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## **Unconventional Solution for Well Operation and Maintenance: A Successful Case History of Surface and Downhole Leak Repair Using Robust Chemical Sealant**

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### **Abstract**

Operating and maintaining a healthy well is a demanding task for every energy producer worldwide. The loss of production and emerging environmental issues due to leaks is a concerning event and needs an immediate solution. Surface and downhole leaks on any well indicate a loss of well integrity barrier. The utilization of high-performance chemical sealant to reinstate the well barrier is evaluated during a non-routine well integrity campaign.

The approach was to gather and analyse the well leaked info data for each leak case. A methodology was then developed to properly design the diagnostic and rectification plan. Various leak-sealing principles were investigated during this stage. Several system integrity tests (SIT) were performed to demonstrate and approve the leak-sealing concept on a laboratory scale. Combinations of Pressure-activated sealant (PAS) and time-activated sealant (TAS), either polymer and epoxy resin-based, provide a wide range of leak-sealing opportunities for surface and downhole leaks.

A total of 10 well barrier elements (WBE) on different wells were diagnosed and rectified using high-pressure sealant, which includes downhole packer, surface wellhead component, sub-surface control line, and conductor casing. Most of the WBE reported experiencing unique leaks during diagnostic, and the correct sealant was deployed according to the design methodology and procedure. Acceptance criteria of well barrier enveloped were followed to qualify the rectification works. Ultimately, all 10 WBE managed to be rectified riglessly during the campaign.

The paper delineates the process of choosing a leak-sealing methodology and sealant working principle for each individual well integrity rectification, while also emphasizing the various factors that must be considered during the engineering study, diagnostic, and rectification activities, and the deployment strategy. Additionally, the paper shares the experiences and lessons learned during the execution phase. Finally, the paper also summarizes the post-monitoring result after one year of leak sealing application.

## Introduction

Well integrity is designed to last throughout the well life cycle, and maintaining it requires a collaborative effort from various stakeholders. These include the well operator, who acts as the well custodian, local government policies that establish rules and regulations for maintaining a healthy well, and service providers who offer holistic solutions for addressing well integrity issues while aligning with local governance objectives. According to the Malaysian Petroleum Management (MPM), such collaboration is essential to ensure that the country's resources are managed optimally. SEA Hibiscus, through its Well Integrity Management Manual (WIMM), has successfully managed to operate wells safely and efficiently while complying with industry regulations. In collaboration with service contractors, the operator has successfully completed all well integrity remediation work during one of the largest non-routines well integrity campaigns in 2022.

Leak occurrence is unavoidable during the operation and maintenance of an oil and gas well. A leak refers to the unintended escape or release of fluids, such as oil, gas, or other hydrocarbons, from a containment system or pipeline. These leaks can occur in various locations within the well construction, whether sub-surface or surface, compromising the well barrier elements (WBEs). According to ISO technical standards, there are approximately 26 typical modes of failures, and any simultaneous occurrence of two or more failures could severely worsen the integrity condition of a well (ISO/TS 16530-2, 2013) as shown in figure 1.

