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Applications of advanced well integrity evaluation technologies for critical decision making

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Dedication

First, I Humbly Thank ALLAH Almighty for giving me health and power to accomplish this work.

I would like to dedicate this work to my beloved parents, Family, Mentors, teachers and friends.

Acknowledgement

I would like to express my acknowledgement to all of those who have supported me throughout the preparation of this dissertation. My special thanks should be attributed to my supervisors Mr; Dobbi Abd El Madjid & Mr; Hani Benaicha. For Miss; C. Lakhal, A. Chakroun and for Mr; Mohamed Kelkouli and all SLB NAF team for the continuous support and for providing me with cutting edge opportunity to join SLB company.

I would like to thank the board of examiners for devoting their time reading and assessing this work.

I would like to thank the teachers and employees for their continuous support & advises.

Abstract

Well integrity failures lead to many issues that can affect the well life cycle and the production, application of advanced well integrity tools and cementing information can identify the material behind the casing and the isolation of critical formation and perforations interval in addition to leak detection interval. This project aims to investigate the impact of well integrity failure on production and well life, the study will involve in comprehensive literature, working on different case of studies by analysing cement evaluation and leak detection field data on Techlog software, assisting industry professionals in enhancing well design and over well production.

Key word: Well integrity, Isolation scanner, SLG map, USIT, CBL, VDL, WOC, TIE, slurry.

Résumé

Les défaillances de l'intégrité des puits entraînent de nombreux problèmes qui peuvent affecter le cycle de vie du puits et la production. L'application d'outils avancés d'intégrité de puits et d'informations sur le ciment peut identifier le matériel derrière le tubage et l'isolation de la formation critique et des intervalles de perforations, en plus de la détection des intervalles de fuite. Ce projet vise à étudier l'impact de la défaillance de l'intégrité du puits sur la production et la vie du puits. L'étude impliquera une littérature complète, travaillant sur différents cas d'études en analysant l'évaluation du ciment et les données de détection de fuite sur le logiciel Techlog, aidant les professionnels de l'industrie à améliorer la conception du puits et la production globale.

Les mots clés : l'intégrité des puits, Isolation scanner, WOC, SLG map, WOC, USIT, TIE, Bouillie de cément.

ملخص

تؤدي فشل سلامة الآبار إلى العديد من المشكلات التي يمكن أن تؤثر على دورة حياة البئر والإنتاج .يمكن أن تكشف تطبيق أدوات سلامة البئر المتقدمة ومعلومات الأسمنت عن المواد خلف العلبة وعزل التشكيل الحرج وفترات الثقب، بالإضافة إلى فترة الكشف عن التسرب .هذا المشروع يهدف إلى التحقيق في تأثير فشل سلامة البئر على الإنتاج وحياة البئر .ستتضمن الدراسة أدبيات شاملة، تعمل على حالات دراسية مختلفة من خلال تحليل تقييم الأسمنت وبيانات الكشف عن التسرب على برنامج ، مساعدة المهنيين في الصناعة على تحسين تصميم البئر والإنتاج العام.

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CHAPTER V

I.1 Abbreviations & nomenclature

CBL: Cement bond log

DSSV: Downhole Safety Valve

ECD: Equivalent circulating

HPH: High-Pressure and High-Temperature

HSE: Health, Safety, and the Environment

HSR: High Sulphate Resistant

IOCs: International Oil Companies

KPI: Key Performance Indicator

LOT: Leak-off test

NCS: Norwegian Continental Shelf

NOCs: National Oil Companies

NOGEPA: Netherlands Oil and Gas Exploration and Production Association

NORSOK: Norwegian Petroleum Standardization Organization

OBM: Oil-based mud

OWC: Oil well cement

P&A: Plugging and abandonment.

PSA: Petroleum Safety Authority

SCSSV: Surface controlled subsurface safety valve

TOC: top of cement

VDL: Variable density log

AI: Acoustic impedance

FA: Flexural Attenuation

SLG map: Solid Liquid Gas map

IBC: Isolation scanner.

GR: Gama Ray.

General Introduction

I.2 General Introduction

This study will begin with a thorough review of relevant literature, examining case studies, industry reports, and scientific publications to identify the various ways in which well integrity failures can affect production. The analysis will focus on understanding the causes of well integrity failure, such as poor cement quality or cement deterioration, casing and tubing failures, and their subsequent consequences.

Data will be collected from field studies and industry databases to quantify the impact of well integrity failure on production performance. Factors to be considered include reduced production rates due to fluid losses or influxes, formation damage resulting from intrusion of unwanted fluids or solids, and the occurrence of water or gas coning. Additionally, the study will evaluate the impact of well integrity failures on safety concerns, and subsequent workovers or interventions, leading to production disruptions and increased operational costs.

Based on the findings, recommendations will be provided to mitigate the impact of well integrity failures on production. These may include best practices for well design and construction, as well as the implementation of robust monitoring and inspection protocols. The study aims to assist industry professionals in enhancing their understanding of well integrity management, enabling them to adopt proactive measures to prevent or minimize well integrity failures and optimize production efficiency.

By comprehensively evaluating the impact of well integrity failure on production, this project seeks to contribute to the knowledge base in the oil and gas industry, fostering safer, more sustainable operations.

CHAPTER ONE: WELL INTEGRITY OVERVIEW

I. CHAPTER ONE: WELL INTEGRITY OVERVIEW

I.3 INTRODUCTION

I.3.1 Well Integrity & HSE? [1]

Well Integrity is defined in Norsok D-010 as: “application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well”.

The well-operator shall ensure that a well is so designed, modified, commissioned, constructed, equipped, operated, maintained, suspended and abandoned that:

a) so far as is reasonably practicable, there can be no unplanned escape of fluids from the well.

b) risks to the health and safety of persons from it or anything in it, or in strata to which it is connected, are as low as is reasonably practicable.

“‘Reasonably practicable’ is a narrower term than ‘physically possible’ … a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants discharge the onus on them.”.

I.3.2 Well integrity History [2]

DEEPWATER HORIZON.

The Deepwater Horizon oil rig disaster that killed 11 workers and spilled millions of gallons of oil into the Gulf of Mexico in 2010.

The investigators concluded that no single catastrophic failure caused the demise of the Deepwater Horizon. Rather, BP's report paints a picture of a rig that was so thoroughly defective that virtually every component of a multi-layered safety system failed at the critical moment. The authors of the report are so focused on blaming subcontractors for specific errors that they don't seem to realize what a damning picture they're painting of the entire operation. BP was not running a tight ship.

The worst oil spill in U.S. history started with what BP calls a "well integrity failure." The cement plug that was supposed to seal off the well didn't actually seal. The leak allowed gas to shoot up the riser pipe and flood the rig.

Figure I-1: Water Horizon accident [2]

The report makes a pretty good case for blaming subcontractor Halliburton for pouring a shoddy plug and failing to test it. Halliburton was in charge of formulating the cement, pouring it, and testing the cement itself to make sure it set up properly. After the accident, BP went to great lengths to expose how poorly Halliburton mixed the cement. The report notes that Halliburton failed to perform key tests and suggests that Halliburton employees may have falsified the parts of the paper trail that does exist. If only BP had paid such close attention to Halliburton's work before the disaster.

Before the accident, the crew had tested the plug to see if it would hold. The results of the negative-pressure test were strikingly abnormal, and everyone knew it. The report concedes that, in retrospect, the test showed that that well wasn't sealed. According to the report, BP well site leaders and Transocean rig crew "misinterpreted" the results of the test and concluded that the well was sealed.

The report implies that interpreting a failure as a pass was an understandable mistake because there wasn't a lot of guidance available on how to interpret these tests. Allegedly, the Minerals Management Service (MMS) doesn't specify what constitutes a minimum standard or a "pass" in a negative-pressure test. The report also claims that investigators were unable to find any industry standards for assessing a negative-pressure test either. Lax federal standards are no surprise, especially where MMS is concerned, but it is hard to believe that no industry standards exist for interpreting negative-pressure tests. Capping wells is a pretty routine operation in the industry.

On the day of the accident, the crew didn't notice that the gas was escaping until it had already risen beyond the blowout preventer, which was designed to clamp down on the riser and pinch off a leak if the crew lost control of the well.

It turned out to be a moot point because the blowout preventer didn't work anyway. It was later discovered that one of the backup systems for activating the blowout preventor had a dead battery, the other had a broken valve. BP would like us to assume that the fault lies with Transocean, the owner and operator of the rig, for failing to maintain the blowout preventer.

The rig was equipped with ventilation and fire control systems in place to prevent gas from spreading through the rig, but those didn't work either.

BP's contractors probably did some shoddy work, and in retrospect BP doesn't seem to have been paying very close attention.

The Picayune investigation found that BP engineers were running the Deepwater Horizon in a hurry and on the cheap. They made a series of timesaving and cost-cutting decisions that left the rig vulnerable to a catastrophic failure – such as choosing to use a single long tube instead of a more expensive "tie back" setup. Independent engineers told the Picayune that the tie back setup is better because it creates an additional barrier to natural gas leaks. The Picayune cites a BP document saying that tie back was BP's preferred option, but that it would have cost an extra $10 million. The Deepwater Horizon project was already millions of dollars over budget.

BP can quibble over who should have checked up on which test results, but the fact remains that BP was ultimately responsible for a string of bad management decisions that ushered in the disaster.

I.3.3 WELL INTEGRITY

I.3.3.1 Definition of well integrity

As mentioned before from NORSOK D-010, Well Integrity is the application of technical, operational and organizational solutions, such as the use of competent pressure seals, to reduce the risk of uncontrolled release of formation fluids into another formation, to the surface, or to the environment, throughout the well life cycle to a level “ALARP” (As Low As Reasonable Practicable).(7)

In another way we can say it is a critical aspect of oil and gas production, ensuring safe and efficient operations throughout the life cycle of a well. However, well integrity failures can have detrimental effects on production rates, posing significant challenges to the industry.

This project aims to comprehensively assess the impact of well integrity failure on production in the oil and gas sector by using advanced cement evaluation technology to help

Figure I-2: Rig Offshore [3]

decision making about integrity of the well and overall, well production.

I.3.3.2 Well Integrity Concepts / Actions

Well Integrity is a matter of principal concern to all Oilfield employees, that may become involved in activities along the lifetime of a well, including non-naturally flowing well, from the planning stage, through its construction, completion, intervention, operation until its final PB & abandonment:

- In the Design of Barriers for Well Construction and Well Intervention (Examples: Cement Slurry, drilling fluid, tie back assembly, Rotating Control Device, etc.).
- In the Building of Physical Barriers in wells (cement or mechanical plugs, SCSSV, Well Head Assembly, Testing String, Flow Control equipment, etc.).
- In Engineering, Manufacturing & Sustaining equipment intended to be used as well barriers (completion packers, sliding sleeve, pressure lubricator, CT stripper).
- Implementing, Testing, and Monitoring Barriers built or installed by the well Operator or by another Company (Drilling BOP, liner hanger, shoe track valves, etc.).
- In the Maintenance and Re-certification of Well Barriers installed or repaired (casing / tubing string, BPV, tubing / casing hanger, Pressure Head, MPD Choke, etc.).

The well integrity is established by implementing and maintaining **well barriers** to prevent uncontrolled release of fluids from the formation while performing well operations or while the well is inactive or abandoned.

I.4 WELL LIFE CYCLE (3)

All wells follow a similar life cycle, regardless of their purpose, with some variations in their design and operational aspects. The well life cycle, as outlined in ISO 16530- 1 Petroleum and natural gas industries has the following phases:

- ✓ Basis of design phase
- ✓ Design phase
- ✓ Construction phase
- ✓ Operational phase
- ✓ Intervention phase
- ✓ Abandonment phase.

I.4.1 Basis of design phase:

The basis of well design phase is where the objectives of the well are set and the full life cycle operational requirements are determined, to allow for detailed design of the well in the next phase. Some of the information that is required at this phase includes: The location, Targets – formations and depths, well type (that is, exploration, production or monitoring), Well subsurface architecture (vertical, deviated or horizontal), Geological information, including expected formations, aquifers, faulting and temperatures, Geomechanical information, including pore pressures, rock strength, in situ stresses, porosity, permeability and temperatures. For an exploration well, data acquisition requirements for a production well, production parameters such as production rates, the composition of the fluids and gasses that will be produced, and the stimulation and testing strategies that will be used,

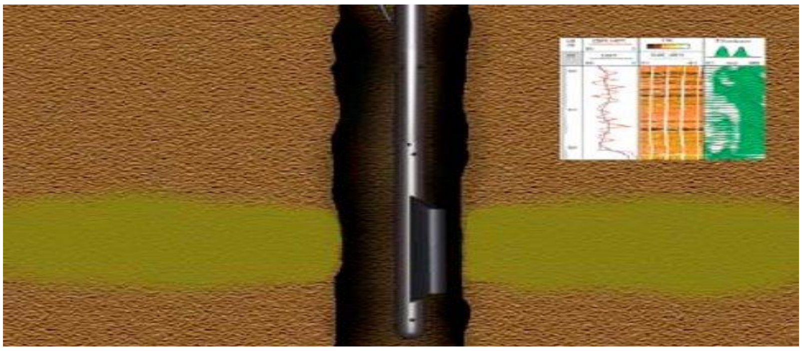


Figure I-3: Open Hole Logging [4]

Potential for planned re- completion or conversion of the well for other purposes (converting an exploration well to a monitor well, for example), The expected operating life of the well.

The geology of the resource and the overly2ing strata that must be drilled through to reach it are important because they determine the depth, thickness and gas content of the target shale horizon. Although shale resources are typically made up of flat lying layers of rock, geological features such as folds and faults are important in determining the geometry of the resource. Igneous intrusions may also cut through the resource, and the design of the well trajectory will need to take these features into account.

These geological, geomechanical and operational considerations are all important for well integrity. These factors need to be taken into account so that the design of the well reduces risks to its integrity.

I.4.2 Design phase:

In this phase, all aspects of the well are designed in detail, taking into account the overall life cycle of the well and all future operations, through to its eventual abandonment. The design is based on a detailed analysis of data and requirements collected during the previous phase, and include the following aspects:

Well design, and specification of materials and equipment (such as casing, cement and completion), Data acquisition program, including well logging, sample collection and well testing, well stimulation activities, if required, **Barriers to managing well integrity**, Operating procedures, including risk management and well integrity management, Plans for final abandonment of the well.

The design of the casing, cementing and completion are important for long- term well integrity. Casing is steel piping that provides a pressure tight conduit between the shale gas resource and the surface. Wellbore casing is a highly engineered product that is designed to cope with anticipated wellbore conditions. International standards cover the manufacture, testing, engineering specification, mechanical properties and performance of the casing. The casing prevents the unintended flow of drilling and hydraulic fracturing fluids out of the well, keeps the well open through weak or broken rock layers, and prevents formation fluids from entering the well and from moving between layers of rock via the well.

I.4.3 Construction phase:

The well construction phase involves drilling and completion of the well in accordance with the design. A focus during this phase is managing the risks associated with drilling and maintaining well integrity. Well control refers to the prevention of ‘kicks’, which are uncontrolled flows of formation fluids or gases into the wellbore that can reach the surface. A severe kick can lead to a blowout, which is the uncontrolled escape of fluid from the well.

Drilling fluids are an essential component of drilling operations and are distinct from the hydraulic fracturing fluids used during well stimulation. These fluids provide cooling and lubrication to the drill bit and drill string, lift drill cuttings from the well and are a component of well control. The density of the drilling fluid is increased by the use of additives to counteract any overpressures in the formation, preventing kicks and helping to maintain wellbore stability in uncased sections of the well. If the density of the drilling fluid is too high, drilling fluid may be lost in layers of rock. Additives that create a low permeability skin on the wellbore can be used to limit these losses.

Casing is installed and cemented in place in a number of stages during the construction phase. Initially, a large- diameter surface casing is set sufficiently deep to protect surface aquifers, and is fully cemented in the ground. Once a well is drilled to either the design depth or a depth where a casing string is required, a steel casing string is run into the borehole and cemented. The cement fills and seals the annulus between the casing strings, or between the casing string and the formation rock. This process is repeated until well construction is complete.

In each stage, the well is prepared (essentially, cleaned by the circulation of drilling

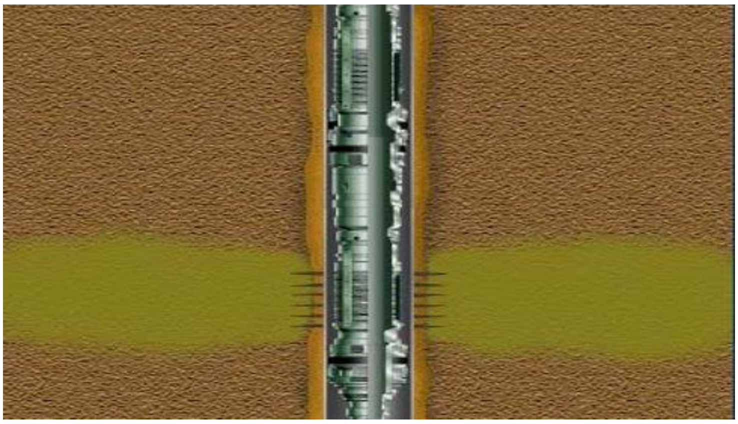


Figure I-4: Perforation Operation [8]

fluid) and cement is then pumped down the centre of the well so that it flows around and up the annulus between the casing and the surrounding rock. The well integrity provided by the cement depends on both the cement slurry design and several other aspects of the well cementing process; for example, preparation of the wellbore, and the condition and centralization of the casing. Ideally, the wellbore and casing would be prepared for cementing as follows: the wellbore diameter should be close to the drill bit size (known as the gauge), the surface of the wellbore should be smooth, during drilling, breakouts or washouts of the surrounding rock should have been minimized by good design of the drilling mud, there should be no formation fluid influx into the wellbore or major loss of drilling mud to the surrounding rock, The casing should be centralized, with a sufficiently wide annulus surrounding the casing to allow cement flow, The drilling mud in the hole should be properly conditioned to remove pieces of rock that may slough off the walls of the well.

During the construction phase, components of the well that contribute to the well's integrity are tested to verify that they are performing as designed. Verification is an important element of well integrity management. The integrity of well casing and cement can be tested by pressurizing the well, to verify that it can hold the pressures that it may be exposed to over its life. A variety of downhole logging tools can be used to measure the state of the casing and the integrity of the bond between the casing, cement and rock.

For production wells or wells used for formation testing, hydraulic fracturing (also known as well stimulation) activities are undertaken as part of the construction phase.

The final activity in the construction phase is the 'completion' of the well, preparing it to produce gas. Completion involves the installation of hardware in the well to allow the safe and efficient production of gas from the well at a controlled rate, and many different completion technologies are available. If the well was drilled for other purposes, or if the well is to be suspended, the completion will be designed accordingly. For example, instruments such as pressure meters or temperature sensors may be installed in a monitoring well during the construction phase.

I.4.4 Operational phase:

For production wells, the operational phase will have the longest duration, with some wells producing hydrocarbons for decades. During this phase, the main activities are monitoring the well's integrity and performance, and maintenance. Abnormal pressures in the annulus between casing strings can indicate integrity issues, as can changes in production rates. **Wireline logging**, in which measurement tools are lowered down the well on a wireline**, is generally the only means of checking the integrity of casing and cement down the well.**

Observations from a sample of wells can be used to indicate the integrity of wells across a field.

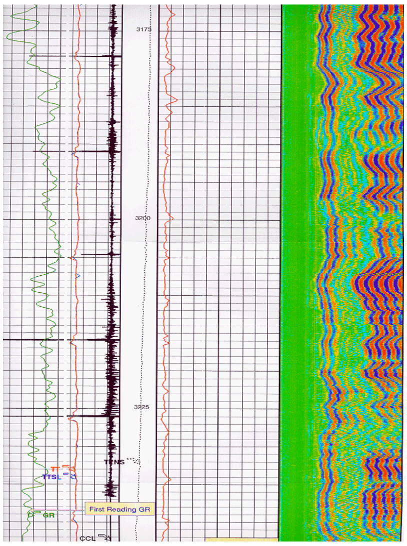


Figure I-5: Cement evaluation Log Example [8]

I.4.5 Intervention phase:

In some cases, a well must be re- entered to perform maintenance, repairs or replacement of components; for surveillance; or to increase productivity. Such interventions are also referred to as ‘workover’. **Interventions can be critical to maintaining well integrity, and a range of technologies are available for repairing casing and cement**. Production wells may be hydraulically re- fractured to extend their production, and the design of such activities needs to be commensurate with the design of the well and its current condition, allowing for any corrosion or other deterioration.

I.4.6 Abandonment phase:

The abandonment phase is the final phase in the well life cycle; in this phase, the wells are decommissioned, plugged and abandoned. The goal of plugging and abandoning the well is to ensure the integrity of the well in perpetuity, effectively re- establishing the natural barriers formed by the impermeable rock layers that were drilled through to reach the resource. Once a well has been abandoned, there is little prospect of re- entering the well for any purpose. Monitoring may be conducted after the well has been abandoned, to confirm that plugs have been properly set in the well. The well’s ongoing integrity should not be dependent on long- term monitoring [although such monitoring may be conducted to confirm the effectiveness of abandonment practices. The aims of abandonment are to:

- Prevent release of formation fluids or well fluids to the environment (including aquifers),
- Prevent the flow of groundwater or hydrocarbons between different layers of rock,
- Isolate any hazardous materials left in the well. The method of plugging and abandoning a well involves confirming the well’s integrity to ensure that there will be no movement of fluid into or out of the well and placing barriers in the well to prevent the vertical movement of fluids between rock layers.

I.5 Well barriers (8)

I.5.1 Well Barriers – Definitions and Principle

Well Barriers are any **device** or **element** (such as fluid column, casing, BOPs) that alone or in combination with other elements is capable of containing well pressure and preventing uncontrolled flow of fluids or gases from the formation, into another formation, or to the surface or environment.

Examples of Well Barrier Elements:

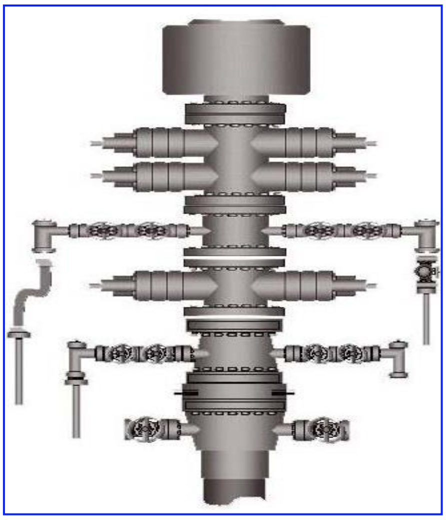


Figure I-6: Surface Bop Stuck [1]

I.5.2 Barrier Envelope

Barrier Envelop is the combination of **barrier elements** (such as casing, BOP, well head, mud column, etc.) which working together, form an envelope that prevents.

uncontrolled flow of fluids or gases from the formation into another formation or to the surface or the environment.

Example of Barrier Envelope for drilling below a casing set in a well:

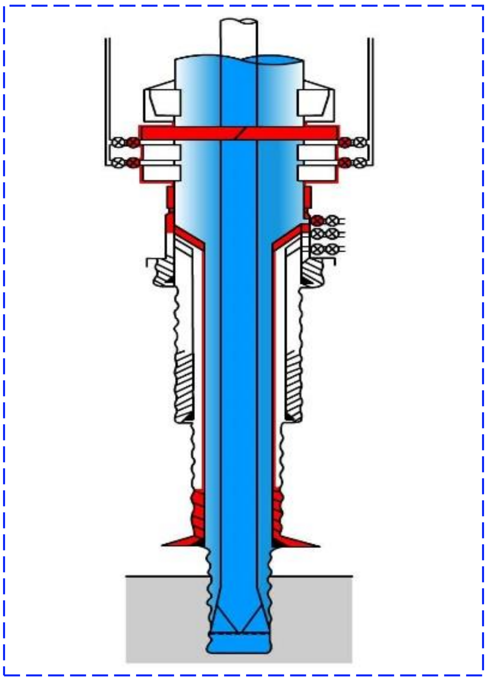


Figure I-8: Barrier envelope [1]

Components of barrier envelope:

- Last casing set in the well.
- Cement behind casing.
- Formation below casing shoe.
- Casing hanger.
- Well head assembly.
- BOP stack installed at surface.

All of them work together as an involving barrier.

Several barrier elements may be installed in the well and available to contain pressure or to prevent flow, But they will only serve as a containing barrier when they are interlinked to form a barrier envelope that blocks all possible leaking paths for pressure and flow If one Barrier Element fails, the whole Barrier Envelope also fails.

