciplinary teams and their allied service companies.

With the multi-finger imaging tool, electromagnetic induction tool and production logging tool, a comprehensive and reliable integrity assessment was achieved, allowing the correct location of abandonment plugs and avoiding false negatives of leaks.

The use of PAC dampened charges proved to be an effective and safe perforating technology for enabling communication between annular spaces and the subsequent injection of cement to achieve isolation between them. Its effectiveness was confirmed after the perforating operation by equalizing the monitoring pressures between the annular spaces.

***Recommendations for future abandonment in mature fields.:***

*Integration of Advanced Integrity Assessment Tools*

Future abandonment operations should systematically incorporate advanced diagnostic tools such as multi-finger calipers, electromagnetic induction devices and production logging tools during the planning and diagnostic phases. These tools enable precise detection of internal wear, metal loss, and corrosion, significantly reducing uncertainty and eliminating reliance on assumptions or incomplete data. In well XXX, their use enabled identification of gas migration through a cement plug at 8,798 ft, confirming their role in verifying seal integrity.

These technologies are not optional enhancements; they are essential for ensuring safety, cost-effective, and regulation-compliant abandonments. Although specific financial data is still confidential, the use of targeted diagnostics avoided incorrect abandonment interventions and unplanned re-entries. This translated into reduced non-productive time (NPT) and improved cost-efficiency. Strategic planning with reliable technical data ensures regulatory compliance while optimizing resources.

*Application of Damped Casing Punching Charges*

The deployment of PAC-7037-451C charges in well XXX proved to be a reliable solution under complex well conditions. These damped charges effectively perforated inner casings without compromising the structural integrity of the 20” conductor casing key to maintaining the final barrier. The precise perforations enabled proper cement placement between annular spaces, ensuring zonal isolation in line with regulatory requirements.

The combined application of advanced diagnostic and perforation technologies in well XXX resulted in a safe, efficient, and environmentally responsible abandonment. Given their effectiveness, these tools should become standard practice in wells with complex histories, pressure anomalies, or multiple casing strings.

## 7. Abbreviations

BHT – Bottom Hole Temperature
MD – Measured Depth
TVD – True Vertical Depth
TOC – Top of Cement
TOL – Top of Liner
BOP – Blow Out Preventor
ANH – National Hydrocarbons Agency
GR – Gamma Ray
CCL – Casing Collar Locator
MIT – Multi-finger Imaging Tool
PA – Primary Array Receivers
BHP – Bottom Hole Pressure
WHP – Wellhead Pressure
TEMP – Temperature

## 8. References

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## 9. Profile of the authors

**Osmary Méndez** is a Petroleum Engineer from Universidad de Oriente, Venezuela, with extensive experience in Cased Hole Services. She joined Halliburton in 2007 and initially served as a Cased Hole Integrated Services Consultant in Mexico. Since 2017, she has been part of Halliburton’s Center of Excellence in Quito, Ecuador,

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**Adriana Borrero Gómez** is a Petroleum Engineer from Universidad América in Colombia and holds a specialization in Project Management from Universidad El Bosque. She has over 10 years of experience in well completions and workover operations for onshore oil and gas wells, as well as in well testing, plugging, and abandonment activities across various Colombian oil fields. Since 2017, she has been working with Ecopetrol S.A., specifically with the Central Hub Completion Management team, where she is involved in the design, planning, and execution of completion, testing, and intervention programs for a wide range of well types, with a particular focus on heavy oil and gas wells.

**Alexander Duarte Perez** is a Petroleum Engineer from Universidad América in Colombia and holds an Executive MBA from IE University and a Master´s degree in QHSE. He has over 29 years of global experience in the Oil & Gas with the best service delivery for onshore / offshore operations in Egypt, Russia, Nigeria, and South America. Since 2019, he has been working with Ecopetrol S.A., as the Technical Authority for Wireline & Perforating operations in Exploration, Drilling, Completions, Plug & Abandon, leading optimization overall continuous operational with the exceptional improvement in SQ and HSE.

**Carlos Andrés Ramírez Echeverri** holds a Bachelor of Science in Geology and has over 17 years of experience in the oil and gas industry, with a strong background in high-pressure/high-temperature (HPHT) wireline projects. His expertise spans technical sales, business development, wireline operations, and formation evaluation. He currently serves as a Wireline Technical Sales Advisor at Halliburton, where he provides tailored solutions and technical support for open hole, cased holes, and borehole seismic services. He is currently enrolled in the Postgraduate Certificate Program in Carbon Capture, Utilization, and Storage, Climate Change, and Sustainability at the Colorado School of Mines.

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