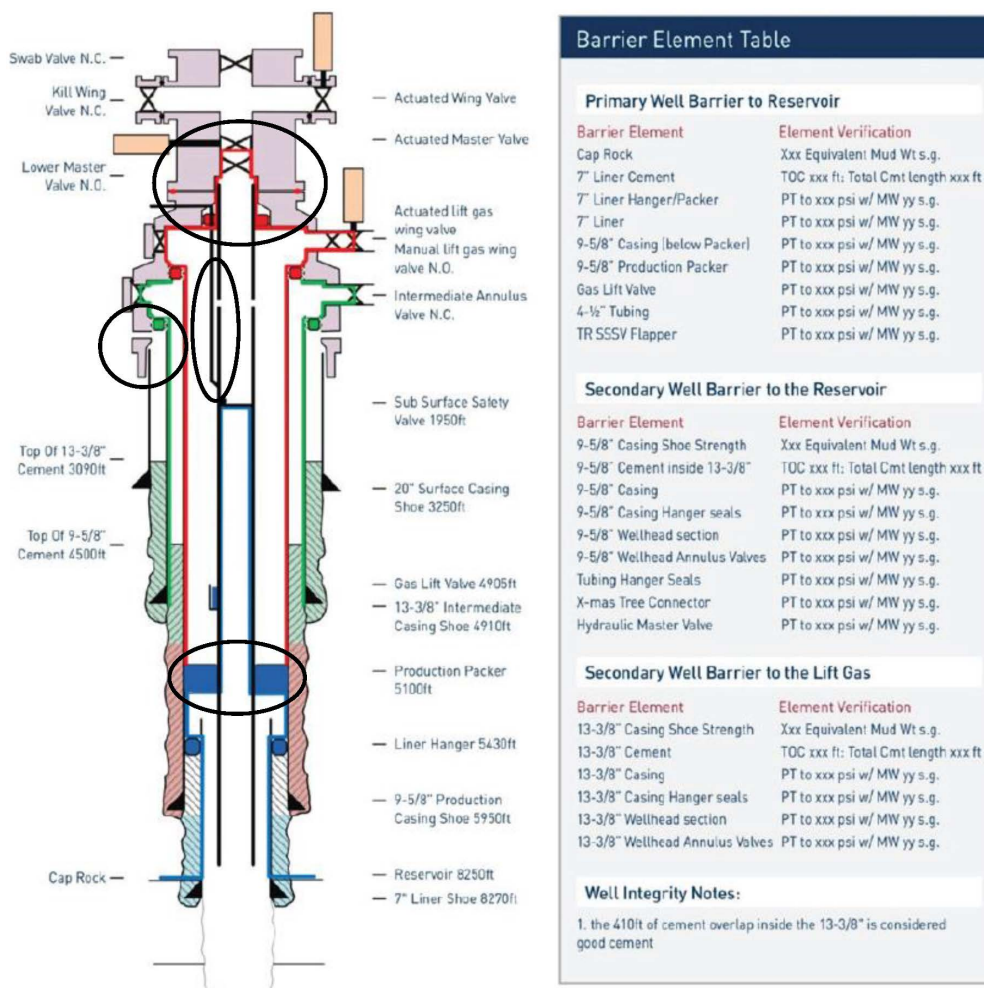


Figure 1—Well Barrier Schematic and Well Barrier Element table according to ISO/TS 16530-2:2013(E) technical standard with affected WBEs integrity to be reinstated in this campaign (in circle).

Reinstating well integrity requires extensive diagnostic testing, well intervention, and leak repair solutions to meet acceptance criteria and performance standards during the design phase (as-built well integrity). Therefore, preventing and promptly addressing leaks is crucial to maintaining safety standards, minimizing environmental impact, and ensuring the efficient operation of oil and gas facilities.

The methodology of utilizing robust chemical sealant applications, namely pressure-activated sealants (PAS) and time-activated sealants (TAS), to reinstate well integrity has been discussed among the well integrity fraternity in recent years. [Rodrigues et al. \(2005\)](#) discussed the use of pressure-activated sealants to cure subsea wells. Repairing subsea well annular integrity using coil tubing and pressure-activated sealants was also explored by [Joel et al. \(2023\)](#). Chemicals epoxy resin have been utilized as alternative barrier solution materials, as discussed by [Colin et al. \(2015\)](#), specifically for plug and abandonment operations. [Saharuddin et al. \(2019\)](#) also presented similar chemical sealant applications, focusing on high annulus pressure rectification procedures during the production phase.

This paper describes how PAS and TAS successfully rectified both surface and downhole leaks, enabling the operator to resume well production. These operations were conducted in tandem with various well service deployment technologies, facilitating efficient rigless well integrity reinstatement that aligned with the operator's objectives. The specifics of this approach are thoroughly discussed in the paper.

## Problem Statement

In 2022, several operator assets located offshore Sabah, Malaysia, were reported to suffer from various well integrity issues triggered during routine well maintenance. Six wells experienced well barrier leaks at the surface, while four wells suffered from downhole leaks. The types of well barrier element leaks investigated are summarized in [table 1](#) below.

**Table 1—Summary of well barrier element affected and the leak category.**

Category	Sub- Category	Well	Well Barrier Element (WBE)
Surface	Wellhead	W 1	Tubing Hanger Void
	Wellhead	W 2	Tubing Hanger Neck Seal
	Wellhead	W 3	PRL / Tubing Hanger Neck Seal
	Wellhead	W 4	Tubing Hanger Body Seal (THBS) & MTM
	Conductor	C 1	Conductor Leak (SCP)
	Conductor	C 2	Conductor Leak (SCP)
Downhole	Packer	P 1	Production Packer
	Packer	P 2	Production Packer
	Packer	P 3	Production Packer
	Control Line	CL 1	Control Line (Sub-Surface)

The location of the assets also varied from one location to another as shown in [figure 2](#), thus requiring proper project planning from the well operator.