Primary & Secondary Barriers

* Primary Barriers:

Element or combination of Barrier Elements in direct (Primary) contact with the potential outflow source, the elements that "see" pressure during well operations, there are two types:

- For conventional drilling:

The Primary Well Barrier is the fluid column which is in direct contact with the outflow source. It controls or overcomes the formation pressure.

- For logging in cased hole:

Primary Well Barrier is formed by those elements which are in direct contact with pressure in the well: cemented casing, well head assembly, pressured lubricator and wire line valves.

Primary Barrier consists of all elements that are in direct contact with formation pressure and prevent flow during well operations. They can be:

- Drilling or Completion Fluid Column
- Production Casing or Tubing
- Well Head Assembly & Valves
- Casing or Tubing Hangers
- Lubricator and Pressure Head, etc.

***Secondary Barriers:**

Element or combination of Elements defined as the ULTIMATE defence should any of the Primary Barrier Elements fails, and as such preventing uncontrolled flow from the well to surface or to the environment.

It is the LAST and ULTIMATE barrier envelope providing well Integrity to be activated. It is not necessarily barrier number two in a sequence. When primary barrier fails the well start flowing up to the surface or to the external environment Formation pressure is contained and uncontrolled flow prevented by activating the defined **Secondary Barrier Envelope** (cemented casing, casing hanger, well head assembly, lateral valves, BOP activation) and by closing the well in (stabbing safety valve on DP).

Secondary Barrier: Redundant Barrier, outside the primary barrier, to be closed as last resort.

Examples of Secondary Well Barrier Envelopes for Drilling, Production and Well Intervention, for all well operations having potential uncontrolled flow of formation fluids to the surface, a second (external) barrier shall be defined and installed to be activated as the Last Resort for containment of formation pressure and flow.

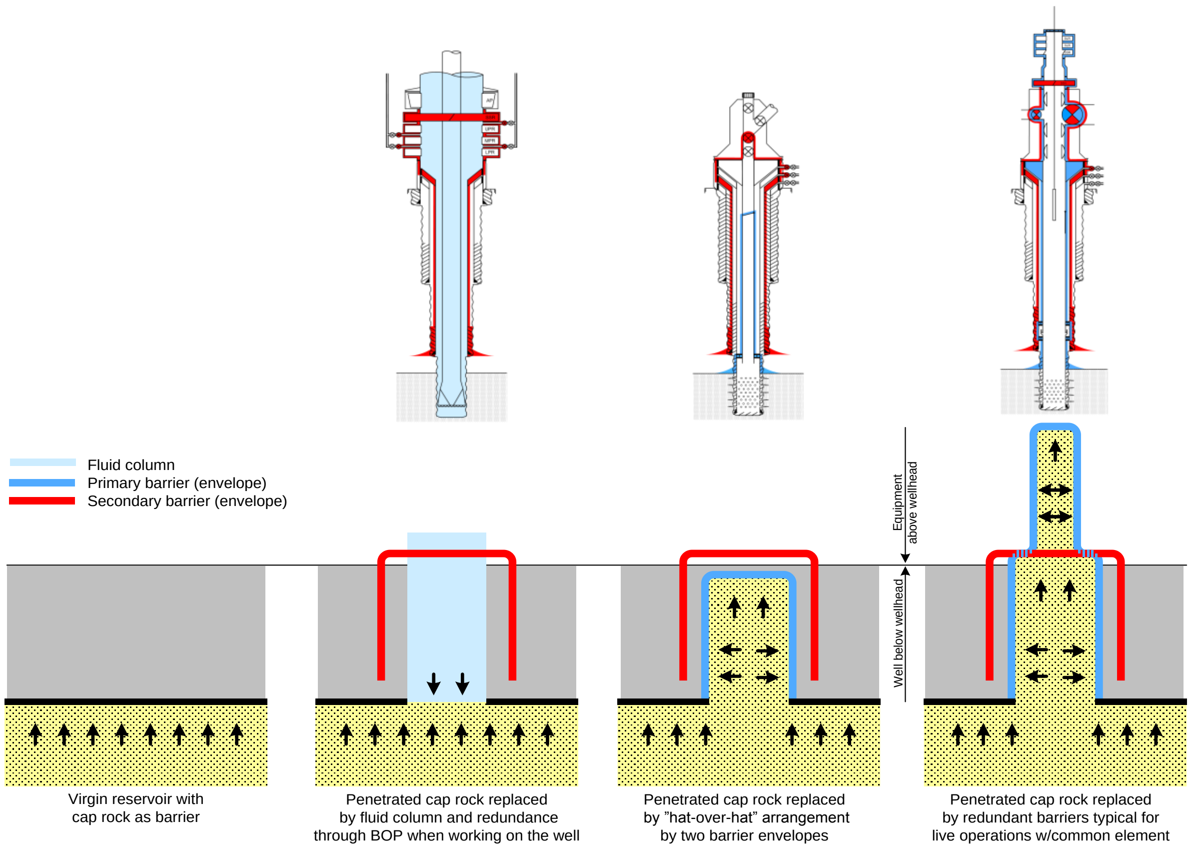


Figure I-9: Primary and secondary well barrier [1]

Common Barrier Element in cased hole

A common Barrier Element that simultaneously is part of the Primary and the Secondary Well Barrier Envelopes

Example:

The Master Valve installed in the base of Christmas Tree is a Common Well Barrier Element

- It is in direct contact with the pressured fluid in the well (PRIMARY BARRIER) and
- Simultaneously it forms part of the surface equipment that ultimately may contain flow and pressure (SECONDARY BARRIER).

If the common element fails, both barriers will also fail.

- So, Primary & Secondary Barriers are not independent.

Adding more valves on top of well head will only add redundancy to the Master Valve, Primary and Secondary Barriers still are not independent because the connection between the Master Valve and Well Head is a Common Well Barrier Element, When the condition of "Common Well Barrier Element" exists, a risk assessment shall be conducted to define the acceptable risk to be assumed and mitigation measures must be implemented, before rigging up equipment or before starting well activities.

The only way to make the two Barriers independent is by installing a down hole safety valve, "DHSV"

- For an abandoned well, the cemented casing, and plug set above the zone form the Primary Barrier while the DHSV is part of the Secondary Barrier. No common barrier element is present.

For a producer well, the Master Valve is part of the Secondary Barrier and the DHSV part of the Primary Barrier. No common barrier element exits in this case. (1)

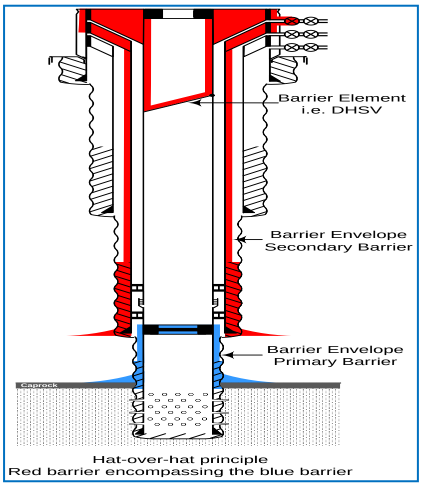


Figure I-10: Abandonment well [1]

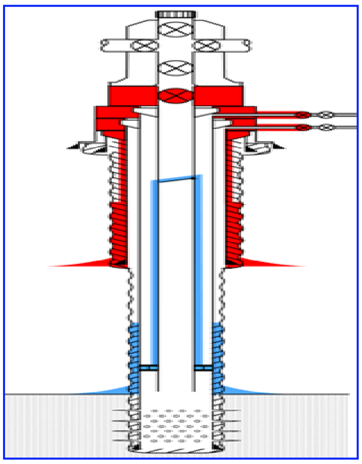


Figure I-11: Production well (1)

I.5.3 Well Barriers Failure:

Ensuring well integrity involves verifying various elements that comprise a well barrier. The concept remains consistent, but the specific barriers and elements employed vary based on the risks and operational needs of each phase. The design of well barriers is influenced by factors such as well design, characteristics of the targeted resource, and identified risks.

A failure in well integrity occurs when all barriers have been compromised, creating a pathway for fluid to enter or exit the well. In a two-barrier design, **both barriers must fail for a well integrity failure to happen**. However**, if the second barrier remains intact, a failure in one barrier will not result in fluid loss to or from the environment**.

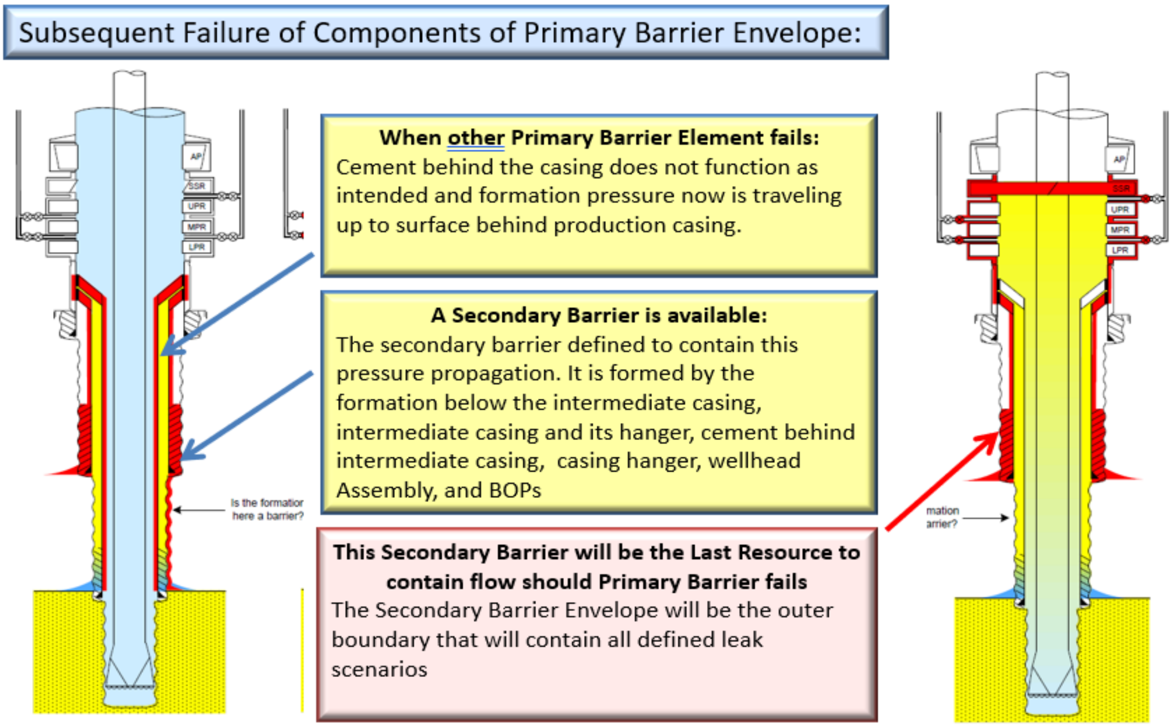


Figure I-12: Subsequent Failure (1)

Multiple factors can contribute to well integrity issues, including:

Well breach: This includes failures in cement sheaths, plugs, bonds, casing, and downhole and surface sealing components.

Hydrological breach: It refers to the movement of fluids between geological formations, including formations not originally intended for exploitation.

Environmental breach: This involves the contamination of or impact on water resources and water balance due to fluid leaks at the surface, causing water source contamination. Poor oil and gas well integrity can have various potential environmental impacts, such as:

Groundwater impact: Shallow and deep aquifers can be at risk of contamination due to inadequate well construction during drilling and production activities.

Localized hydraulic connectivity: Failed casing, insufficient cementing, or overall poor well construction, decommissioning, or abandonment practices can lead to hydraulic connectivity between isolated aquifers along the trajectory of a well.

Fugitive gas emissions: Oil and gas wells may experience localized gas leakage into both the atmosphere and aquifers, resulting from equipment failure or inadequate well construction and abandonment practices.(7)

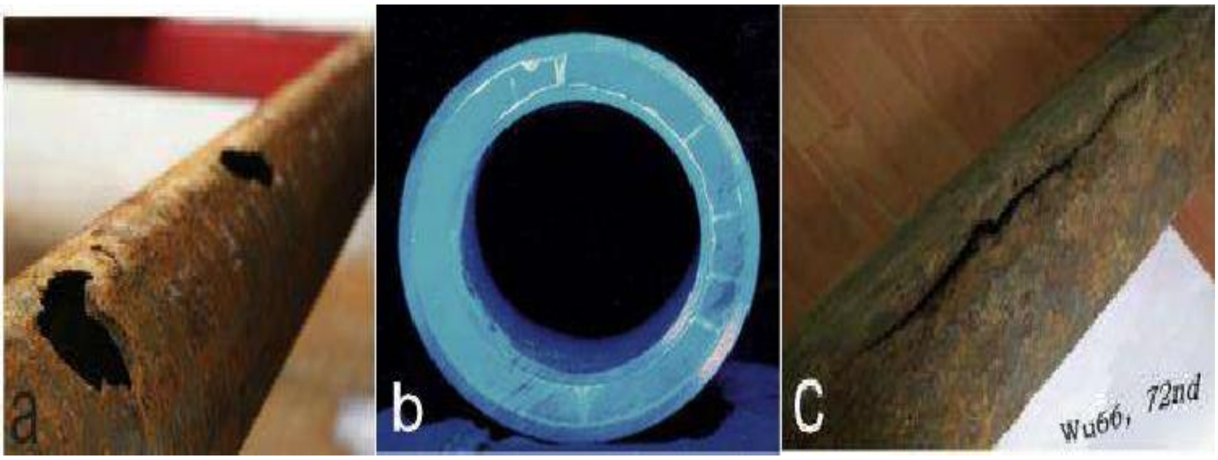


Figure I-13: Examples of casing failure [8]

CHAPTER II: CEMENTING JOBS OVERVIEW

II. CHAPTER TWO: CEMENTING JOBS OVERVIEW

II.1 Cementing (4)

Cement plays a crucial role in the petroleum industry, particularly in oil well construction and plug and abandonment (P&A) operations. It serves as a key well barrier element, creating a protective barrier between the casing and the formation, as well as functioning as a plug to seal the well during abandonment. The primary purpose of pumping cement slurry during drilling operations is to prevent the flow of fluids between formations or to the surface. It also helps bond the casing to the formation, provides support to the casing string, safeguards against corrosion from formation fluids, and seals off unwanted fluid zones.

The successful application of cement in well construction is essential for achieving zonal isolation and maintaining well integrity throughout the drilling and production phases. However, achieving the desired outcomes is not always straightforward, as various factors and downhole conditions can contribute to the failure of the annular cement sheath over the well's lifetime (Figure below). When the cement sheath fails, it compromises well integrity and can lead to undesirable consequences.

To ensure effective zonal isolation and prevent well integrity failures, it is vital to consider factors such as the cement mixture's composition, its permeability, and the downhole conditions during cementing operations. By understanding the complexities involved and identifying the influencing factors, the petroleum industry can develop strategies and best practices to mitigate the risks associated with cement sheath failure and enhance well integrity, However, challenges can arise due to various factors, underscoring the need for careful consideration of cementing practices to ensure long-term well integrity.

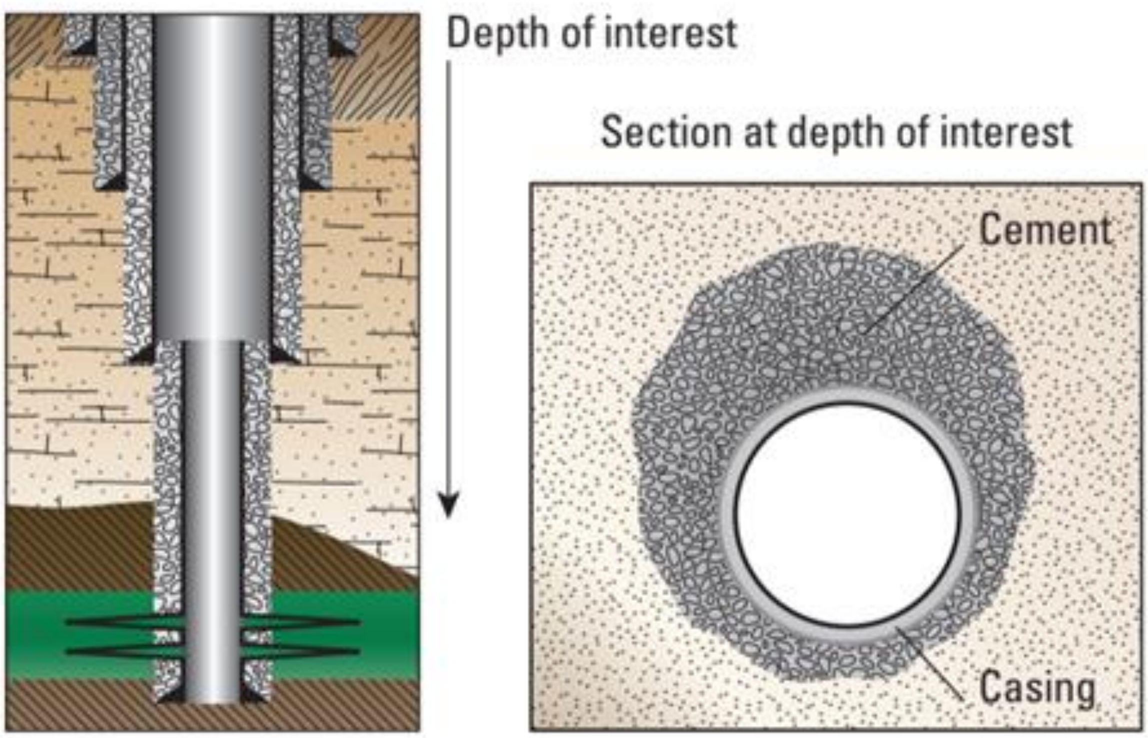


Figure II-1: A cross section of the well (4)

II.2 Classification of oil well cement:

Oil well cement can be classified based on different criteria, including their composition, setting time, and performance characteristics. The American Petroleum Institute (API) and the American Society for Testing and Materials (ASTM) provide widely used classifications for oil well cements. Here are the common classifications:

II.2.1 API Classes:

a. Class A: This class of oil well cement is typically used for surface and shallow well applications. It has a moderate sulfate resistance and is suitable for use in areas with low to moderate temperatures.

b. Class B: Where cement is designed for intermediate-depth wells. It offers higher sulfate resistance compared to Class A cement and is suitable for use in wells where moderate to high temperatures and pressures are expected.

c. Class C: This class of cement is primarily used for deep wells and high-temperature, high-pressure (HTHP) applications. It provides excellent sulfate resistance and is capable of withstanding harsh downhole conditions.

d. Class D: This cement is specifically designed for use in extremely deep wells with HTHP conditions. It offers superior sulfate resistance and exceptional durability.

These classifications provide guidelines for selecting the appropriate oil well cement based on well conditions, environmental factors, and specific operational requirements. Operators should consider these classifications along with other factors such as well depth, temperature, pressure, and wellbore conditions when choosing the most suitable cement for their applications.

II.3 Types of cementing job:

There are two main types of cement jobs in oil and gas operations: primary and secondary (or remedial) cementing.

II.3.1 Primary Cementing

This is the first cementing operation performed on a well. It involves pumping cement into the annular space between the casing and the drilled hole to isolate different zones within the reservoir, prevent fluid migration between zones, and support the casing. also Primary cementing, an essential procedure within the realm of oil and gas well construction, fundamentally underpins the structural sturdiness of the well. It's an integral process that meticulously assures zonal isolation and staunchly safeguards the environment by systematically encapsulating subterranean fluids.

This crucial process, in its quintessential form, constitutes the injection of cement slurry down the casing, guiding its ascent into the annular expanse between the casing string and the enveloping geological formation. This procedure aims at providing robust anchorage to the casing, imparting structural resilience to the well and effectuating zonal isolation. This signifies impeding fluids and gases from intermixing between distinct geological strata, thereby preserving the integrity of underground potable water sources.

The commencement of the primary cementing process involves circulating drilling mud throughout the wellbore, with the intent of purging it and conditioning the mud. This stage is paramount as it facilitates the removal of cuttings and ensures the maintenance of an appropriate mud weight to counteract the formation pressures effectively. Post the sanitation of the wellbore, the casing is introduced into the well to the stipulated depth. It is imperative to centralize the casing to ensure uniform thickness of the cement sheath.

Upon the preparation of the cement slurry, a plug, often referred to as a bottom plug, is dropped into the casing, being pushed by the cement slurry as it is pumped downwards. This plug functions to prevent the cement slurry from intermixing with the drilling mud. The cement is then directed down the casing and up into the annulus, displacing the drilling mud in its course.

Once the cement is correctly positioned, it is left undisturbed to set and harden, a process termed curing. Throughout this phase, the cement acquires the requisite compressive strength to support the casing and withstand the pressures exerted by subsurface formations. The final step of the cementing process encompasses pressure testing the casing to ascertain the integrity of the cement job.

Despite the significance of primary cementing, it comes with its own set of challenges. Common issues encountered during primary cementing operations encompass poor mud removal, inadequate cement coverage due to lost circulation, gas migration during the cement curing process, and cement shrinkage leading to an inadequate cement-to-casing bond.

To counter these challenges, extensive pre-job planning is undertaken, which involves the meticulous selection of casing centralizer placement, cement slurry design, and displacement mechanics. Moreover, various technological advancements, such as the usage of cement evaluation tools and software simulations, are employed to predict and analyze the outcomes of the cement job.

Nevertheless, even with these technological strides, primary cementing remains a delicate blend of art and science, heavily reliant on the experience and expertise of the cementing crew. In summary, a well-executed primary cementing job is the cornerstone of the long-term success and safety of an oil or gas well.

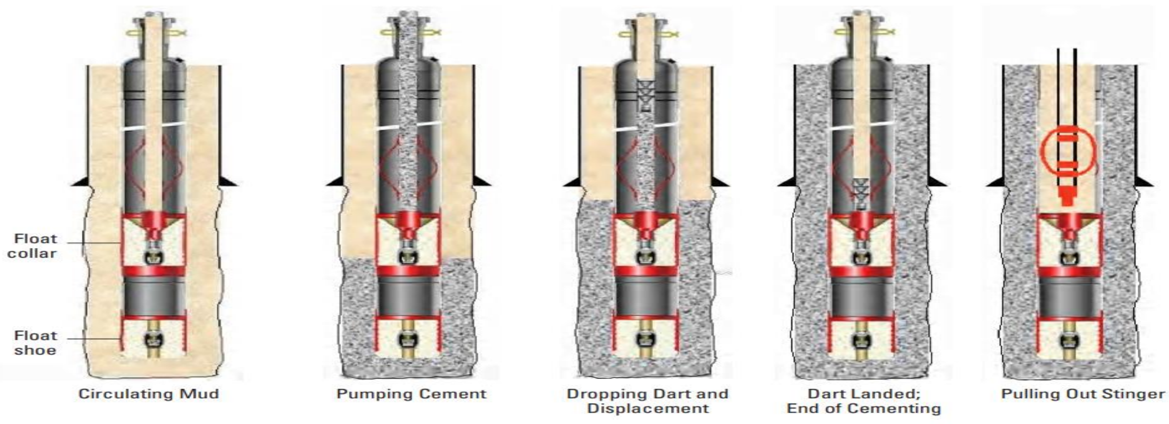


Figure II-2: Cementing job stages (8)

II.3.2 Secondary/Remedial Cementing

Also known as squeeze cementing, remedial cementing is performed to correct problems associated with the primary cement job. This could be for sealing off unwanted water or gas zones, repairing leaks in the casing, or plugging old wells.

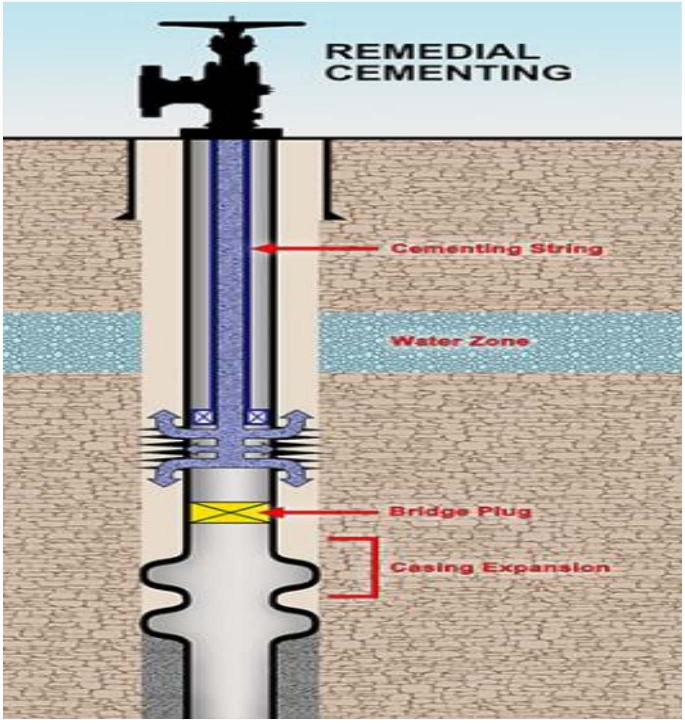


Figure II-3: Example of remedial cementing (8)

II.4 Cementing Operation Execution

The cementing operation can be divided into several key steps:

- Job design: This involves selecting the appropriate cement type, designing the cement slurry, determining the amount of cement needed, and planning the logistics of the operation.

- Mixing: The cement slurry is prepared by mixing cement, water, and other additives in a cementing unit.

- Pumping: The cement slurry is then pumped down the casing and up the annular space. A plug, known as a bottom plug, is pumped ahead of the cement slurry to separate it from the drilling fluid. A top plug is then pumped behind the cement slurry to ensure all the cement is displaced into the annulus.

- Waiting on Cement (WOC): After the cement has been displaced, the well is shut-in to allow the cement to harden and set. The length of the WOC period depends on the cement formulation and downhole conditions.

- Pressure Testing: Once the cement has set, the casing is pressure tested to ensure a good seal has been achieved.

II.4.1 Fluid Loss Considerations

When cement slurries are introduced into the formation, a pressure gradient emerges between the slurry and the formation, initiating a filtration process. The aqueous component of the cement slurry permeates the formation, segregating from the solid constituents. Depending on the balance between erosive forces during fluid movement and adhesive forces instigated by filtration, these solids may either form an external filter cake along the formation boundary or remain suspended within the cement slurry. A minority of the solids may penetrate larger pores within the formation, giving rise to an internal filter cake.

During the primary cementing process, the cement slurry travels adjacent to the formation wall, activating a dynamic tangential filtration mechanism. Generally, prior to the cement slurry, the formation would have interacted with drilling mud, chemical washes, and spacers, resulting in some degree of filtration into the formation. Subsequently, when pumping operations cease, a period of static filtration ensues. In contrast, during remedial cementing, filtration predominantly occurs under static conditions.

Deficient control of fluid loss can trigger primary cementing failures due to dramatic slurry viscosity increases during placement, annular bridging, or rapid pressure reductions during the waiting-on-cement (WOC) period. Moreover, the intrusion of cement filtrate into the formation can induce damage and depress production rates. However, fluid loss can occasionally have beneficial impacts, such as enhancing the bond between cement and formation, and increasing the formation fracturing pressure. Yet, these benefits are typically overshadowed by the associated drawbacks.

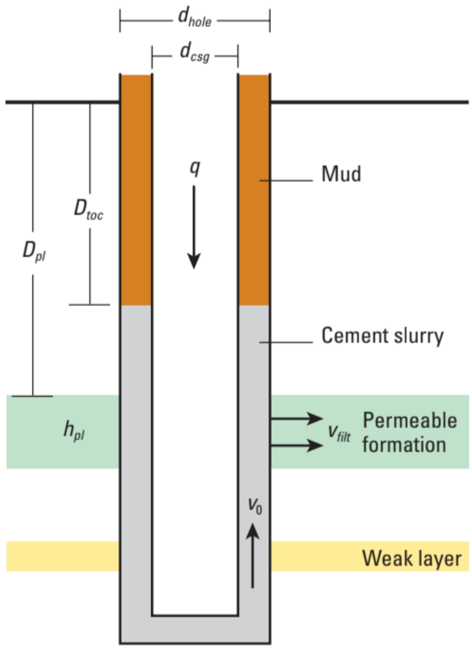


Figure II-4: Schematic of the well geometry (4)

Lost circulation, also known as the uncontrolled flow of drilling fluid into geological formations instead of returning up the wellbore, can be a serious problem during oil or gas well drilling. Lost circulation can result in the loss of drilling fluid and make it difficult to maintain well control and can range from minor leaks to severe losses exceeding 50 barrels per hour.

Some possible causes of lost circulation include:

- Naturally fractured or porous formations: These types of formations allow the drilling fluid to flow into the formation, which can cause a loss of circulation.
- Faults and fissures: Similar to fractures, faults and fissures in the formation can allow drilling fluid to enter and cause lost circulation.
- High differential pressure: This occurs when the hydrostatic pressure of the drilling fluid in the wellbore exceeds the formation pore pressure, causing the drilling fluid to enter the formation. Drilling into depleted zones: Sometimes, drilling into a zone with lower pressure than the wellbore can cause the drilling fluid to enter the depleted zone, causing a loss of circulation.
- Inadequate drilling fluid properties: If the drilling fluid properties are not appropriate for the formation being drilled (for instance, if the mud weight is too high), this can cause lost circulation.

Various techniques can be used to mitigate this problem, some of which are:

- Spotting lost circulation materials (LCMs) into the formation: LCMs are materials such as fibres, calcium carbonate, and bridging agents that can be spotted into the formation to seal fractures and permeable zones and prevent further loss of fluid.
- Using low-density fluids or foams: Drilling fluids or foams with low densities can be used to reduce the hydrostatic pressure and prevent further losses into the formation.
- Reverse circulation: This technique involves circulating the drilling fluid in a reverse direction from the bottom of the hole to the surface. The higher density fluid at the bottom of the hole can help to seal off the lost circulation zones.
- Managed pressure drilling (MPD): This is a technique where the fluid pressure is controlled to maintain a balance between the hydrostatic pressure in the wellbore and the formation pressure, which can be used to prevent losses.
- Cementing: Cement can be placed across the lost circulation zone to seal off the formation and prevent further losses.

It's important to note that the choice of technique will depend on several factors such as the severity of the lost circulation, the well conditions, and the type of formation being drilled.

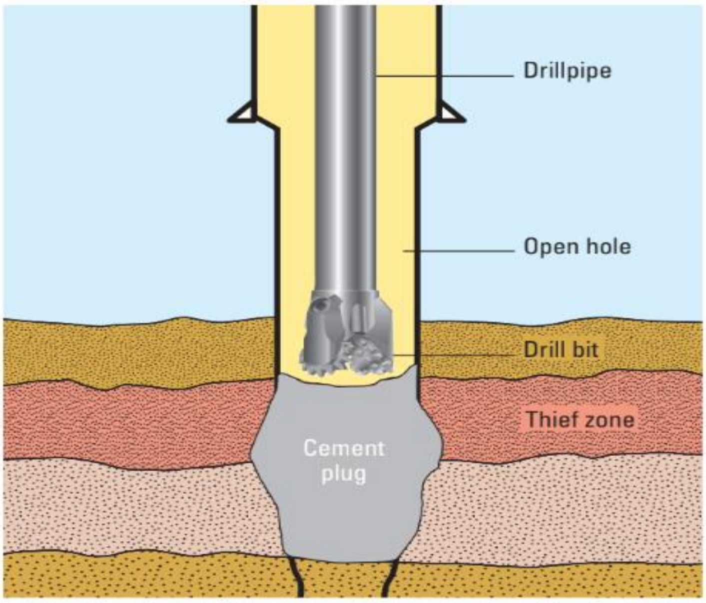


Figure II-5: Lost-circulation plug (4)

The practice of incorporating fluid loss-control agents into well cement slurries has been ongoing for decades, as their potential to substantially elevate the quality of both primary and remedial cementing jobs is widely acknowledged. Historically, straightforward fluid-loss criteria have been employed to justify the degree of fluid-loss control necessary for achieving satisfactory cementing outcomes. Yet, field verification of these criteria has presented challenges. More contemporary studies have sought to determine the optimal degree of fluid-loss control for specific scenarios.

In this section, fundamental concepts relating to static and dynamic cement-slurry filtration are explored. Subsequently, the significance of fluid loss in the context of primary and remedial cementing is examined. Finally, the discussion culminates in an overview of field measurements pertaining to fluid loss.

Effects of fluid loss on cement-slurry properties, a hypothetical primary-cementing situation is considered in which a cement slurry flows along a permeable formation. Only water can enter the permeable formation, and all of the cement particles remain in the slurry and do not form a dynamic filtercake. The fluids are assumed to be incompressible. This simplified problem allows one to derive quantitative fluid-loss criteria and rank the relative importance of each, although the direct use of these criteria is limited by our knowledge of dynamic filtration.

II.5 Implication of Cementing for well production and performance:

The implications of cementing for well production and performance are far-reaching and crucial in the oil and gas industry. Cementing plays a vital role in achieving zonal isolation, which is essential for the safe and efficient extraction of hydrocarbons from the subsurface reservoirs.

Zonal isolation refers to the isolation of different geological formations within the wellbore, preventing the unwanted flow of fluids between these zones. It ensures that production fluids, such as oil, gas, and water, are contained within their respective zones, minimizing the risk of cross-contamination and maintaining the integrity of the well.

Proper zonal isolation is critical for optimizing production rates, maximizing recovery, and mitigating potential environmental hazards.

The primary cementing operation is performed during the well construction process. It involves the placement of cement slurry into the annular space between the casing and the wellbore walls. The cement slurry is designed to create a strong bond between the casing and the formation, sealing off any potential pathways for fluid migration and maintaining the structural integrity of the well.

A successful primary cement job is essential for several reasons. Firstly, it ensures the mechanical support and stability of the casing, preventing its collapse and maintaining the wellbore integrity. This is crucial for drilling subsequent sections of the well and for the overall longevity of the well.

Secondly, a well-executed cementing operation facilitates efficient well production. By effectively isolating different reservoir zones, it allows for optimal reservoir management. This includes controlling the inflow of formation fluids, enhancing wellbore stability, and minimizing the risk of unwanted fluid migration or crossflow between zones. Proper zonal isolation ensures that the produced fluids are representative of the targeted reservoir, allowing for accurate reservoir evaluation and production optimization.

Furthermore, cementing influences well performance by mitigating potential production challenges. For instance, it helps prevent the unwanted production of water or gas from lower or non-targeted zones, which can lead to decreased production rates, increased operating costs, and potential safety hazards. It also aids in managing reservoir pressures, maintaining reservoir connectivity, and preventing unwanted fluid influx or outflow during production or stimulation operations.

However, if the primary cement job is not performed effectively, it can lead to zonal isolation failures. Such failures can result in unwanted fluid migration, the loss of well control, sustained casing pressure (SCP), gas or water channeling, or casing damage. These issues can significantly impact well productivity, increase operational costs, and pose risks to personnel safety and the environment.

To address these challenges and improve cementing practices, the industry continues to develop advanced cementing techniques, additives, and monitoring technologies. These advancements aim to enhance cement job quality, increase zonal isolation reliability, and optimize well performance. Additionally, thorough quality assurance and quality control processes, including cement bond logging and post-job evaluations, are conducted to verify the effectiveness of the primary cementing operation and identify any remedial actions if required. Proper cementing practices contribute to optimized production rates, increased hydrocarbon recovery, and minimized operational risks. Conversely, inadequate cementing.

II.6 Cement-Formation Interactions: The Crucial Role of Cement Sheath Bonding

The effectiveness of zonal isolation provided by a cement sheath within a wellbore is intimately linked to a triad of pivotal attributes:

1.The bond established at the cement-casing interface,

2.The inherent properties of the bulk cement,

3.The interface between cement and the geological formation.

Prevailing cementing recommendations are frequently anchored in the compressive or tensile strength of the set cement. In fact, a number of governmental regulatory entities have stipulated minimum strength prerequisites for well cements. This institutionalized assumption suggests that a material that conforms to certain strength benchmarks will invariably provide a satisfactory bond with both the casing and the formation. However, field and laboratory experiences have consistently revealed the occasional fallibility of this assumption.

Within the wellbore environment, two key criteria typically employed for assessing effective zonal isolation at the cement/casing and cement/formation interfaces are the shear bond and the hydraulic bond. The shear bond performs a crucial mechanical function, sustaining the pipe within the wellbore. This bond is gauged by calculating the initial force necessary to induce pipe movement within a cement sheath. Dividing this force by the contact surface area between the cement and casing yields the shear-bond strength. The hydraulic bond, on the other hand, plays an essential role in inhibiting the migration of fluids within a cemented annulus. This bond is typically quantified by the application of pressure at the pipe/cement or pipe/formation interface until the point of fluid leakage. In the context of zonal isolation, the hydraulic bond bears greater significance than the shear bond.

II.7 Practical Implications of Gas Migration

The potential repercussions of gas migration subsequent to primary cementing are manifold, often subtle, and not always instantly discernible. In extreme cases, symptoms surfacing at the surface like sustained casing pressure or gas flow at the wellhead, may necessitate well abandonment. More commonly, remedial cementing is carried out until gas flow is halted and gas pressure is reduced to levels congruent with the operator's safety protocol and local regulations. Nonetheless, the effectiveness of squeeze cementing under these circumstances tends to be quite low, due to three fundamental reasons:

1.Gas channels, particularly those less than 1mm in size, are hard to identify.

2.Gas channels might be too diminutive to be effectively filled by cement.

3.The pressure applied during the squeeze job could potentially rupture cement bonds or even instigate formation fracturing, thereby exacerbating downhole communication problems.

Gas migration between two or more subsurface zones without any surface indications is exceptionally challenging to detect (Fig). Under these circumstances, gas production might be compromised, gas could be redirected to an upper depleted zone (potentially leading to gas migration to the surface via another well), or the efficacy of stimulation treatments might be curtailed. Such downhole channeling can occasionally be assessed through specialized techniques like noise log.

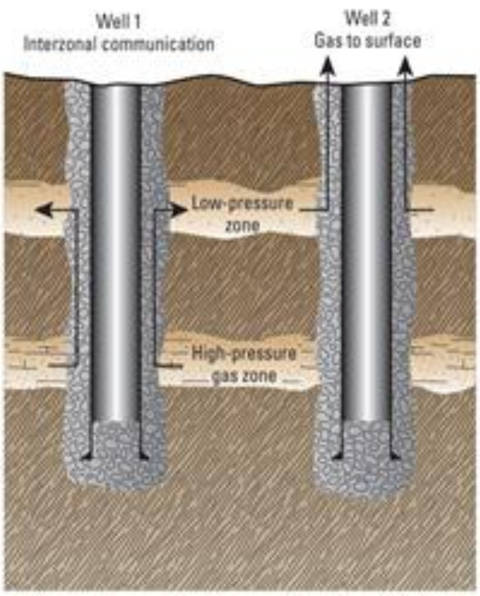


Figure II-6: Two scenarios of annulare gas migration (4)

II.8 Test on perforation:

Tests through perforations in some areas, especially when the production interval has a low permeability, the isolation provided by the cement is evaluated after the perforation of the intervals to be produced. The well then produces through the perforations and the production is analyzed. The presence of water in the produced fluid typically indicates annular communication and the need for remedial cementing. When cement bond logs (CBLs) show poor results or when effective isolation is required over short intervals, the casing is perforated in two different locations. A packer is set between both sets of perforations, and pressure is applied at the lower perforations. This is a communication test. If pressure transmission or annular transmission is observed, hydraulic isolation in the annulus is inadequate, and remedial cementing is necessary. Because many operators are reluctant to add extra perforations to a casing string, this test is rarely performed today. Temperature, nuclear, and noise logging measurements and Ultrasonic logging also Temperature logging is often used to evaluate primary cement jobs, mainly to detect the top of the cement column. Temperature surveys are also performed to detect leaks or channeling. Fiber optics can also be used to measure the temperature in the wellbore. The fiber is placed inside the annulus (in a control line) or inside the casing. The temperature is recorded versus time and depth. Such measurements provide valuable information regarding cement placement.

Cement hydration detector Temperature surveys are often used to detect cement in the annulus several hours after cement placement. The exothermic cement-hydration reactions raise the wellbore temperature, resulting in a deviation from the normal temperature gradient. Temperature logs may not be suitable for evaluating very long cement columns, because there may be a large temperature differential between the top and the bottom of the well; also, the cement at the top of the column may require a long time to set. (4)

II.9 Casing (4)

The casing used in well construction plays a significant role in determining the overall cost and performance of the well. It is crucial to carefully select the appropriate casing type, including its length, grade, and size, based on the specific requirements and geological data. Casing serves several important functions within a well.

One key function is the isolation of well fluids from both the formation and other fluids present in the well. This ensures that the production fluids are contained within their intended zones and prevents cross-contamination. Additionally, casing helps prevent borehole collapse during drilling operations by providing structural support. It also provides a clear pathway for the circulation of drilling fluids and minimizes damage to the subsurface environment.

There are five main types of casing used in well construction.

II.9.1 Types of casing

The first type is the conductor casing, which is the largest and typically set approximately 100 feet below the ground surface. Its primary function is to seal off unconsolidated formations near the surface, which can be easily washed out during continuous mud circulation. These formations often have low fracture gradients that can be surpassed by the hydrostatic pressure exerted by the drilling fluids.

Surface casing, the second type, is used to seal off freshwater zones and provides support for the blowout preventer (BOP). Its setting depth needs to be accurately determined, especially in areas where high pressure is anticipated. If the surface casing is set too high or its depth is underestimated, the formation at the casing shoe may not withstand the pressure generated during the circulation of gas influx while drilling the next section.

Intermediate casing is set between the surface and production casings. Its purpose is to isolate formations that could impede drilling to the total depth of the well. These troublesome zones often exhibit abnormal formation pressures, lost circulation, or unstable shales and salt sections.

Production casing is set through the prospective productive zones, unless an open-hole completion is planned. It is designed to withstand the maximum shut-in pressure of the producing formations and may also need to withstand stimulating pressures during completion and work-over operations. Furthermore, production casing provides environmental protection in the event of tubing string failure during production and allows for repair and replacement of the production tubing.

The last type is liners, which are strings of casing that do not extend to the surface. Liners are hung on the intermediate casing using a liner hanger. In liner completions, both the liner and the intermediate casing act as the production string. The design criterion for liners often revolves around their ability to withstand the maximum expected collapse pressure.

II.9.2 Types of Liners

The strength properties of casing are vital considerations in casing design. Three main loads must be taken into account: yield strength, collapse pressure, and burst pressure. Yield strength refers to the tensile stress that produces 0.5% elongation per unit length of the casing specimen. It varies depending on the steel alloy used for the casing joint, and data for both the main body and coupling yield strengths are provided by the manufacturer.

Collapse pressure results from the hydrostatic pressure exerted by the column of mud within the well, acting on the outside of the casing. As the hydrostatic pressure increases with depth, the collapse pressure is highest at the bottom and decreases towards the top. It can be calculated using equations such as Collapse Pressure = External Pressure – Internal Pressure.

Burst pressure is an important factor to consider in casing design. It is based on the maximum formation pressure expected during drilling of the next hole section. In the event of a kick, where influx fluid displaces the drilling mud, the entire casing string is subjected to the bursting effects of formation pressure. The burst pressure is highest at the top of the hole, where the external pressure due to the hydrostatic head of mud is zero, and the internal pressure must be supported entirely by the casing body. On the other hand, the burst pressure is least at the casing shoe.

The burst pressure can be calculated using the following equation:

Burst pressure = internal pressure – external pressure

Another equation commonly used for calculating burst pressure is:

$$P_{br} = 0.875 * ((2 * \sigma_y) / (d_0 / t))$$

Where:

P_{br} is the burst pressure

σ_y is the yield strength of the casing

d_0 is the outer diameter of the casing

t is the thickness of the casing

Tensile forces in casing occur due to combined buoyant weight, shock loads, and pressure tests. In casing design, the topmost joint is considered the weakest in tension as it must carry the total weight of the casing string. The casing liner hanger, which supports the casing string when it is lowered into the wellbore, is typically assessed for tensile forces. Casing hangers provide a seal between the casing hanger and the spool and are usually part of the secondary well barrier. They are typically welded or screwed to the top of the surface casing string.

The biaxial effect refers to the reduction in collapse resistance of the casing in the upper part of the string due to the weight hanging below. Axial tension reduces the collapse resistance, and biaxial stress further reduces the collapse resistance of the casing in plastic failure mode.

Casing wear is a common problem in deep and highly deviated wells, where doglegs and large tensile loads on the drill string produce high lateral loads on the casing. It is a complex process influenced by variables such as temperature, drilling fluid type, percentage of abrasives in the drilling fluid, tool joint hard facing, revolutions per minute, tool joint diameter, contact load, and others. Casing wear can compromise the integrity of the casing, leading to blowouts, lost circulation, and other costly and hazardous problems. Measurement and analysis of casing wear over the lifetime of a well are necessary, and the risk of induced casing wear during P&A (plug and abandonment) operations should be studied in abandonment designs.

Casing corrosion can cause metal loss if hydrocarbons containing CO2 and/or H2S continuously enter an annulus. However, a leak path from tubing to annulus usually allows only a small quantity of hydrocarbons to be introduced at any one time. This results in a static annulus condition that forms more protective corrosion films than suggested by corrosion models. Mitigation strategies for casing corrosion include the use of corrosion inhibitors and oxygen scavengers in completion fluids or maintaining positive pressure in the annulus to prevent oxygen ingress at the surface.

Casing shoe strength (CSS) is crucial for ensuring well integrity. Determining CSS is part of the drilling and well completion design process. Subsurface failure of a well due to sustained casing pressure requires knowledge of the casing shoe strength at the casing depth. Accurate knowledge of the maximum pressure that the casing shoe can withstand is essential for planning mud weight, casing setting depths, kick tolerances, and the design of fracture operations. The weight of the overburden and reservoir pressure primarily create the in situ stresses. Measurement of casing shoe strength involves considerations such as formation tests and extended leak-off tests (XLOT), which are used to determine the integrity of shallow casing shoes.

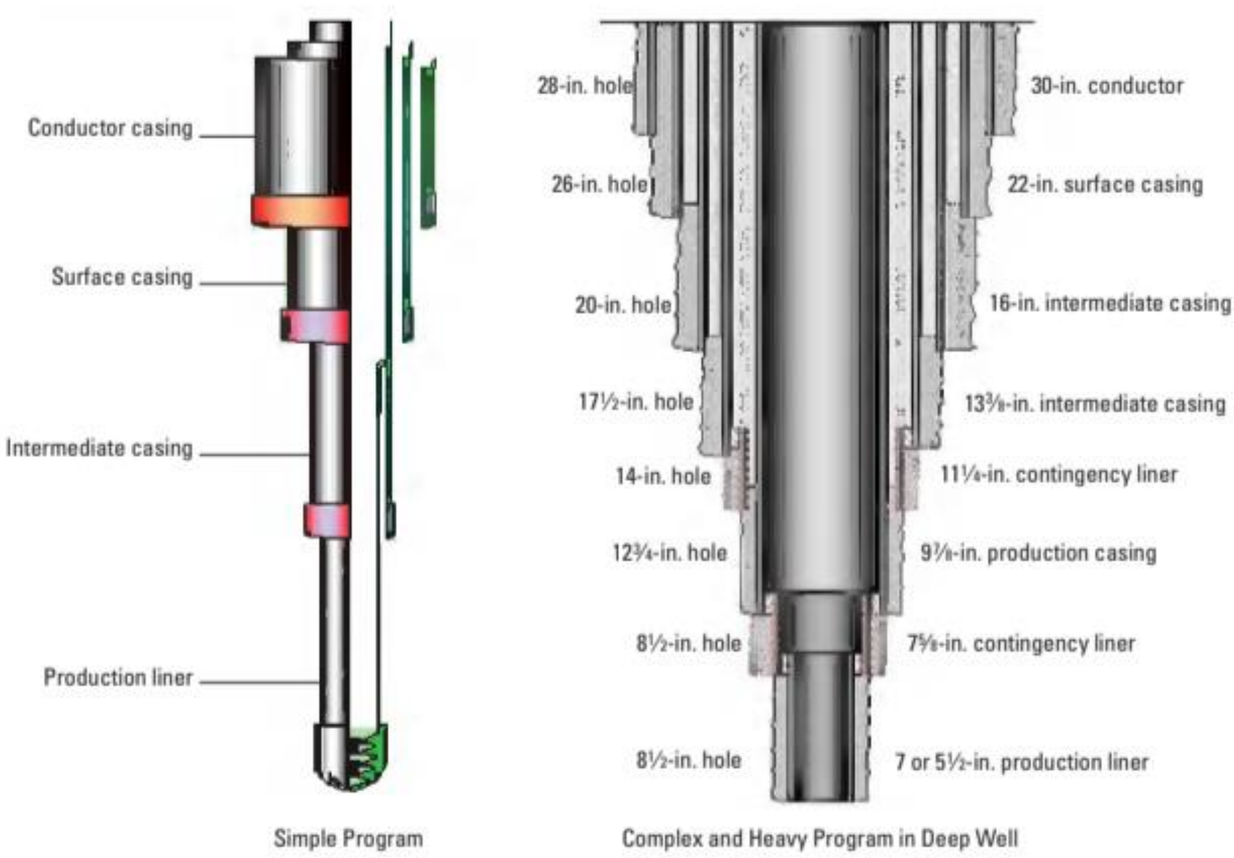


Figure II-7: Example of casings program (4)

CHAPTER III: WELL INTEGRITY EVALUATION TOOLS

III. CHAPTER III: WELL INTEGRITY EVALUATION TOOLS

III.1 Introduction

Cement evaluation in oil and gas well is very important to ensure the integrity and longevity of the well. It is a key aspect in preventing fluid migration between formations and maintaining zonal isolation. In this regard, various techniques, both conventional and advanced, have been developed to effectively assess the quality of the cement job in several. This chapter will discuss two major types of cement evaluation methodologies: the conventional Cement Bond Log/Variable Density Log (CBL/VDL), Ultrasonic Imaging Tool (USIT) and advanced latest technology Isolation Scanner (IBC).