Figure 2—Location of each well leak repair candidate on Field A, B and C.

Preliminary data studies have shown that each leak is unique and requires several deployment strategies to ensure better placement of sealant, thus increasing the chances of success in the leak remedial job. The selection process involves multiple deployment equipment from vendors to suit different rectification methods.

There are several consequences of these leaks for the operator, such as loss in production due to Unplanned Deferment (UPD), halting intervention plans due to leaks in surface Well Barrier Elements (WBE), and, most critically, surface release of hydrocarbons triggering environmental issues.

### Chemical Sealant Leak Sealing Principle

Having a selection of various unique sealant characteristic properties and activation mechanisms provides operators with a valuable opportunity to approach leak issues differently. Each sealant type offers distinct advantages tailored to specific leak scenarios, allowing operators to choose the most appropriate solution based on factors such as leak rate, location, and severity.

By understanding the unique properties and activation mechanisms of each sealant type, operators can strategically select the most suitable option to effectively mitigate leaks, optimize well integrity, and minimize operational disruptions.

### Pressure Activated Sealant (PAS)

Pressure Activated Sealant (PAS) is a liquid sealant that solidifies at the site of a leak where a pressure differential exists. When pressure is applied, it generates a significant shearing force within the sealant flow at the leak point, prompting the sealant to transform into interlocking polymeric fibres as seen on [figure 3\(a\)](#), effectively sealing the leak. PAS possesses a viscosity akin to water, making it ideal for addressing minor leaks. Furthermore, this sealant is chemically inert and compatible with oil, gas, and water.

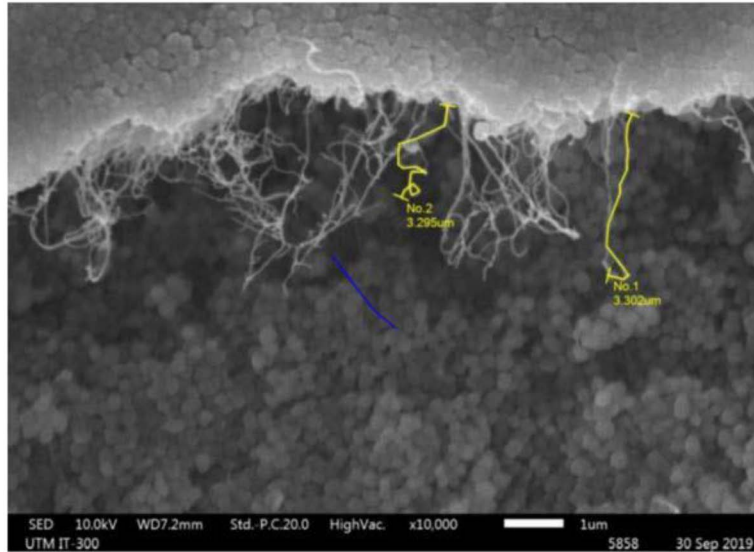


Figure 3(a)—20K times SEM micrograph of a solidified PAS

PAS has a specification of pressure rating of 10,000 psi and temperature rating maximum of 260 °C. Standard density and viscosity of the sealant is 12.6 ppg and 20 cP and can be modified and adjusted to suit leak scenario.

Common application of PAS can be used to rectify:

- Surface wellhead and Xmas tree leaks
- Gate valve leaks
- Metal to metal (SRL/SBMS) seals
- Casing hanger seals
- Pack-off seals.
- Conductor leaks
- Down-hole/Subsea leaks
- Control line.
- Downhole safety valve
- Inflow control valve
- Production packer
- Liner leaks
- Tubing connection/Body
- Casing connection/Body

- Seal assemblies.
- Sliding side door
- Side pocket mandrels/Injection valves
- Umbilical lines

### Time Activated Sealant (TAS)

Time Activated Sealant (TAS) is formulated in liquid form and comprises two (2) components: a base fluid and an activator. These components must be thoroughly mixed and allowed time to cure, solidifying over time. The duration of solidification is influenced by factors such as temperature and the volume of activator added to the mixture. Figure 3(b) illustrates a scanned electron microscopy (SEM) micrograph of solidified TAS.