III.2 Definition of CBL/VDL

The Cement Bond Logging tools have become the standard method of evaluating cement jobs. It’s a conventional tool used to determine the quality of the cement bond between casing and formation. A cement bond log (CBL) evaluation of the integrity of cement job performed on an oil well. It is basically a sonic tool which is run on wireline. A ttransmitter fires an acoustic signal in all directions down the casing which is then reflected to the receiver 3-ft. Similar to a ringing bell, when no cement is bonded to the casing, pipe is free to vibrate (loud sound). When the casing is bonded to hard cement, casing vibrations are attenuated proportionally to bonded surface.

The Variable Density Log (VDL) is a continuous amplitude presentation (received from the 5-ft receiver, which displays the amplitude of the reflected wave, allowing for a detailed interpretation of the bond quality.

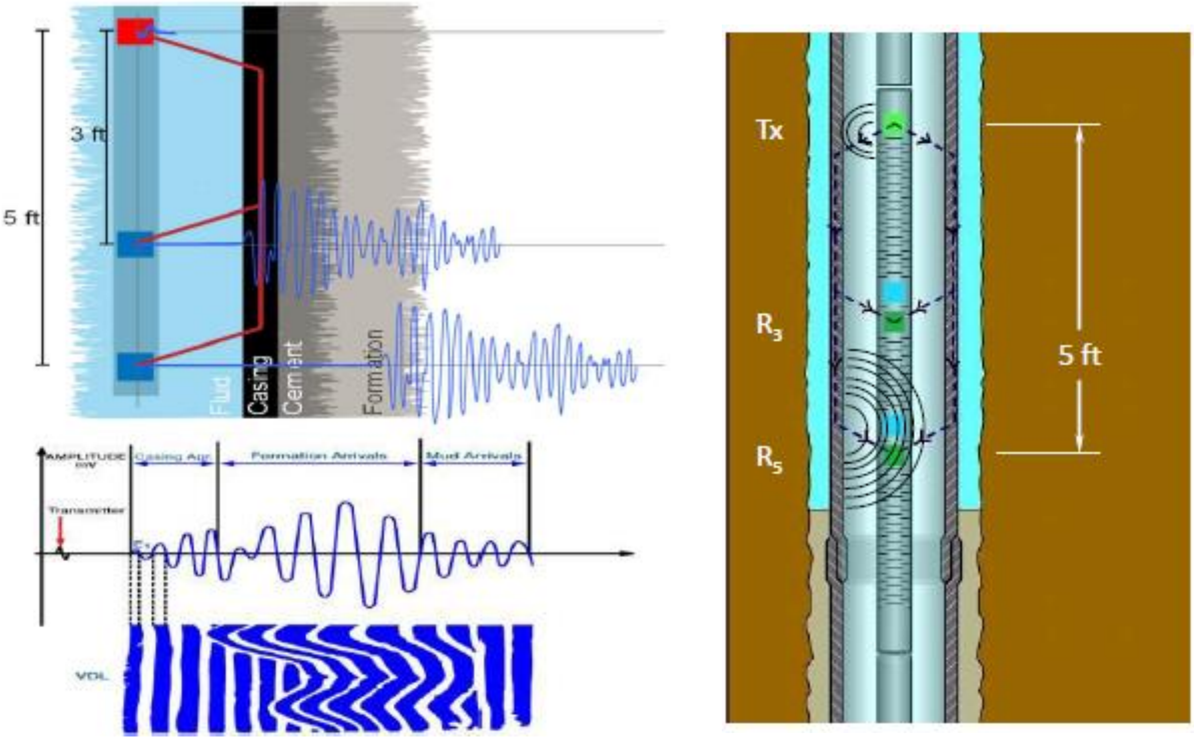


Figure III-1: CBL/VDL function (8)

CBL/VDL methodology primarily measures the amplitude of the reflected wave to assess the bond quality. It is based on the principle that sound waves travel faster through solid mediums (like well-cemented casing) than through liquid mediums (like poorly cemented casing or fluid-filled annulus). Therefore, a low CBL amplitude with strong VDL arrivals indicate a good cement bond, while a high CBL amplitude and no formation arrivals on VDL indicate a poor bond or potential channeling behind the pipe.

However, the CBL/VDL technology has its limitations. It struggles to identify micro-annulus, partial bond, or channels in the cement due to the omnidirectional measurements. It also cannot distinguish between bonded and free pipe, making it difficult to identify gas, liquid or Solid behind the casing.

III.3 Ultrasonic Imaging tool USIT (8)

The Ultrasonic Imaging Tool (USIT) is the upgrade technology after CBL/VDL in Slb, that have greatly improved cement evaluation. The USIT tool uses high-frequency ultrasonic waves to create a detailed, 360-degree image of the annulus behind casing. It not only determines the quality of the bond but also identifies the exact location of bond anomalies, such as channels or micro-annulus in the cement. This tool can differentiate between materials behind casing, making it more accurate in detecting gas, liquid or solid behind the casing by using Acoustic Impedance (AI) thresholds logic.

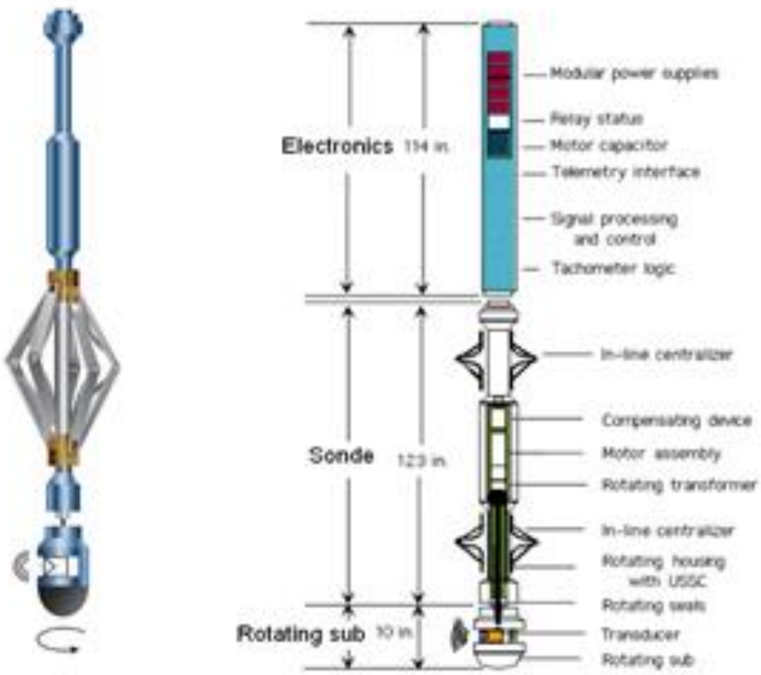


Figure III-2: USIT schematic tool (8)

The USIT tool is displayed on the far right. It consists of an acquisition cartridge above a motor that turns the rotating measurement device at the bottom.

The USIT provides 4 main measurements:

-The initial echo amplitude provides an indication of the condition of the internal surface of the casing. A smooth surface will yield a high amplitude when well-centered. Low amplitudes are caused by a rough internal surface and/or eccentering of the tool.

-Through the knowledge of the mud velocity obtained in an FPM pass, the transit time for the first amplitude is converted into an internal radius measurement.

- Operating the transducer at the casing resonance frequency allows the casing thickness to be measured.

- The decay rate of the signal determines the acoustic impedance of the material immediately behind the casing.

Acoustic impedance is defined as the product of density and compressional velocity.

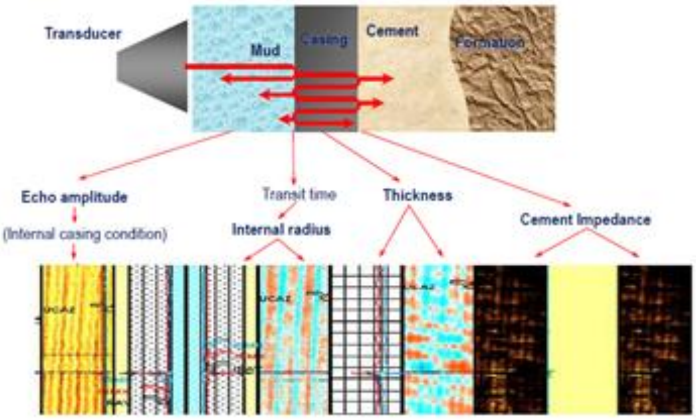


Figure III-3: USIT measurement principle (8)

The USIT making cement Evaluation more accurate in detecting the material gas, liquid or solid behind the casing by using Acoustic Impedance (AI) thresholds logic map. But have a limitation in low acoustic impedance materials, like lightweight slurries and contaminated cement.

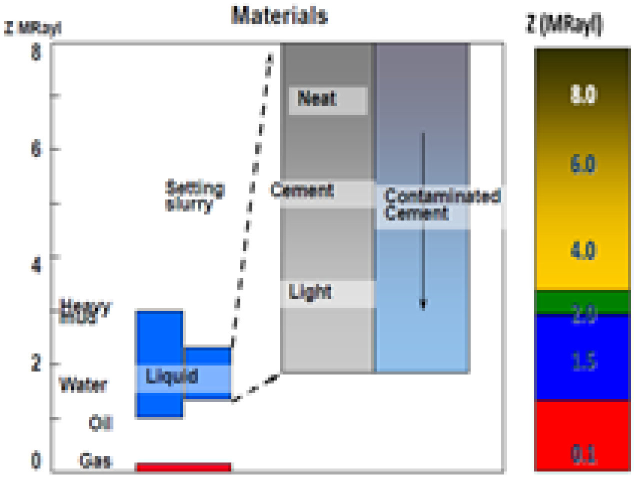


Figure III-4: AI threshold logic map (8)

III.4 Isolation Scanner (8)

The Isolation Scanner (IBC) is the latest technology of Ultrasonic Slb tool in cement evaluation by using high-frequency ultrasonic waves. It uses an array of transducers to emit ultrasonic echo pulses that travel through the casing and cement to the formation. The reflected pulses are then measured to provides a quantitative measurement of the cement-casing and cement-formation bonds also the 3rd interface. This refers to the interface between the annulus material and the next major acoustic event – either the formation or the 2nd casing outside of the casing string in which the tool is operating. The 1st and 2nd interfaces are those that are currently measured with the USIT. The Isolation Scanner has the capability to deliver information about the 3rd interface.

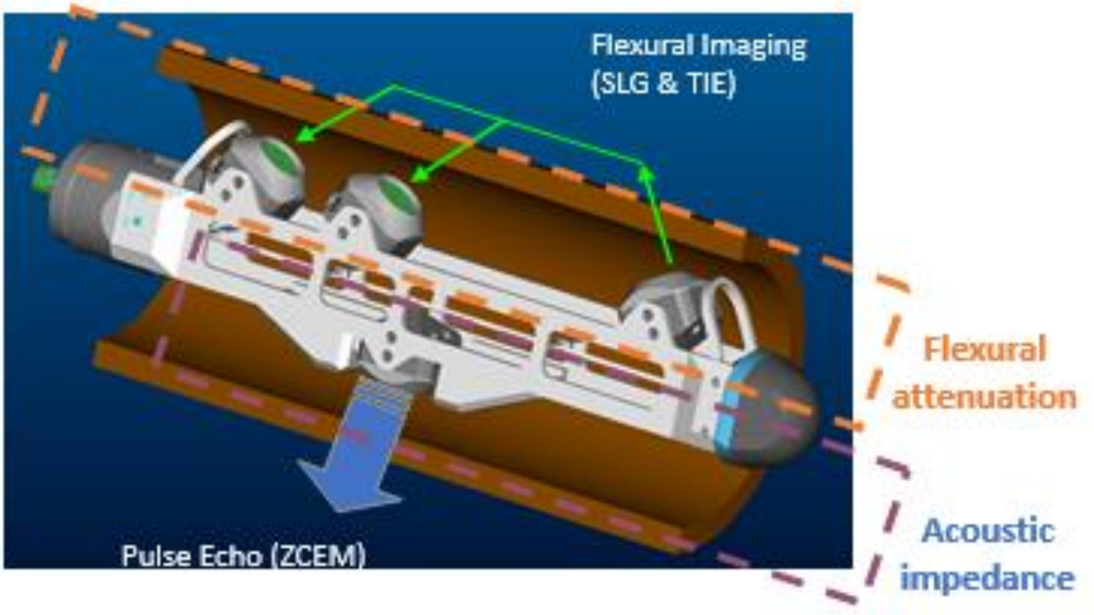


Figure III-5: Isolation Scanner measurement principal (8)

Compared to the USIT, the flexural attenuation measurement has a lot more advantages, the drawback is mostly that the flexural attenuation curve versus impedance goes through a maximum, so that one measured value has two solutions.

The discrimination between high and low acoustic impedance is not possible. To resolve the ambiguity, both measurements, USIT impedance and flexural attenuation, must be combined.

III.5 Conclusions:

In conclusion, Cement evaluation is important for many operation in oil and gas industry in while the conventional CBL/VDL technology provides a basic assessment of the cement bond, but the advanced tool USIT / IBC technology offers a more comprehensive and accurate evaluation in hard well condition. The choice between the two will depend on the specific requirements of the well and the type of material behind the casing.

III.6 Collar Locator Principle

The CCL output signal size depends on:

- Changes in steel thickness [seen by the CCL at the collar]

– Rate of change of magnetic flux depends on cable speed*

– Average proximity to the collar

– Strength of the magnetic field depends on magnets strength.

5.2. Collar Locator Storage

Casing Collar Locators contains two very powerful magnets.

– Do not store or manipulate the CCL near objects sensitive to a magnetic field, such as watches, compasses, magnetic tapes, etc...

– Always store CCL’s in their shunt tubes.

– Do not store too close to each other [→ weaken magnets]

– Check magnets for cracks and always replace them if damaged.

– Ensure similar poles of each magnets are facing each other

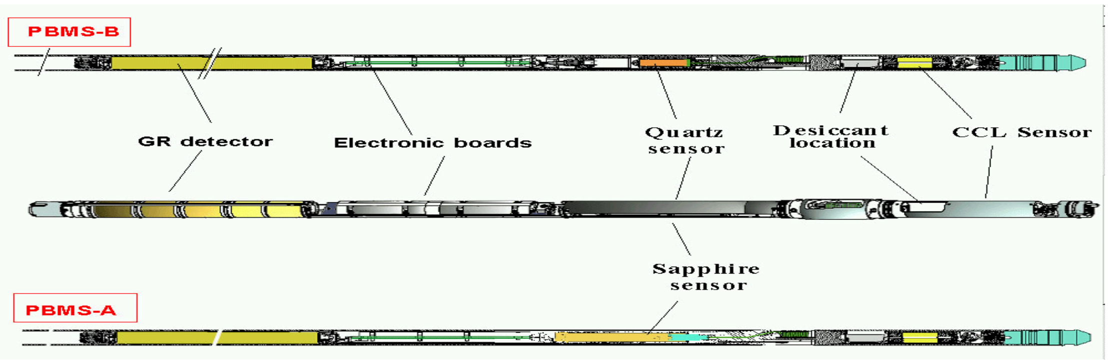


Figure III-6: PBMS tool configuration (8)

III.7 PBMS Sensors (8)

Pressure

Pressure is another key measurement in understanding the reservoir. Pressure aids the understanding fluid movements in the reservoir and is the mechanism by which the fluids flow. It is also key to understanding the thermodynamic behavior of the fluid (PVT analysis etc). It is one of the most common measurements made in producing wells.

Pressure sensors are known as MANOMETERS and consist of 2 parts:

1- the SENSOR which physically and mechanically reacts to the pressure

2- the TRANSDUCER which converts the physical reaction to an electrical signal

There are 2 types of pressure sensor used in Schlumberger tools: STRAIN GAUGE sensors and VIBRATING CRYSTAL sensors.

- **STRAIN GAUGE**

These consist of resistors that are strain sensitive. These are mounted on a device which deforms when pressure is applied, changing the length of the resistor and hence it resistance. The change in resistance is proportional to a pressure. The reading is temperature sensitive needs to compensate.

2 Strain gauges are used in Schlumberger: Paine Gauge and Sapphire Strain Gauge (both shown below).

- **VIBRATING CRYSTAL**

Quartz Crystals have the property of vibrating at very specific resonant frequencies (like a tuning fork). An Oscillator vibrates the Quartz electronically at a very high frequency (resonant frequency). Pressure applied to the crystal changes its resonant frequency in proportion to the stress (pressure). The Oscillator ‘adjusts’ to vibrate the Quartz at the new resonant frequency. This ‘adjustment’ is proportional to the Pressure. Needs temperature compensation.

3 Crystal gauges are used in Schlumberger: Hewlet-Packard (HP), Crystal Quartz (CQG).

Temperature

Measuring the temperature and recording temperature changes in the borehole has an array

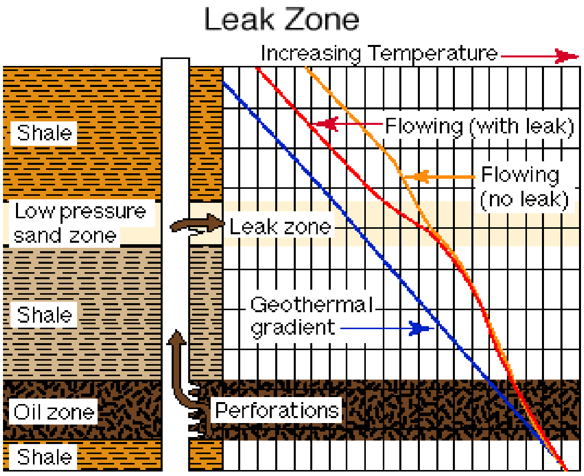


Figure III-7: Example of leak zone log (8)

of uses in production logging.

Applications

- ✓ Downhole reservoir temperature
- ✓ Flow detection behind casing
- ✓ Gas entry detection

- ✓ Fluid properties conversion to surface conditions
- ✓ FRAC job evaluation

Sensor and theory of measurement

The temperature resistor, or Resistance Temperature Detector (RTD), relies on the increase in resistance of metal with increasing temperature. Temperature resistors consist of a coil of fine metal wire or a deposited film of pure metal on a nonconductive surface. They can be made of different metals and have different resistances, but platinum has become the most popular because of its excellent accuracy, large linear range of operation and wide temperature span. (They can be designed to measure over 1000°F.)

GR & CCL

The GR-CCL log is normally presented with the GR curve in track 1 and the collar locater presented in track 1 or track 2.

GR Sensor

- Scintillation detector. NaI crystal size 0.75” diameter, 6” long
- Single supply low power detector with integrated power supply, amplifier, and discriminator (<20ma @ 5V)
- Fixed (hard wired) operating high voltage:
  - – No calibration (but check is possible)
  - – HV monitoring only.

CCL Sensor

- With the PSTC, the CCL signal is acquired at about 183 HZ and is decimated by a factor of three. Only the algebraic sum of the minimum and maximum on three consecutive samples is transmitted.
- With the PRMC, the CCL signal is sampled at 0.1s (cannot be changed).

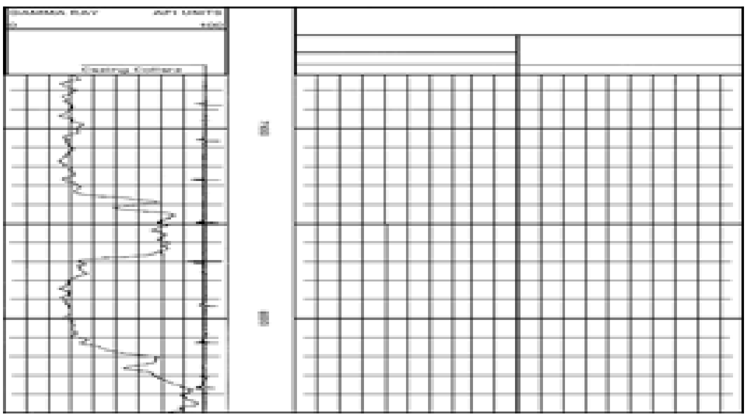


Figure III-8: Example of GR log (8)

CHAPTER IV: SOFTWARES TECHNOLOGY OVERVIEW

IV. CHAPTER IV: SOFTWARES TECHNOLOGY OVERVIEW

IV.1 Techlog Platform (8)

The oil and gas industry relies on advanced software to optimize well planning, completion, and production processes. Three such software used during working on this project are, Techlog Platform, Ultrasonic Tool Planner, and Acquisition software Maxwell. These softwares play crucial roles in various stages of well operations. This chapter will provide a deep understanding of these Softwares and discuss how they can be effectively utilized from data preparation to report delivery. Really these powerfully software streamlines workflows by providing a unified environment for data acquisition, analysis, processing and interpretation.

IV.1.1 Introduction to Techlog

In the field of oil and gas, the evaluation of well integrity is a critical task that ensures safe and efficient operations. Schlumberger's Techlog software platform offers a comprehensive suite of tools for this purpose, facilitating a detailed evaluation of well integrity logs to monitor, maintain the health of oil and gas wells and and facilitating informed decision-making. This chapter delves into the utilization of Techlog for well integrity log evaluation, outlining its various features and their applications in maintaining well integrity.

IV.1.2 Techlog: Overview

Techlog is a wellbore software platform that integrates data from various sources to deliver a unified and comprehensive view of well status. It supports a multitude of data types, including wireline, LWD, MWD, core, and production data. The versatility of Techlog enables users to perform a wide range of analyses, from basic log interpretation to advanced petrophysical evaluations and well integrity assessments.

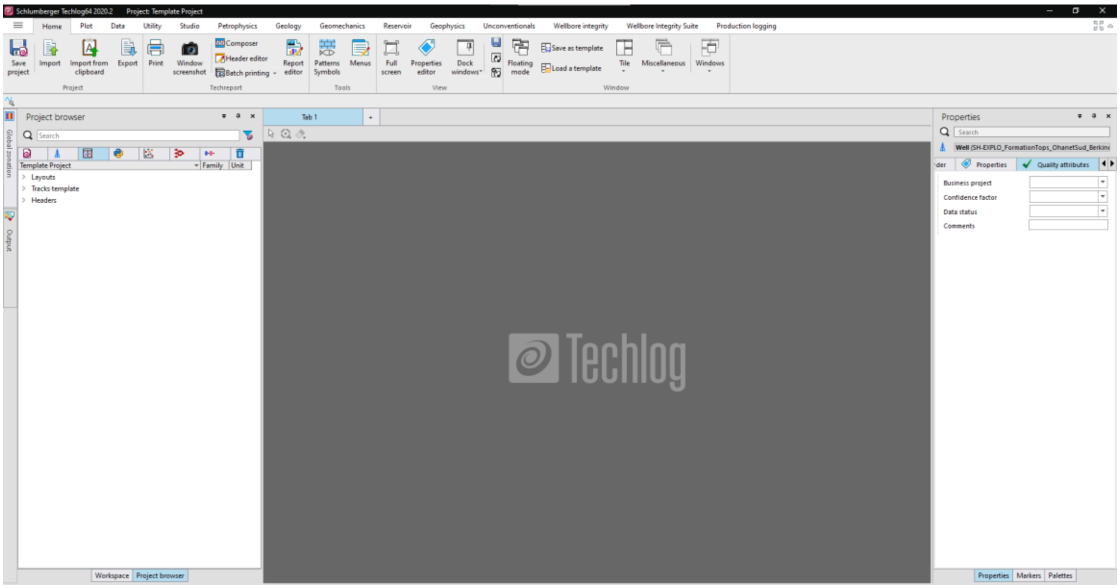


Figure IV-1: Techlog Processing Interface (8)

IV.2 Well Integrity Log Evaluation:

IV.2.1 Process Overview

The process of well integrity log evaluation in Techlog begins with data importation. This can be done using multiple formats such as LIS, DLIS, LAS, and more. Once imported, data can be visualized in various formats, including log plots, histograms, and cross-plots, offering a comprehensive view of the well's condition.

The next step is data quality control and corrections. Techlog provides functionalities for handling outliers, spikes, and other data anomalies. It also offers tools for depth matching and environmental corrections, ensuring that the data is accurate and reliable.

Following this is the interpretation stage, where the processed data is analyzed to identify potential integrity issues. For example, cement bond logs can be interpreted to assess the quality of cement bonding, while casing inspection logs can be used to identify potential casing damage. Techlog supports both manual and automatic interpretation, offering a range of advanced algorithms and models to aid in the process.

IV.2.2 Techlog Well Integrity Module

Techlog Well Integrity module provides a platform for integrating and interpreting data from various sources to evaluate well integrity. It enables users to visualize and analyze data from different logging tools, including advanced ultrasonic tools, in a single interface. The module supports the interpretation of data to identify potential integrity issues, such as poor cement bonding or casing corrosion, and aids in the decision-making process for well interventions.

IV.2.3 Well Integrity data Processing in Techlog

Once the data from the ultrasonic tool is imported into Techlog, it undergoes a series of processing steps. These may include noise reduction, calibration, and normalization, among others, to ensure the accuracy and reliability of the data. The processed data is then visualized in various formats, such as radial plots or images, providing a comprehensive view of the cement and casing condition.

Next, the data is interpreted to identify potential integrity issues. For instance, areas of poor cement bonding or casing corrosion can be identified based on the ultrasonic reflections. This interpretation is often aided by Techlog's advanced algorithms and interpretative models, which can help identify subtle signs of integrity issues that may be missed in a manual interpretation.

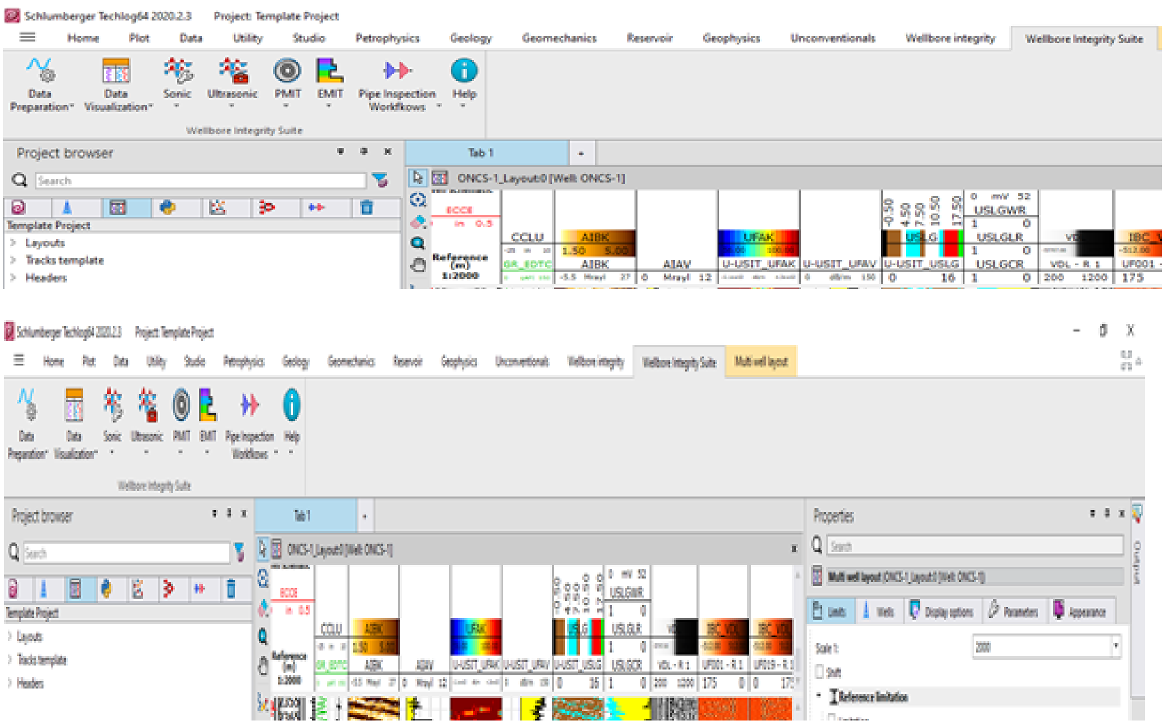


Figure IV-2: Well integrity plugging interface (8)

IV.2.4 Decision-Making Based on Techlog Evaluation

The final step in the evaluation process is decision-making. Techlog provides various tools to aid in this process, such as trend plots and cross-plots, which allow users to visualize data trends and correlations. Additionally, the software enables users to generate comprehensive reports, which include all the data, interpretations, and recommendations for well interventions.

The information derived from Techlog's Well Integrity module, combined with the high-resolution data from advanced ultrasonic tools, provides a robust basis for decision-making. Whether the decision is to proceed with production, perform a well intervention, or even abandon the well, it is informed by a comprehensive analysis of the well's integrity.

IV.2.5 Advanced Features for Well Integrity Log Evaluation

Techlog offers a variety of advanced features for well integrity log evaluation. These include multi-well analysis capabilities, enabling the comparison of data from multiple wells in a single interface; advanced visualization tools, offering 3D views of the wellbore and surrounding formations; and predictive modeling tools, which can forecast future well behavior based on current and historical data. The wide control and commend showing how Techlog was used to evaluate well integrity logs and guide successful interventions under his slogan: Because every well count.

IV.2.6 Conclusion

Techlog offers a robust and comprehensive solution for well integrity log evaluation. Its ability to integrate, process, and interpret a wide range of data types, coupled with its advanced analysis and visualization tools, make it an invaluable tool in maintaining the integrity and performance of oil and gas wells.

IV.3 Ultrasonic Tool Planner

Tool Planner is a SLB software application used for planning and designing operations data in several Domaine; well Evaluation, completion and intervention operations. It enables engineers to select appropriate data, tools and equipment based on well parameters, operational constraints, and project objectives. Some notable features of Tool Planner include:

a. Tool database: Tool Planner hosts an extensive database of oilfield tools and equipment, allowing engineers to choose the best-suited options for their projects.

b. Compatibility analysis: The software ensures compatibility between selected tools, avoiding conflicts during well completion or intervention operations.

c. Performance evaluation: Tool Planner facilitates the analysis of tool performance in various well conditions and scenarios, helping engineers optimize their designs.

In my study I worked on Ultrasonic tools data preparation when I prepared Acoustic parameter for field operation and for log interpretation and data tuning in Techlog.

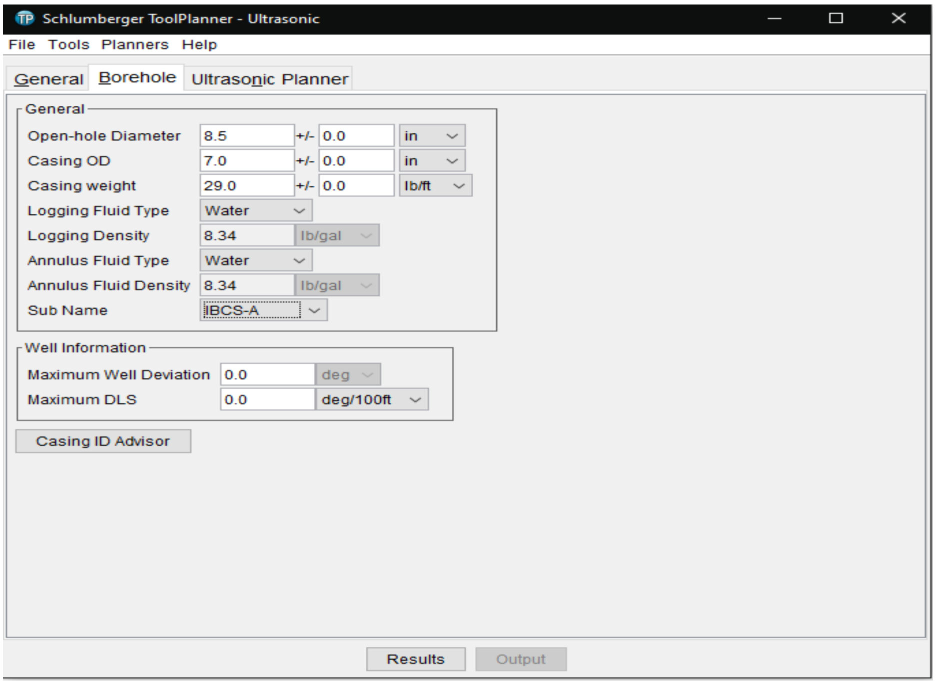


Figure IV-3: Tool planner USIT/IBC data preparation (8)

IV.4 Acquisition software "Maxwell":

Maxwell is proven software, which has been tested for over years in various locations, and now when it is more robust and supports most of the services that SLB running in Norway, that's why they started deployment. In SLB they are always investigating in new tools, services where can provide their customers best efficiency, data quality and introducing new service to meet and exceed their customers' expectations. So what are the advantages of Maxwell over operations?

IV.4.1 Service delivery:

It is very intuitive, has one console to QC data, to control acquisition parameters by using Acquisition console, this is only window we need to look at during logging, and includes all what engineers need to look at during logging.

Figure IV-4: Maxwell deliverable interface (8)

Tool string configuration, wellbore data, well parameters and all pre logging tasks could be easily set form one console – which called setup console, and it gives you more control over the parameters.

Also, during logging data could be recomputed (played back) if you need to change processing parameters. Once we change any parameter that could affect data, recompute button becomes active, and software will not allow to make any deliverables unless whole data is recomputed.

IV.4.2 Operational Efficiency:

It is proven to bring more operational efficiency. Once we stop the log – for example for USIT log it takes 15mins to finish final log. This is done by making ready deliverables console before logging or while logging, and once log stopped, the only thing required is to set correspondent parameters, recompute the log and by one click print final PDF.

One of the simplest advantages of Maxwell is if there is a need to change scale or color or track of the curve, no need to recompute (playback as in OP) whole data, just need to change it in log format and print in one click.

Realtime data transfer is supported in Maxwell as well through interact.

Maxwell is using windows interface, and in case it crushes it will first of all crash in one of the consoles, which could be restored from the place it crashed, or if Maxwell crashes totally, it will automatically restore from the place it crashed on next start.

These are not all advantages Maxwell has over OP, that’s why we decided to introduce new generation software, which will support next generation tools we are aiming to provide our customer!

APPLICATIONS AND CASE STUDIES

V. APPLICATIONS AND CASE STUDIES

V.1 Case01: Comprehensive Cement Evaluation and Restoration in a 9.625'' Casing Section: A Successful Case Study.

Well X-01: 9.625” casing evaluation.

V.1.1 Abstract:

This case study provides an in-depth analysis of the cement evaluation procedure and restoration of X-1 well in a 9.625" casing section traversing a water formation (Horizon B), utilizing an advanced isolation scanner technology (IBC) Tool. The study spotlights the systematic approach used to identify problem areas, develop a tailored solution, and implement a successful cement restoration job and evaluated post-restoration. The evaluation demonstrated the effectiveness of the remediation, ensuring safe and efficient operations and good hydraulic isolation across Horizon B.

V.1.2 Introduction:

In the field of oil and gas (XZ) operations, maintaining the integrity of casing cement is of paramount importance. It ensures zonal isolation, preventing the migration of fluids between different geological layers. This study revolves around a case where in a 9.625" casing section, which traversed a water formation (Horizon B), required cement evaluation.

V.1.3 Cementing program:

Here in below in the figure below, is the cementing program set prior to cementing job, where a volume of 45.9m3 of slurry 2.29 g/cc is planned to be pumped in the annulus 9.625”/13.375” to have TOC at 2249m.

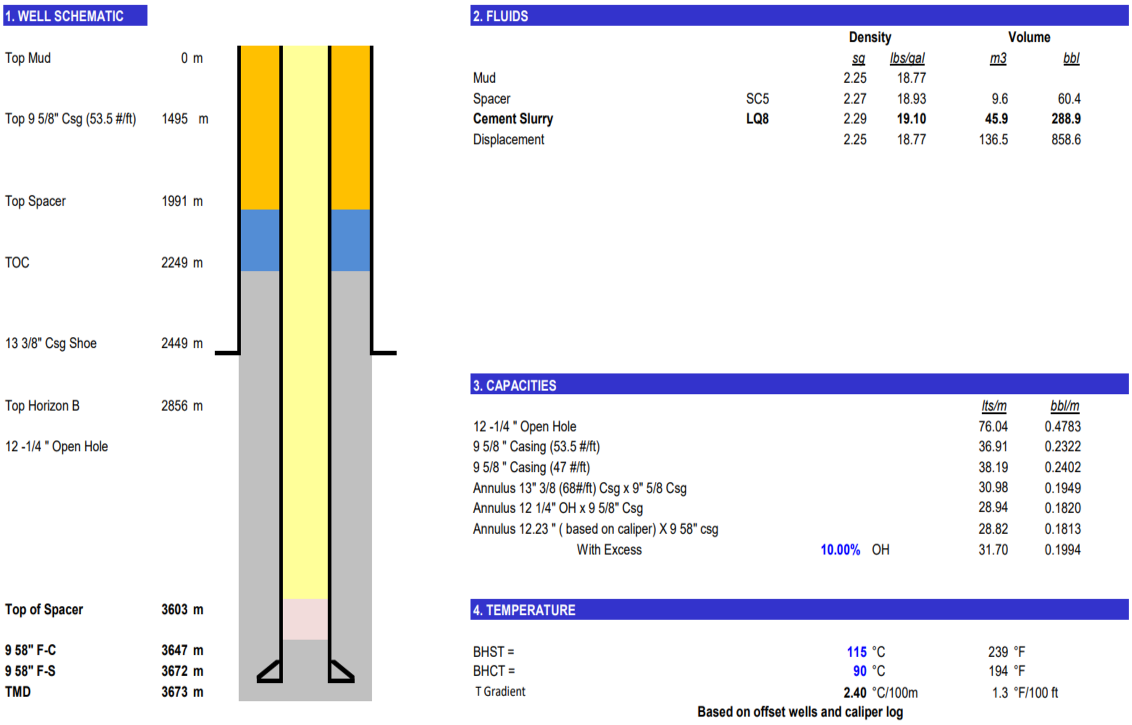


Figure V-1: Cementing programme plan (8)

V.1.4 Problem Identification:

The initial step was to diagnose the condition of the casing cement. An Isolation Scanner in combination of CBL-VDL were utilized for this purpose. The use of Isolation Scanner as advanced tool provides a comprehensive evaluation of the material behind casing, by combining Acoustic Impedance and Flexural attenuation measurements, thereby identifying the presence of channels, contamination, or compromised cement quality by the (Liquid-Solid-Gas) SLG map.

V.1.5 Isolation Scanner log evaluation for cement quality and TOC determination:

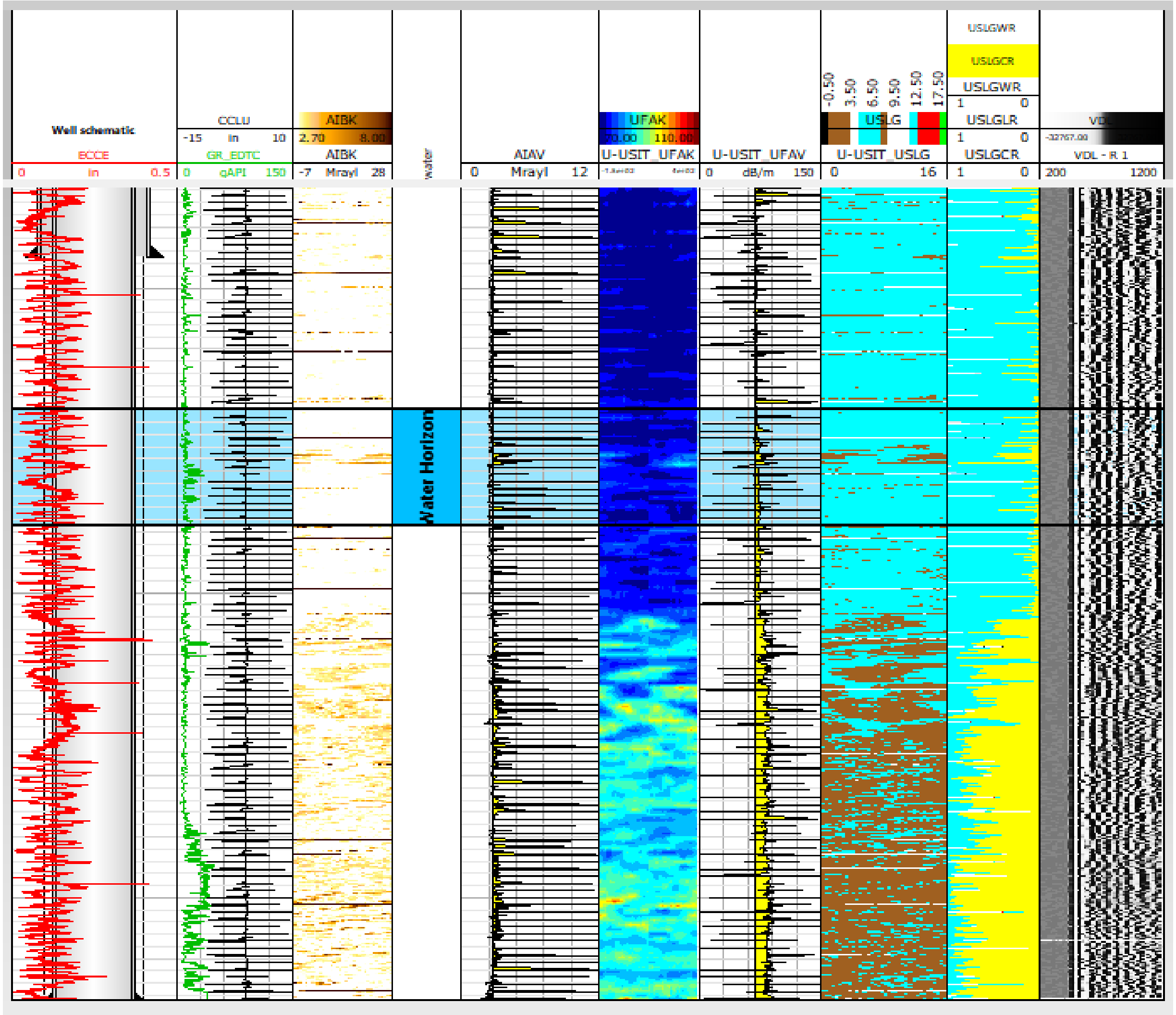


Figure V-2: IBC compressed log well X:1 (8)

V.1.6 Log Analysis:

X-01- is a well in XZ field.

9.625" Casing was run from the surface to XX72m and cemented with a slurry 2.29 g/cc.

In order to evaluate the integrity of this casing, ensure the proper hydraulic isolation of cement over the double casing and open hole section, Including the Horizon B interval. An ultrasonic tool (IBC) in combination with CBL-VDL were run over the interval [XX70m – XX60m].

During the job, the well was full of 2.25 g/cc of Mud. Good data quality was obtained from the tools.

The interpretation can be summarized as follow:

- Over the interval [XX70m – XX40m]: SLG map shows free pipe also there is no formation arrival on VDL. Top of cement was identified below Horizon B formation.
- Over the interval [XX40m – XY20m]: SLG map shows patchy cement behind casing, with several Liquide pockets/ channeling.
- Over the interval [XX20m – XX60m]: SLG map shows Azimuthal cement behind casing with patchy Liquide pockets.

V.1.7 The zone of interest (Horizon B) log:

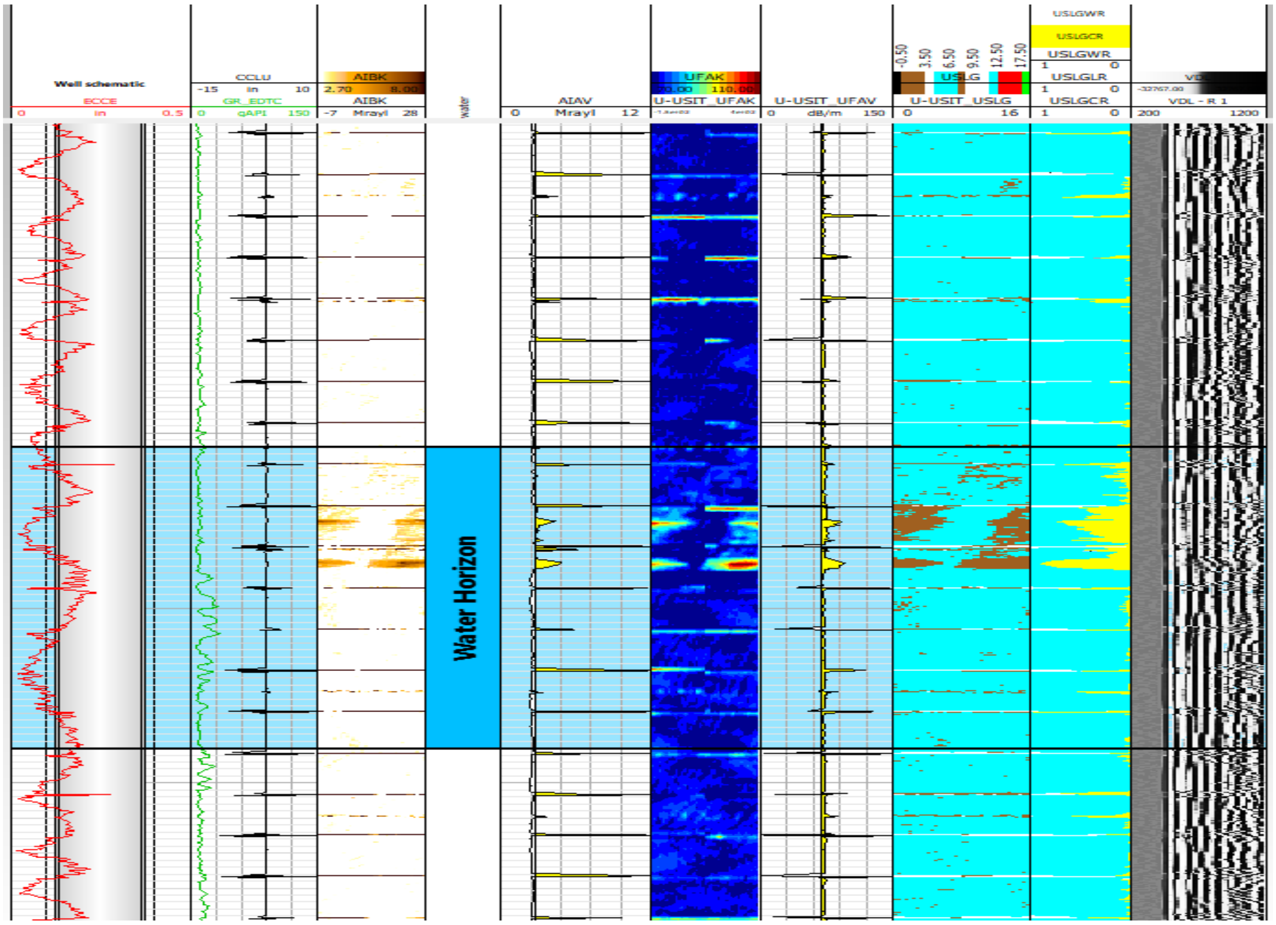


Figure V-3: IBC zonation log well X1 (8)

V.1.8 Proposed Solution:

Based on the data gathered, it was observed that the casing section in question required cement restoration. The scanner detected areas of inadequate isolation belong the interval of Horizon B, suggesting potential fluid migration, which could compromise the safety and efficiency of the operations. Hence, a cement restoration job was proposed After a deep Evaluation.

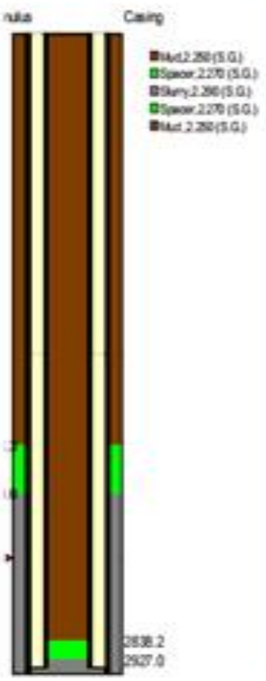
V.1.9 Recommendation:

After the log interpretation, and the information of the well. For ensure the proper hydraulic isolation of the casing specially on the water horizon interval. We recommend Cement restores job at the interval of horizon B [XX61m – XY95m], please be advice that you can select any point over the interval [XX55m – XY40m] to inject the cement if there is good circulation, if not you can circulate inversely, by injection the cement slurry between the 13.625" and 9.625" casing.

V.1.10 Execution of cement restore job:

The cement restoration job was meticulously planned and executed. The objective was to restore the casing cement to its optimal condition, ensuring complete zonal isolation. The process involved preparing the casing section, pumping the cement slurry, and allowing it to set.

Here below the cementing program planned prior to cementing restore job.



Open hole	Cement Retainer Depth **2960 m MD** Perforation Depth: **2990 m MD** Bit size: **12.25 in.** Caliper ID :**12.30" (average caliper from previous casing to 2990 m)** Excess in OH: **(10 % over Caliper)**
Current Casing data **Previous casing data** **Drill Pipe DATA**	9 5/8" (47 ppf), from 1495 m to surface 9 5/8" (53.5 ppf), from 3672 m to 1495 m 13 3/8" (68 ppf), Casing shoe: 2449 m MD 5" ½ DP (21.9 ppf) (capacity:11.26 l/m) , from 2960 m to surface
BHST/BHCT, T Gradient	**107 °C /74 °C gradient: 2.7 C /100m (temperature taken based on regional gradient)**
Drilling fluid	Type: **OBM Mud,** Density: **2.25 SG**
Pre-flushes/ Spacers	**7 m³** of Spacer ahead SC-5 **2.27 SG** **1 m³** of Spacer Behind SC-5 **2.27 SG**
Displacement	**OBM: 2.25 SG , Volume: 32.96 m3 (under Displacement to have 10 m of cement above CR is already included) (spacer behind is included)**
Cement Slurry	**Cement slurry:** - Type: **LQ-8** slurry @ **2.29 SG** - Volume: **29.01 m3** - T.T. **10 hrs 10 min** - TOC @ **2149 m** (300 m inside Previous Casing)

Figure V-4: Cementing restore job design (8)

V.1.11 Isolation Scanner log evaluation after the Cement restore job (Poste Restore Evaluation)

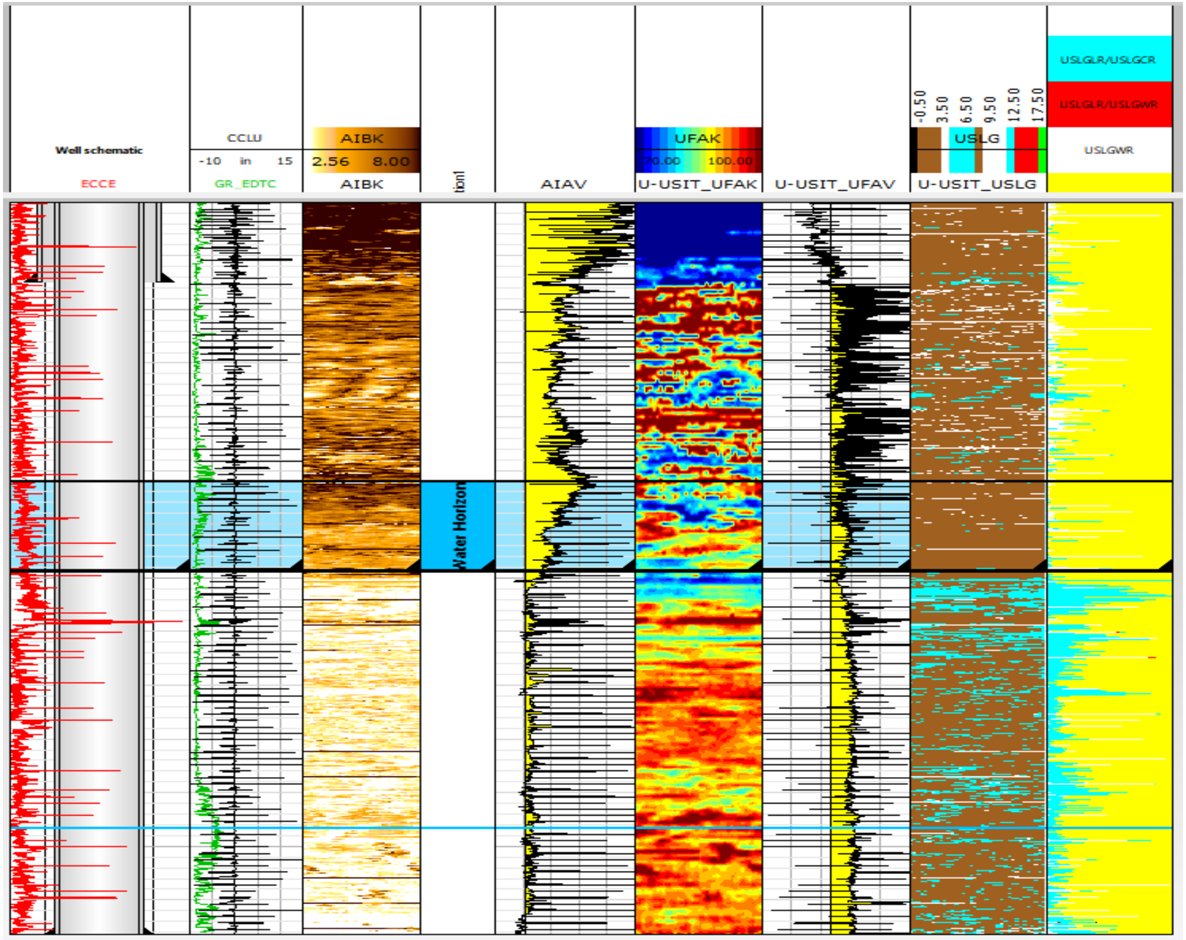


Figure V-5: IBC compressed log after restoring (8)

V.1.12 Log Analysis:

A cement restore job was performed across this 9.625” casing to restore the cement quality behind this casing, specialty across and above Horizon B interval.

An ultrasonic tool (IBC) was runed over the interval [XY70m – XX00m]. During the job, the well was full of 2.25 g/cc of Mud. Good data quality was obtained from the tools.

The interpretation can be summarized as follow:

- Over the interval [XX72m – XC40m]: SLG map shows Azimuthal presence of cement behind casing, across horizon B interval. The cement is also present up to double pipes interval, which indicate the good hydraulic isolation.
- Over the interval [XC40m – XK05m]: SLG map shows patchy cement behind casing, with several Liquide pockets/ channeling.

V.1.13 The zone of interest Horizon B:

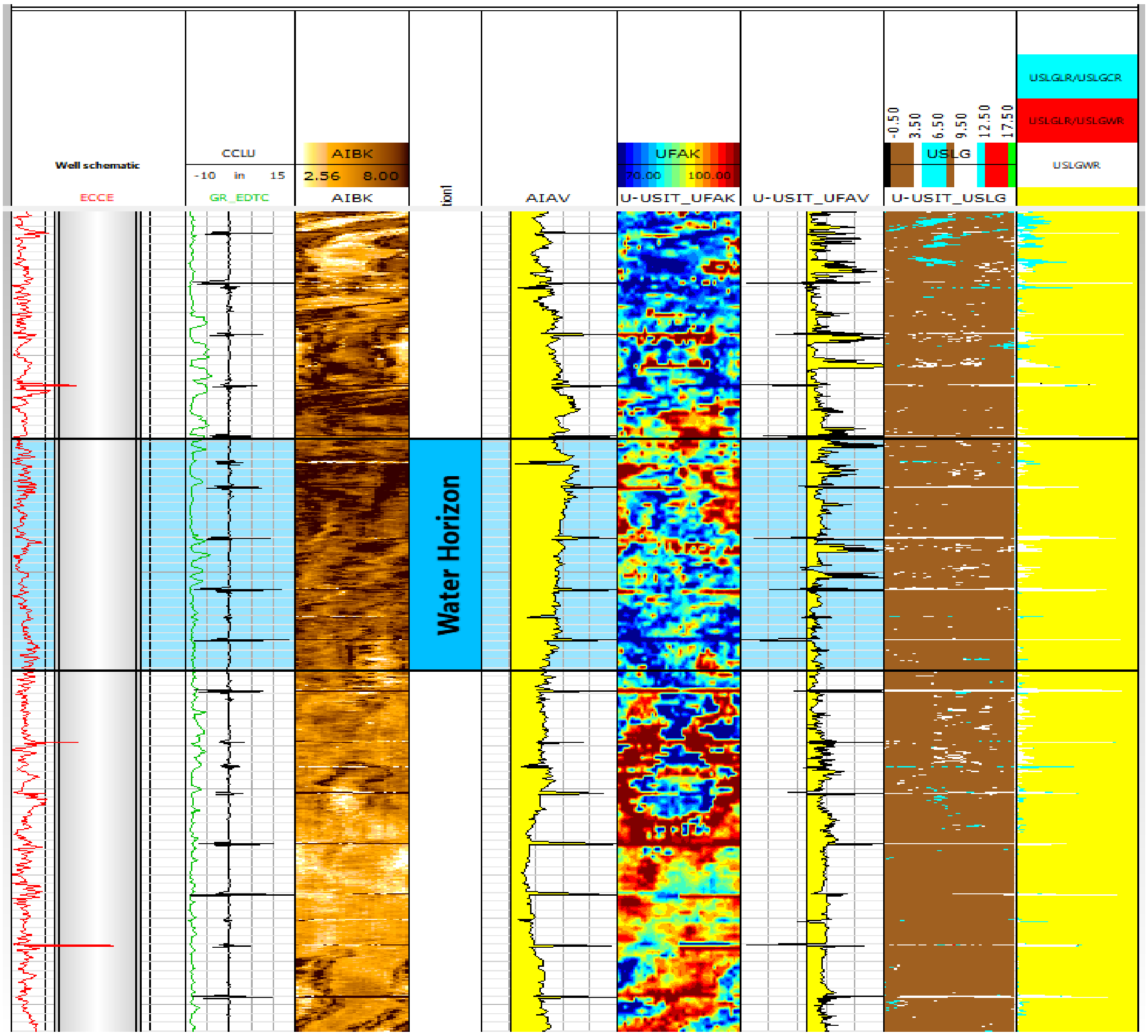


Figure V-6: IBC zonation log well X1 (8)

Post-Restoration Evaluation:

Once the cement restoration job was completed, a post-job evaluation was conducted using the isolation scanner. The IBC tool provided quantitative data, confirming the successful restoration of the cement around the casing. This post-job evaluation indicated that the restoration had achieved the intended objectives of sealing off potential channels, thus re-establishing the zonal isolation on all the 9.625” Section including the proper isolation of the Horizon B.

V.1.14 The Comparative logs:

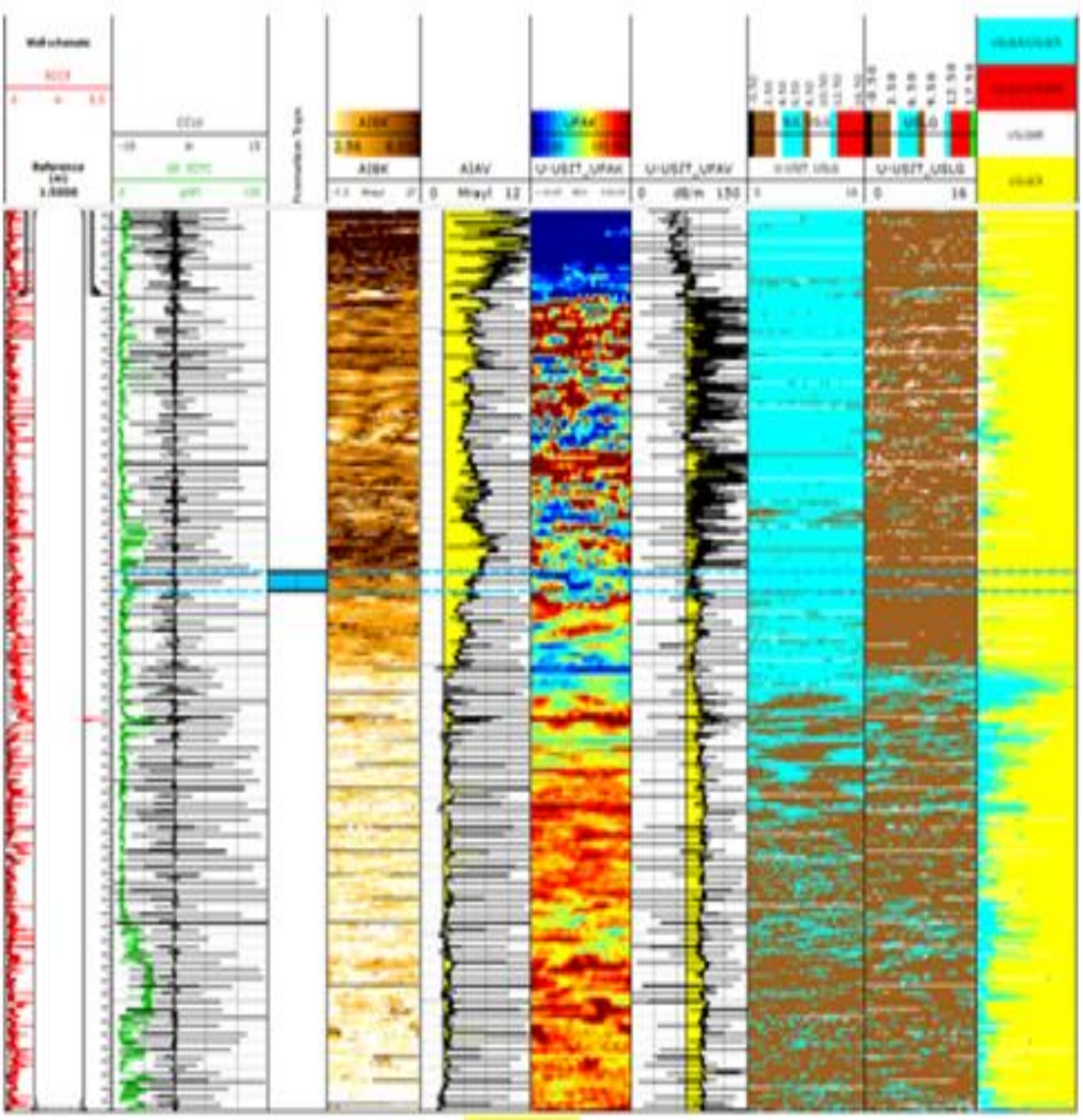


Figure V-7: IBC comparative log well X1 (8)

V.1.15 Conclusion:

This case study illustrates the significance of comprehensive cement evaluation in maintaining the integrity of casing sections, especially those traversing water horizons. By leveraging advanced isolation scanner technology, potential problems were identified, a solution was developed and implemented, and its success was confirmed through post-restoration evaluation. This process underscores the importance of regular evaluations and timely restoration work in ensuring safe and efficient oil and gas operations.

V.1.16 Lessons Learned and Recommendations:

The case study offers valuable insights into the complexities involved in cement restoration jobs. It supports for the continuous monitoring of casing cement conditions and timely interventions to prevent any operational disruptions or environmental hazards. Furthermore, it emphasizes the importance of using advanced diagnostic tools like isolation scanners in facilitating accurate evaluations and successful restorations. Future work should continue to focus on improving these technologies and techniques to ensure the safe and efficient functioning of oil and gas operations.

V.2 Case02: Successful Cement Evaluation by Advanced Technology IBC in the Section of 7" Liner and 4.5" Liner to Guide Interval of Perforations.

Well X-02: 7" Liner evaluation.

V.2.1 Introduction:

A case study was conducted to evaluate the success of an advanced technology Isolation Scanner for cement bond evaluation (also known as IBC) for optimizing the cement evaluation process in a 7" liner section. The primary goal of the study was to help guide the interval of perforation and maximize hydrocarbon production by ensuring proper zonal isolation.

Open hole	Depth: **3198 m MD** Bit size: **8.5 in,** Caliper ID: **8.73 in** Excess Over Caliper: **(75% excess)**
Current Casing data **Previous casing data**	**7 in Liner # 32 ppf** Casing shoe: **3197** m MD, LC: **3159.60 m MD** TOL: **2486.28 m** **9 5/8" (# 47 ppf)** From **1967.98 m** to **Surface** **9 5/8" (# 53.5 ppf)** From **2931 m** to **1967.98 m**
BHST/BHCT, T Gradient	**105°C / 74°C *(the temperature was based on Well logs)***
Drilling fluid	Type: **OBM Mud,** Density: **1.58 SG**
Pre-flushes/ Spacers	**07 m³** of Spacer ahead: **1.70 SG** **01 m³** of Spacer behind: **1.70 SG**
Displacement	**OBM: 1.58 sg, Volume: 35.17 m3 (1 m3 of Spacer is included)**
Cement Slurry	Tail slurry: - Type: **LQ-10** slurry @ **1.90 SG** - Volume: **13.75 m3** - T.T. **06 hrs 25 min** - TOC @ **2436.28 m** (50 m above TOL.)

Table V-1: Cementing program plane (8)

V.2.2 Background:

The well under evaluation was drilled in a complex reservoir with one producing zone. A 7" liner was run to isolate the targeted producing zones. A cement job was performed to ensure zonal isolation between these zones, as well as between the formation and wellbore. Proper zonal isolation is critical for efficient and safe hydrocarbon production.

V.2.3 Methodology:

The advanced technology IBC tool was deployed for this case study. An Isolation Scanner in combination of CBL-VDL were utilized for this purpose. The use of Isolation Scanner as advanced tool provides a comprehensive evaluation of the material behind casing, by combining Acoustic Impedance and Flexural attenuation measurements, thereby identifying the presence of channels, contamination, or compromised cement quality by the (Liquid-Solid-Gas) SLG map. This allows a more accurate assessment of the cement bond and the identification of potential problem areas. The IBC tool was run by wireline crew to cover the entire section of the 7" liner.

V.2.4 Isolation Scanner & CBL-VDL log evaluation:

X-02 is a well in LN field.

7" Liner was run from the XX86m to XX97m and cemented with a slurry 1.90 g/cc. In order to evaluate the integrity of this Liner, ensure the proper hydraulic isolation of cement over the double section and open hole section, an ultrasonic tool (IBC) in combination with (CBL-VDL) sonic tool, we run them over the interval [XX90m – XX97m].

During the job, the well was full of 1.58 g/cc of Mud. Good data quality was obtained from both tools. The interpretation can be summarized as follow:

- Over the interval [AB90m-CD62m]: SLG map shows presence of cement material behind Liner with Liquide pockets, with low CBL amplitude.
- Over the interval [CD62m – EF97m]: SLG map shows liquid material behind Liner with patchy cement, Liquide Pocket and channeling, in addition to high CBL amplitude.

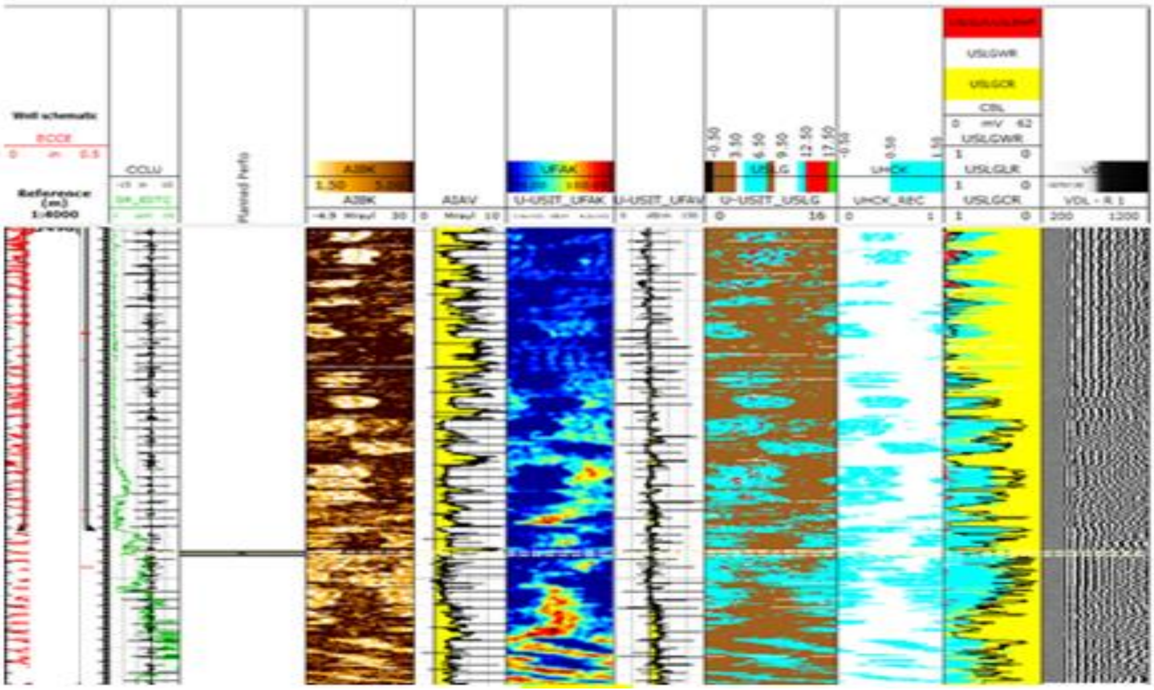


Figure V-8: Compressed log in 7" liner

V.2.5 The perforation interval:

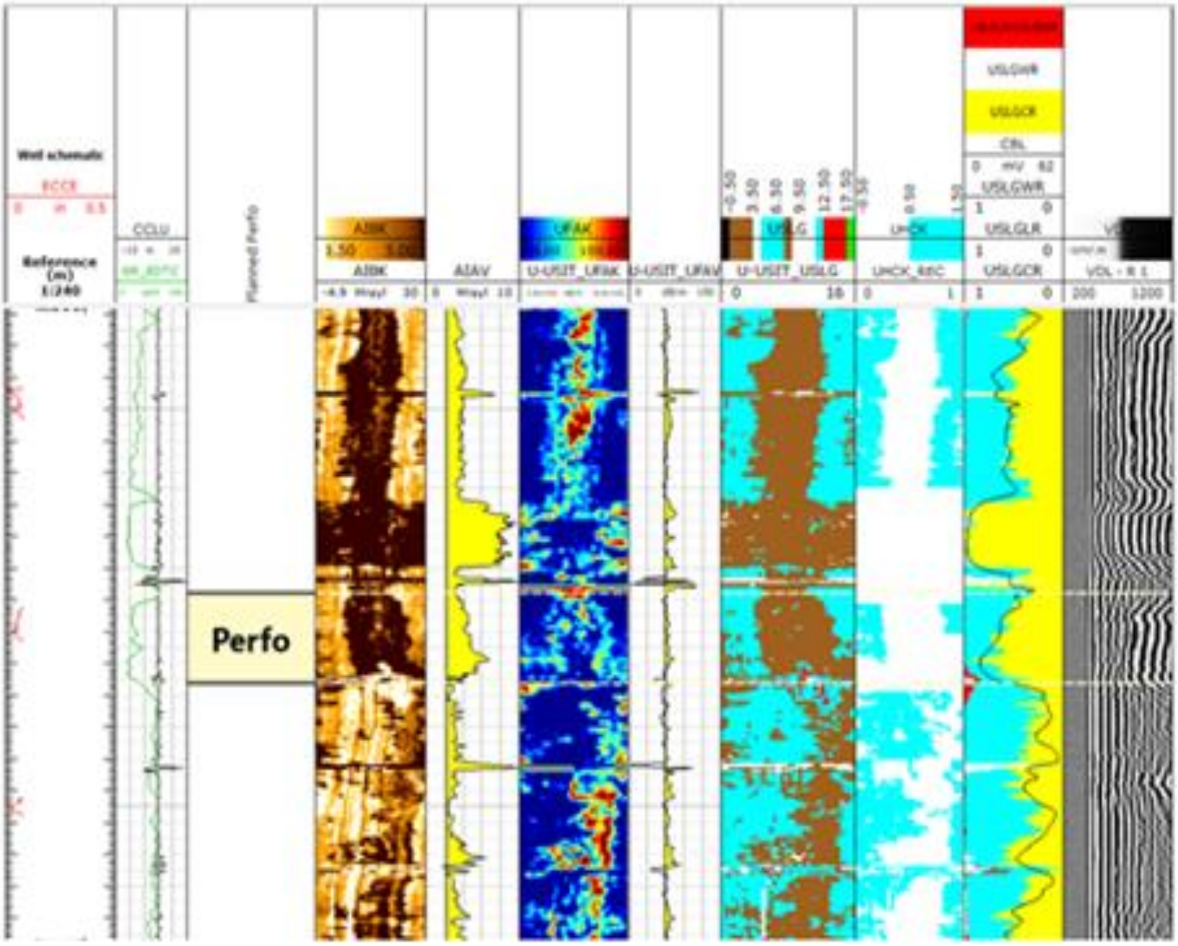


Figure V-9: IBC perforation interval log (8)

V.2.6 Perforation recommendations

Referring to the cementing job, the advanced technologies (Isolation Scanner) log was recorded to evaluate the cement quality. The ultrasonic measurements (AI & FA) map helped identify regions with poor cement bonding, which could be addressed before proceeding with the perforation.

As the planned perforation interval is: [CC61m – CC67m], and SLG map SLG map shows liquid material behind 7" Liner with patchy cement, also Liquide Pocket and channeling, in addition to high CBL amplitude, we don't recommend the perforation job in this interval.
We recommend cement restore job and after the interpretation of the cement log of the restore job we will see the good intervals of perf job.

V.2.7 Conclusion:

The case study demonstrated the successful application of the advanced technology IBC, for cement evaluation in a 7" liner section. The comprehensive data acquired by the IS tool enabled the identification of optimal perforation intervals and ensured proper zonal isolation, ultimately leading to maximized hydrocarbon production and mitigate unwanted fluid problems, like we are presenting in the bellow DST report. This case study serves as an example of how advanced technology can improve well completion and production efficiency in the oil and gas industry.

Production data from DST show:

PERFORMANCE SUR DUSE :

Date	13/04/2021	
Duse (in)	24/64''	32/64''
WHP (psi)	1185-1200	860
Débit huile (m3/h)	6.51	9.27
Densité huile (15°C)	0.813	0.818
Débit gaz moyen (Sm3/h)	1858	1941
Densité du gaz (air =1)	0.800	0.806
Débit d'eau moyen (l/h)	350	400
Densité d'eau	1.23	1.23
Salinité d'eau (g/l NaCl)	320	320
GOR (Sm3/m3)	285	209
BSW (%)	Traces d'eau	Traces d'eau
CO2 (%)	0	0
H2S (ppm)	0	0
Volume de gaz torché	5337 m3	

Table V-2: DST data well X2 (8)

V.3 Well X-03: 4.5" Liner evaluation.

V.3.1 Introduction:

The well under evaluation was drilled in a complex reservoir with one producing zone. A 4.5" liner was run to isolate the targeted producing zone. A cement job was performed to ensure zonal isolation between these zones, as well as between the formation and wellbore. Proper zonal isolation is critical for efficient and safe hydrocarbon production.

V.3.2 Methodology:

The advanced technology IBC tool was deployed for this case study. An Isolation Scanner in combination of CBL-VDL were utilized for this purpose. The use of Isolation Scanner as advanced tool provides a comprehensive evaluation of the material behind casing, by combining Acoustic Impedance and Flexural attenuation measurements, thereby identifying the presence of channels, contamination, or compromised cement quality by the (Liquid-Solid-Gas) SLG map. This allows for a more accurate assessment of the cement bond and the identification of potential problem areas. The IBC tool was run by wireline crew to cover the entire section of the 4.5" liner.

V.3.3 Cement report:

Open hole	Depth: **2721 m MD** Bit size: **6.0 in, ID Caliper = 6.036"** Excess in cement volume: **(100% Excess)**
Current Casing data **Previous casing data** **Drill pipe data**	**4.5 in Liner # 13.5 ppf ,** Casing shoe: **2720 m** MD, Landing Collar: **2691.63 m,** Top of Liner: **2305.08 m MD** **7in CSG** (32.0 ppf) , **2456 m MD** **3.5 in DP,** (13.3 ppf) from **2305.08 m** up to surface
BHST/BHCT, T Gradient	**99 °C /65 °C,** Base on the Temp Log
Drilling fluid	Type: **OBM Mud,** Density: **1.55 SG**
Pre-flushes/ Spacers	**6.0 m³** of Spacer ahead: **1.75 SG** **1.0 m³** of Spacer behind: **1.75 SG**
Displacement	**OBM: 1.55 sg, Volume: 11.82 m3 (to be checked with actual Pipe tally)**
Cement Slurry	Tail slurry: - Type: **LQ-10** slurry @ **1.90 SG** - Volume: **6.50 m3** - **T.T: 06hr 45 min** - TOC @ **2255.08 m** (including 50 m above Top of Liner)

Table V-3: Cementing job design well X2 (8)

V.3.4 The compressed log:

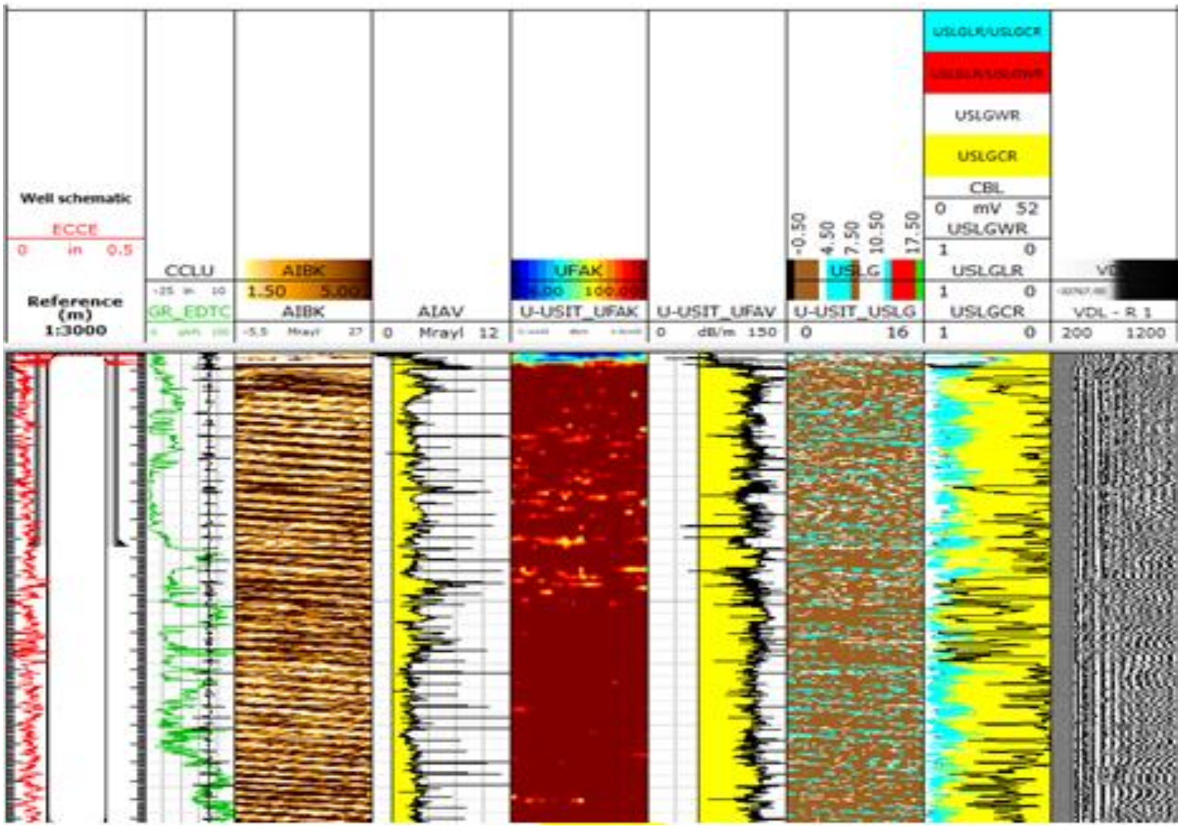


Figure V-10: compressed log well X3 (8)

V.3.5 Log Analysis:

X-03- is a well in AS field.

4.5" Liner was run from the surface to XX75m and cemented with a slurry 1.90 g/cc.

In order to evaluate the integrity of this casing, ensure the proper hydraulic isolation of cement over the double casing and open hole section.

An ultrasonic tool (IBC) was runed over the interval [XX15m – XX75m] on 07-Nov-20XX. During the job, the well was full of 1.55 g/cc of Mud. Good data quality was obtained from the tools. The interpretation can be summarized as follow:

- Over the interval [XX15m – XX75m]: SLG map shows azimuthal presence of cement behind the casing with strange formation arrival on VDL.

V.3.6 The interval of interest (perforation):

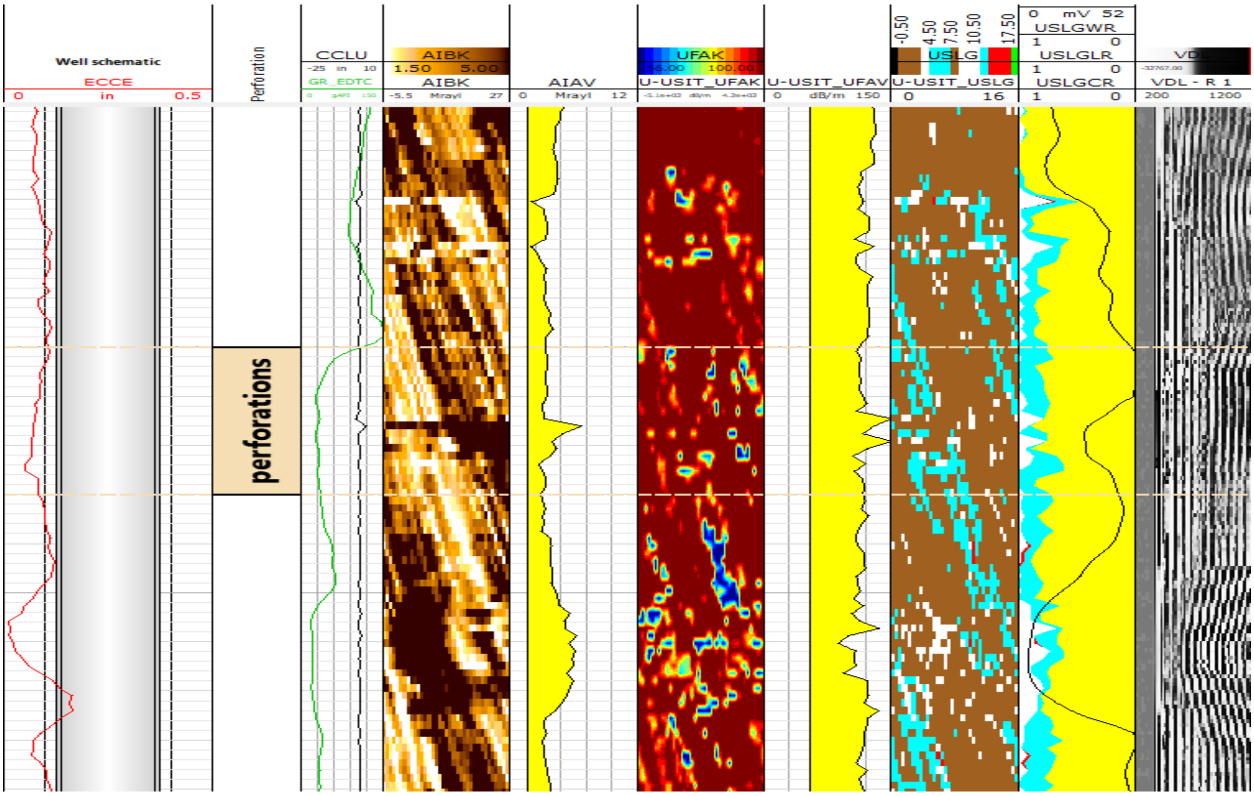


Figure V-11: IBC perforation log interval Well X3 (8)

V.3.7 Conclusion.

After a successful Cement evaluation on 4.5" liner, by the powerful Isolation scanner tool and the reviewing of the planned perforation interval, we see that there is a good isolation in this interval and the DST report confirm the result with the production without water presence.

V.3.8 Production data from DST report:

Performance sur duse :

Date	12/05/2020	
Duse (in)	24/64	32/64
WHP (psi)	1250	800
Débit huile (m3/h)	9.27	11.26
Densité huile (15°C)	0.821	0.824
Débit gaz moyen (Sm3/h)	1726	2052
Densité du gaz (air =1)	0.768	0.770
GOR (Sm3 /Sm3)	185	182
BSW (%)	Traces	Traces
CO2 (%)	0	0
H2S (ppm)	0	0

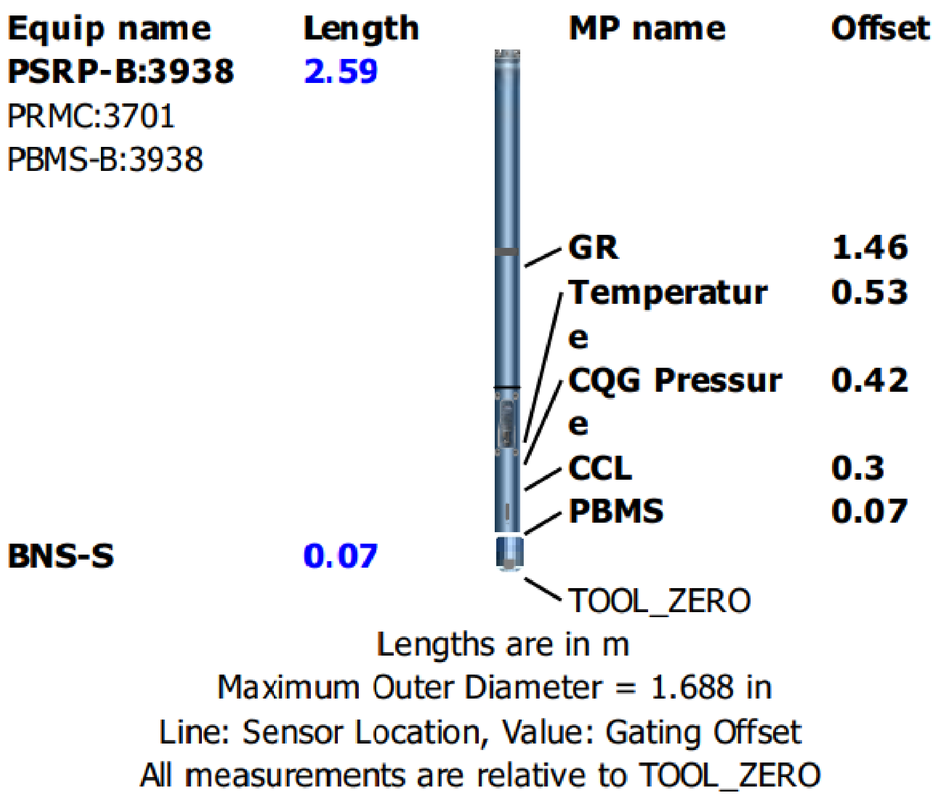
Table V-4: DST data well X2 (8)

V.4 Case 03: MCCL Correlation, Leak detection with PBMS Tool

The objectives from these jobs are:

1. **Top plug depth determination.**
2. **Detecting the interval of completion leak.**

First: Top plug depth determination



Remarks:

- CCL Correlation Stage 04 & 05
- The objective of the job: Depth determination, leak detection.
- All depths are collected from Tally.
- Intervals chosen by client.
- Correlation Passes:10 m/min and 15 m/min.

V.4.1 Results after logging:

V.4.1.1 Objective 01: Top plug depth determination

As we mention before all depth are collected from tally, so here we have stage 04 part from tally:

39	4 1/2" 12.6# L80 V.T Jt.	31	12.350	0.08183	12.268	442.911	2506.129	
40	4 1/2" 12.6# L80 V.T Jt.	32	12.388	0.08183	12.306	455.218	2493.822	
41	4 1/2" 12.6# L80 V.T Jt.	33	12.583	0.08183	12.501	467.719	2481.321	
42	4 1/2" 12.6# L80 V.T Jt.	34	12.574	0.08183	12.492	480.211	2468.829	
43	4 1/2" 12.6# L80 V.T Jt.	35	12.480	0.08183	12.398	492.609	2456.431	
44	4 1/2" 12.6# L80 V.T Jt.	67	12.587	0.08183	12.505	505.114	2443.926	
45	4 1/2" 12.6# L80 V.T Jt.	37	12.575	0.08183	12.493	517.607	2431.433	
46	4 1/2" Pup Joint, 12.6#, L80 Vam Top BxP	IA-BH-L80-PKR-30	1.580	0.08183	1.498	519.106	2429.934	Frac Stage 4
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	519.436	2429.604	
	4 1/2" Frac-Point Express OHP, 12.6#, Q125, Vam Top BxP		1.670	0.00000	1.670	521.106	2427.934	
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.340	0.00000	0.340	521.446	2427.594	
	4 1/2" Pup Joint, 12.6#, L80 Vam Top BxP		3.890	0.00000	3.890	525.336	2423.704	
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	525.666	2423.374	
	4 1/2" Frac-Point Express OHP, 12.6#, Q125, Vam Top BxP		1.670	0.00000	1.670	527.336	2421.704	
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	527.666	2421.374	
	4 1/2" Pup Joint, 12.6#, L80 Vam Top BxP		1.990	0.00000	1.990	529.656	2419.384	12.048
47	4 1/2" 12.6# L80 V.T Jt.	38	12.340	0.08183	12.258	541.914	2407.126	
48	4 1/2" 12.6# L80 V.T Jt.	39	12.282	0.08183	12.200	554.114	2394.926	
49	4 1/2" 12.6# L80 V.T Jt.	40	12.700	0.08183	12.618	566.732	2382.308	
50	4 1/2" 12.6# L80 V.T Jt.	41	12.371	0.08183	12.289	579.021	2370.019	
51	4 1/2" 12.6# L80 V.T Pup Joint	PJ-25	1.988	0.08183	1.906	580.928	2368.113	

Table 5: Stage 4 liner tally (8)

The log is delivered by Maxwell software, shown all the required data

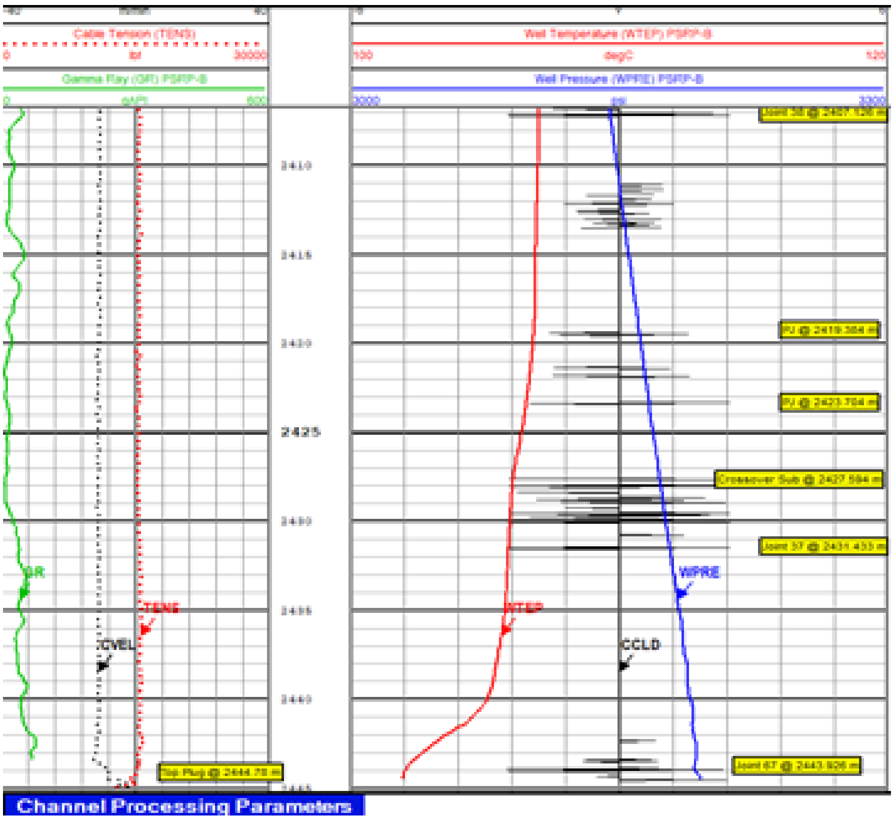


Figure V-12: Maxwell interface GR, CCL log (8)

To determine the right depth of the plug number 03 # stage 04 and to correct Coiled tubing unit depth we do two correlation Passes Up, from top plug which considering at 2448m with coiled tubing depth to 2370m with two different speeds, the first Pass Up with 10 m/min, the second Pass Up with 15 m/min, After shifting time of PBMS Data (GR, CCL, Temperature, pressure) with Coiled tubing Data(Speed, Depth, weight) and correlating CCL indications with Tally we found the Top of plug at 2444.78 m, and 3.52 m error of coiled tubing measuring system, We get the right depth off top plug with taken the slack off point (the last point in weight log before stabilization) so we have the new log interval from 2444.78 m to 2366 m, also we have stable temperature and pressure above the plug, that mean a good integrity of the plug (no leaks) and a stable GR log with scale of (0_150 gAPI) so no leaks or damaging in casing or in collars.

V.4.1.2 Objective 02: Detecting the interval of completion leak.

After setting plug#4 to biggen stage 05 well testing team face an issue with plug pressure test, as pressure log shown below pressure test of plug #4 failed, we can compare failed plug pressure test log with the previous pressure test of plug #3:

Note: pressure test of plugs was performing by sections.

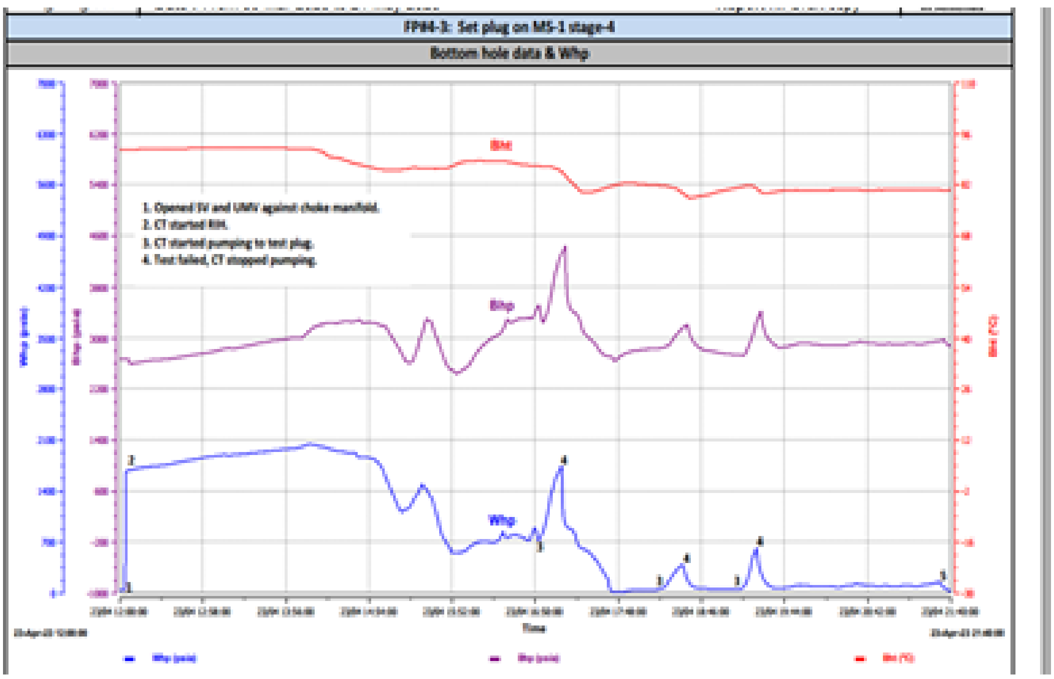


Figure V-13: Pressure test failed in plug 4 (8)

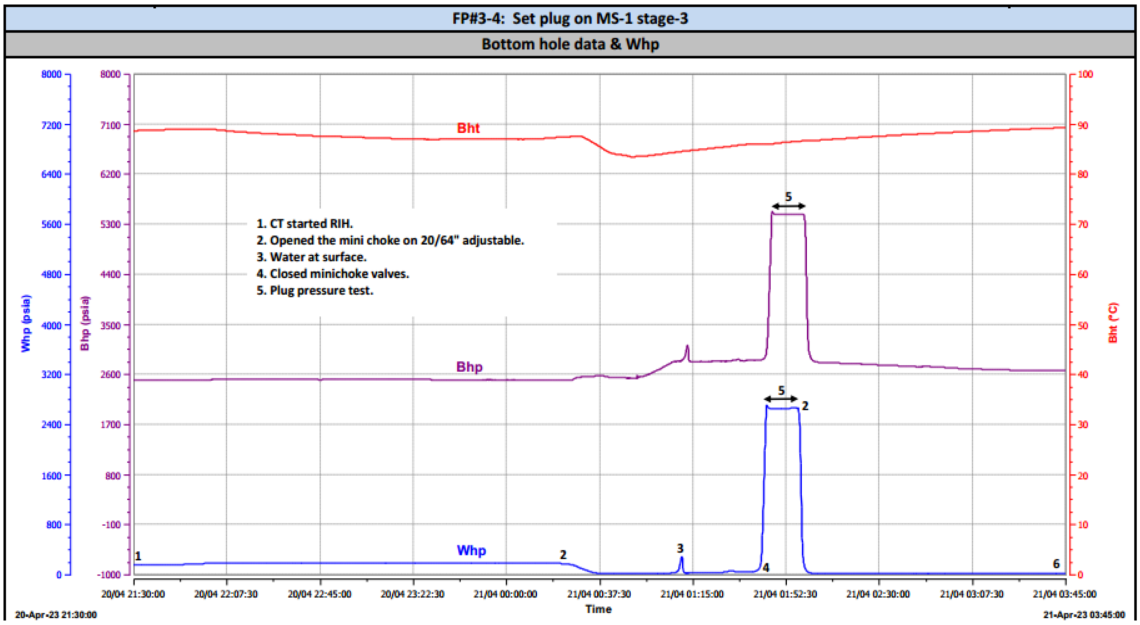


Figure V-14: Pressure test succeed in plug 4 (8)

As we mention before, all depth are collected from tally, so here we have stage 04 part from tally:

48	4 1/2" 12.6# L80 V.T Jt.	39	12.282	0.08183	12.200	554.114	2394.926	
49	4 1/2" 12.6# L80 V.T Jt.	40	12.700	0.08183	12.618	566.732	2382.308	
50	4 1/2" 12.6# L80 V.T Jt.	41	12.371	0.08183	12.289	579.021	2370.019	
51	4 1/2" 12.6# L80 V.T Pup Joint	PJ-25	1.988	0.08183	1.906	580.928	2368.113	
	4 1/2" Pup Joint, 12.6#, L80 Vam Top BxP		1.600	0.08183	1.518	582.446	2366.594	
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	582.776	2366.264	
	4 1/2" Frac-Point Express OHP, 12.6#, Q125, Vam Top BxP		1.670	0.00000	1.670	584.446	2364.594	
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	584.776	2364.264	
52	4 1/2" Pup Joint, 12.6#, L80 Vam Top BxP	IA-BH-L80-PKR-33	4.020	0.00000	4.020	588.796	2360.244	Frac Stage 5
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	589.126	2359.914	
	4 1/2" Frac-Point Express OHP, 12.6#, Q125, Vam Top BxP		1.670	0.00000	1.670	590.796	2358.244	
	4 1/2" Crossover Sub, 12.6#, P110 Vam Top BxP		0.330	0.00000	0.330	591.126	2357.914	
	4 1/2" Pup Joint, 12.6#, L80 Vam Top BxP		2.010	0.00000	2.010	593.136	2355.904	12.208
53	4 1/2" 12.6# L80 V.T Jt.	42	12.400	0.08183	12.318	605.454	2343.586	
54	4 1/2" 12.6# L80 V.T Jt.	43	12.590	0.08183	12.508	617.962	2331.078	
55	4 1/2" 12.6# L80 V.T Jt.	44	12.675	0.08183	12.593	630.555	2318.485	
56	4 1/2" 12.6# L80 V.T Jt.	45	12.701	0.08183	12.619	643.174	2305.866	
57	4 1/2" 12.6# L80 V.T Jt.	46	12.173	0.08183	12.091	655.266	2293.774	
58	4 1/2" 12.6# L80 V.T Jt.	47	12.318	0.08183	12.236	667.502	2281.538	
59	4 1/2" 12.6# L80 V.T Jt.	48	12.365	0.08183	12.283	679.785	2269.255	
60	4 1/2" 12.6# L80 V.T Jt.	49	12.218	0.08183	12.136	691.921	2257.119	
61	4 1/2" 12.6# L80 V.T Jt.	50	12.492	0.08183	12.410	704.331	2244.709	
62	4 1/2" 12.6# L80 V.T Jt.	51	12.558	0.08183	12.476	716.807	2232.233	
63	4 1/2" 12.6# L80 V.T Jt.	52	12.423	0.08183	12.341	729.149	2219.891	
64	4 1/2" 12.6# L80 V.T Jt.	53	12.465	0.08183	12.383	741.532	2207.508	
65	4 1/2" 12.6# L80 V.T Jt.	54	12.595	0.08183	12.513	754.045	2194.995	

Table 6: stage 5 liner tally (8)

The log is delivered by Maxwell software, shown all the required data

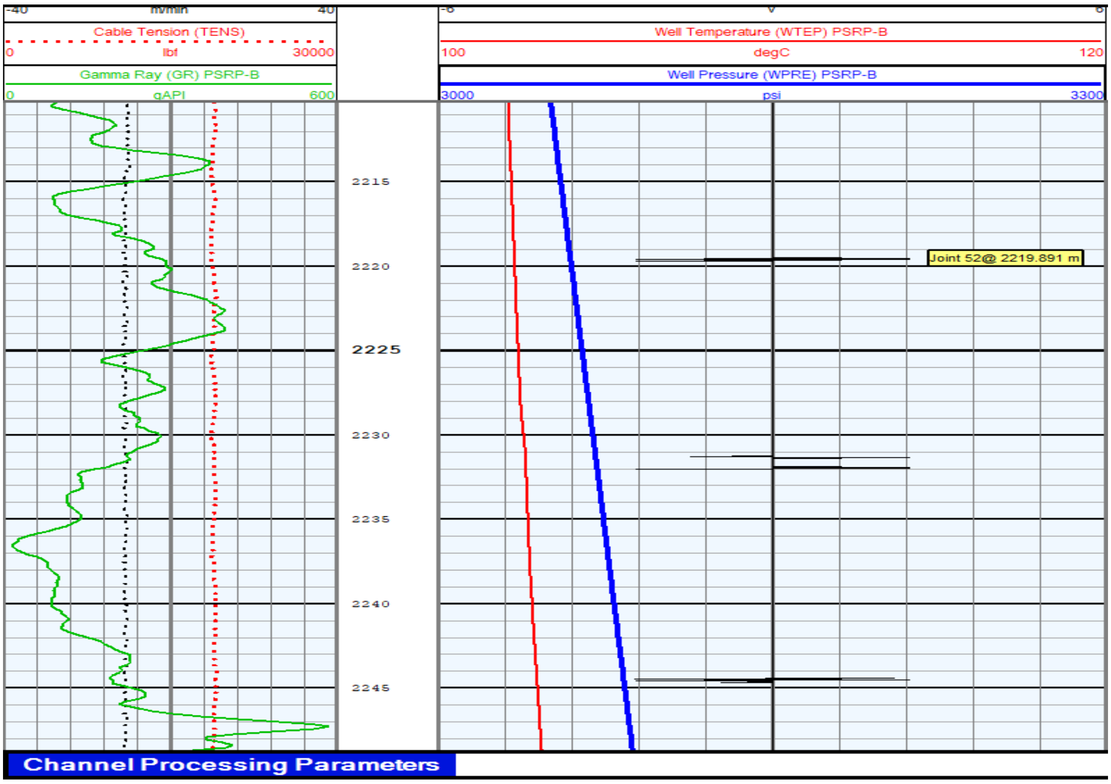


Figure V-15; GR leak interval (8)

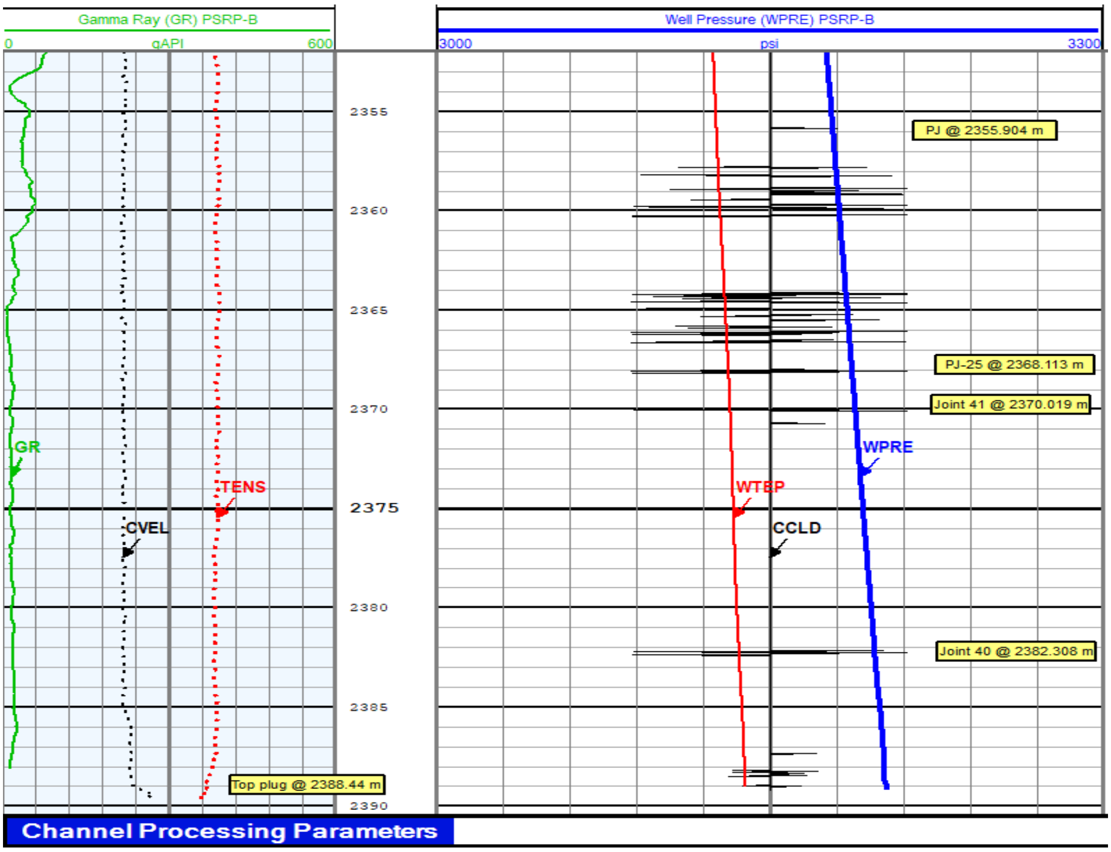


Figure V-16: GR log normal interval (8)

After failure of plug#4 pressure test, client run Leak detector, and finally they confirmed that there is a leak in the interval between 2200m and 2388m,To have more precision in the interval of the leak through the liner and the right depth of the plug number 04 # stage 05 and to correct Coiled tubing unit depth we do two correlation Passes Up, from top plug which considering at 2392m with coiled tubing depth to 2200m with two different speeds, using GR & CCL log, the first Pass Up with 10 m/min, the second Pass Up with 15 m/min, After shifting time of PBMS Data (GR, CCL, Temperature, pressure) with Coiled tubing Data(Speed, Depth, weight) and correlating CCL indications with Tally we found high GR with scale of (0_600 gAPI) so there is a communication with anulus in interval 2210m to 2250m with tree High GR picks at 2247m, 2222.5m and 2214m , we have also the Top of plug at 2388.44 m, and 3.56 m error of coiled tubing measuring system, so we have the new log interval from 2388.44 m to 2196 m, also we have stable temperature and pressure above the plug, that mean a good integrity of the plug (no leaks).

This case of study gives us the opportunity to check well integrity by verify the performance of two barriers, PLUG & CASING using PBMS Tool in memory mode with Coiled tubing unit which have the capacity to work in horizontal well, the first result is positive, but the second result explored a failure in well integrity (casing failure through 50 m).

Involving multistage hydraulic fracturing and a potential leak above a plug, and also observing a high Gamma ray peak in an interval of 20 meters. Given the situation, here are some interpretations: Leak Detection Above Plug in Multistage Fracturing: In a multistage fracturing operation, plugs are utilized to isolate different stages so that each can be fractured independently. If there is a leak above a plug,

This could lead to communication between stages, which is undesirable as it can reduce the efficiency of the fracturing operation. In diagnosing the cause, operators can run diagnostic tests such as pressure testing or temperature logging to help identify the location and severity of the leak. Once the problem is identified, remedial action such as squeeze cementing or running a patch can be considered. High Gamma Ray Peak in an Interval of 20 meters: Gamma ray logging is used in the oil and gas industry to measure the natural radioactivity of formation rocks. This helps in identifying lithology and stratigraphic changes.

A high gamma ray peak usually indicates the presence of shales or clay-rich formations, as they typically contain more radioactive isotopes (like potassium, uranium, and thorium) than sandstones or carbonates. If you're observing this in a 20-meter interval, this could mean that you are dealing with a clay-rich zone in that section. If this is the case, the rock could have lower permeability and more complex stress conditions, which may affect the fracturing operation and production behaviour. These are very general interpretations based on the information provided. It's worth mentioning that every well and reservoir is unique, and it's important to consider the specific conditions and data you have. For more accurate diagnosis and solution planning, it's recommended to involve experts like reservoir engineers, geologists, and petrophysicists.

V.5 Case04: Isolation Scanner Technology helped identify formation collapse behind liner and set a way forward to restore its integrity.

V.5.1 Abstract:

This case study provides an in-depth analysis of the material evaluation behind the casing, formation collapse of X-4 well in a 7" liner section, utilizing an advanced Slb cement evaluation tool, which is Isolation Scanner (refer to chapter3). The study Focus on the systematic approach used to identify problem areas, develop a tailored solution, and implement a successful evaluation of the material behind the casing, the evaluation demonstrated the effectiveness of the SLG map & TIE map, ensuring safe and efficient operations and restore the integrity of the 7” Liner.

V.5.2 Formation collapse definition:

Formation collapse in a wellbore typically refers to a scenario where the borehole wall or nearby formation has experienced a loss of integrity or strength, leading to the collapse of material into the wellbore. This can be due to various reasons such as poor cement job, high drilling fluid pressure, improper mud weight, or simply the nature of the formation itself.

V.5.3 Introduction:

In the field of oil and gas (XM) operations, maintaining the integrity of the 7” liner is of paramount importance. It ensures proper circulation of mud and cement slurry. This study revolves around a case where in a 7" liner section, which require a deep evaluation.

V.5.4 Problem Identification:

The initial step was to diagnose the condition of the 7” liner integrity. Isolation Scanner as advanced tool provides a comprehensive evaluation of the material behind casing, by combining Acoustic Impedance and Flexural attenuation measurements, thereby identifying the annulus material by the (Liquid-Solid-Gas) SLG map. The interval is the entire 7” liner [XD70m – XR40m].

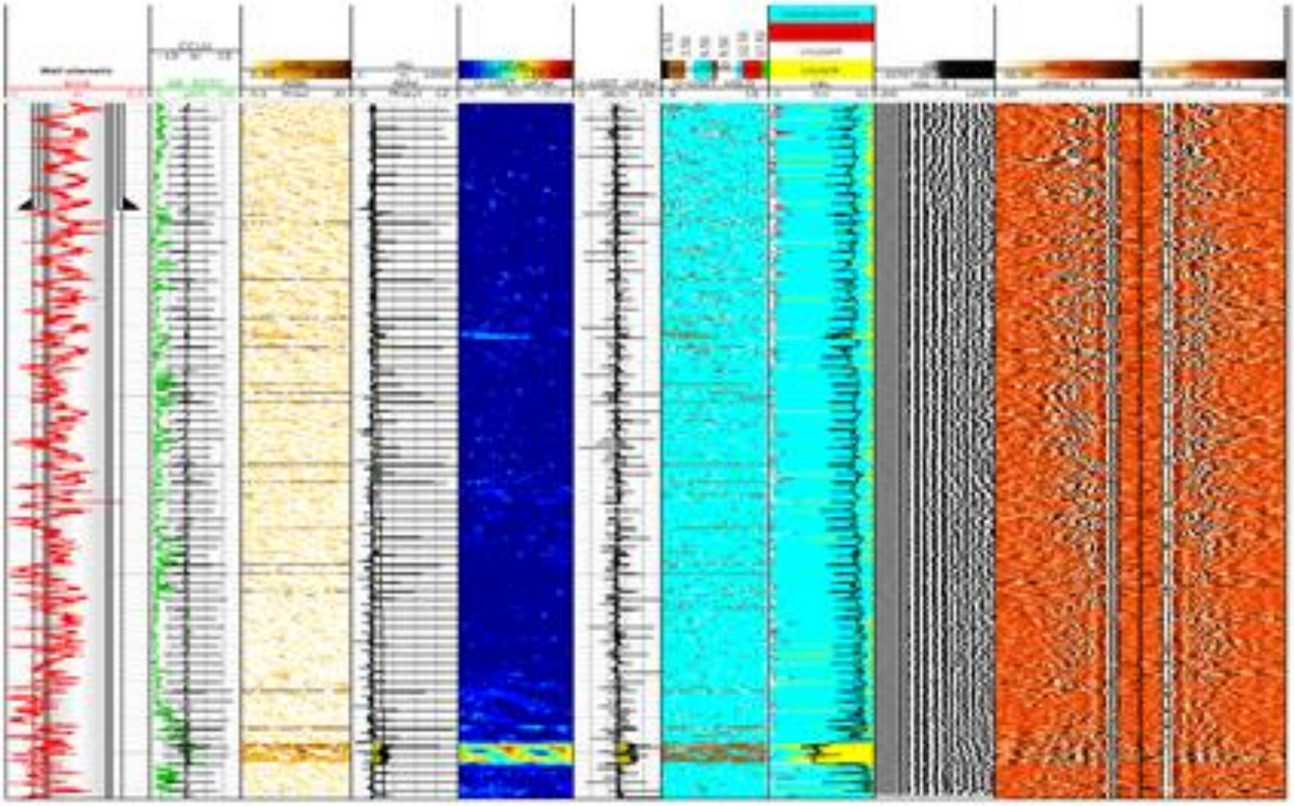


Figure V-17; The compressed log of the well X4

During the job, the well was full of 2.05 g/cc of OBM. Good data quality was obtained from both tools. The interpretation can be summarized as follow:

- Over the all the interval pass SLG map show Free pipe, High amplitude from CBL and we can see clean third interface arrival which confirm free pipe section. Except the interval [XD70m – XR40m]: SLG map shows Azimuthal presence of solid behind liner, with high pick of GR (shale formation indicator), in addition to the TIE arrivals signatures.

The zone of interest:

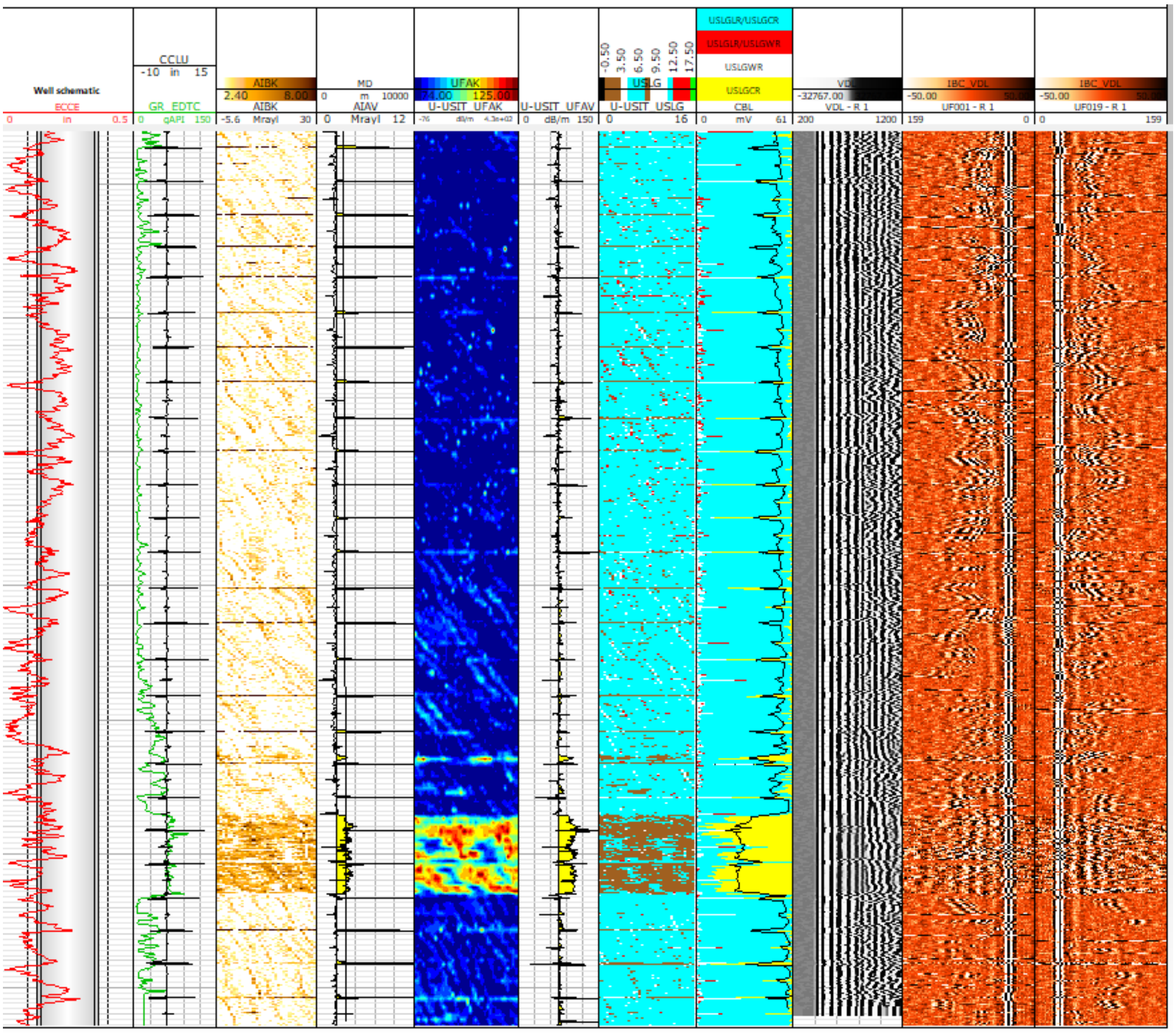


Figure V-18: IBC zonation log, formation collapse (8)

V.5.5 Conclusion

After a successful evaluation for this case, we can say for identifying the formation collapse after casing run the Isolation Scanner is a good tool for providing clear answer regarding annulus material by SLG map & TIE, in addition to CBL amplitude and GR pick over the interval of interest.

GENERAL CONCLUSION

General conclusion

In conclusion, our project untitled “Applications of Advanced Well Integrity Evaluation Technologies for Critical Decision Making" focused on the crucial area of well integrity, its evaluation, and interpretation. Throughout the project, a comprehensive examination of various advanced technologies and techniques was conducted to address well integrity issues, leading to informed decision-making processes in the oil and gas industry. The project shed light on the importance of well integrity, as it directly impacts the safety, productivity, and profitability of operations. By utilizing advanced evaluation technologies, such as advanced ultrasonic sensors, data analytics and interpretation.

The project demonstrated how critical decision-making processes can be enhanced, resulting in improved well integrity management. The findings of the project highlighted the significance of early detection and prevention of potential well integrity failures, which can lead to catastrophic consequences and substantial financial losses.

Through the application of advanced technologies, it was shown that timely identification of integrity issues and accurate interpretation of data can facilitate proactive maintenance strategies, reducing operational risks and minimizing unplanned downtime. Furthermore, the project emphasized the importance of collaboration among various stakeholders, including Well integrity engineers, production and data analysts, and decision-makers. By integrating their expertise and utilizing advanced evaluation technologies and software, a holistic approach to well integrity evaluation and interpretation can be achieved, fostering a culture of proactive decision-making and risk management.

Overall, our graduation project on this subject provided valuable insights into the field of well integrity management. It highlighted the significance of leveraging advanced technologies and interdisciplinary collaboration to enhance well integrity evaluation and interpretation, ultimately enabling more informed decision-making processes, and improving the overall efficiency and safety of petroleum operations.

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