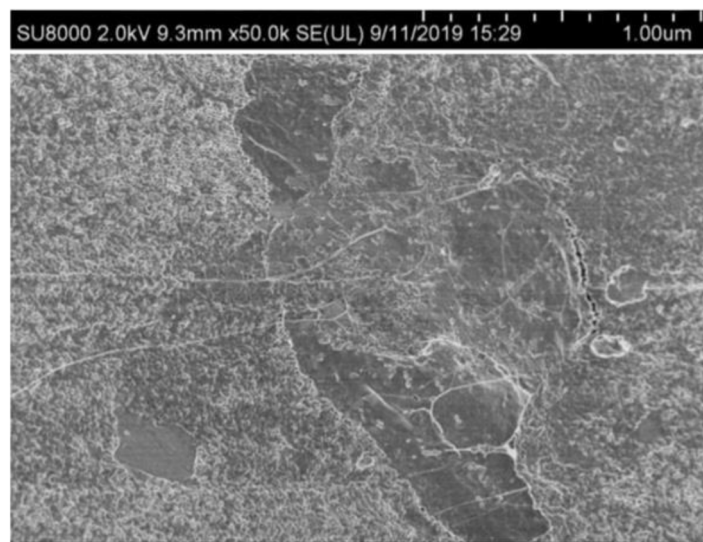


Figure 3(b)—500 times SEM micrograph of a solidified TAS

The activation mechanism involves polymerization resulting from the reaction between the activator and base fluid. This reaction transforms the mixed liquid into a solid state characterized by hardness yet slight flexibility. The solidified flexible polymer exhibits high tensile strength, enabling it to withstand elevated pressure and temperature conditions. Importantly, zero shrinkage occurs during the solidification process, ensuring comprehensive coverage over the leak area. TAS demonstrates resistance to most chemicals and is compatible with hydrocarbons or produced fluids.

TAS has a specification of pressure rating of 10,000 psi and temperature rating maximum of 260 °C. Standard density and mixed viscosity of the sealant is 9 ppg and 15,000 cP respectively, which can also be modified and adjusted to suit leak scenario on site. TAS was included in the rectification program as the secondary candidate to seal narrow leak paths either in surface or downhole condition.

Common application of TAS can be used to rectify:

- Surface wellhead and Xmas tree leaks
- Wellhead/Xmas tree body
- Metal to metal (SRL/SBMS) seals
- Tubing hanger seals

- Casing hanger seals
- Conductor
- Down-hole leaks/Subsea
- Tubing connection/Body
- Casing connection/Body
- Sustain Casing Pressure (SCP) – Micro annular/Poor cement.

There are two different types of TAS distinguished by their base materials:

- i. TAS with a Polymer Base
- ii. TAS with an Epoxy Base

Time Activated Sealant (TAS - Epoxy Base) requires a high viscosity pump capability for deployment. Typically, the repair area doesn't necessitate cleaning since epoxy TAS possesses the ability to self-level and bond/adhere with metal and cement surfaces. Upon activation, the sealant undergoes polymerization, releasing heat in a controlled exothermic effect. It functions by hardening to create a plug with very high compressive strength, effectively blocking any leak path.

This type of sealant is commonly employed to address sustain casing pressure (SCP) issues stemming from cement leaks, such as cement cracks or micro-annulus leaks. Additionally, it serves as a permanent plug for Plug and Abandonment (P&A) and Control Line (CL) leaks. Its properties closely resemble those of cement but are superior in several aspects. However, TAS with epoxy base is not suitable for wellhead surface leak remediation.

In general, PAS was selected as the primary solution for addressing most wellhead leaks due to its effectiveness in remedying smaller leaks and its ability to seal in-situ. In cases where the leak proved to be irreparable with PAS, TAS served as the secondary option. By utilizing both sealants, all leak issues were effectively resolved.

### **Composite Repair Epoxy Grout**

This composite repair uses a specialized epoxy adhesive consisting of three components, designed specifically for use in the epoxy grout application. Its unique physical properties enable its deployment in demanding situations, offering high load-bearing strength and exceptional adhesion to create a seal for this project. When there's active gas emission during deployment, diverting the reservoir gas to a safe zone using tubing temporarily contains the leak to prevent gas bubble formation that can affect grout quality.

Figure 3(c) demonstrates the mechanism of epoxy grout absorbing the load-bearing force and increasing structural strength.

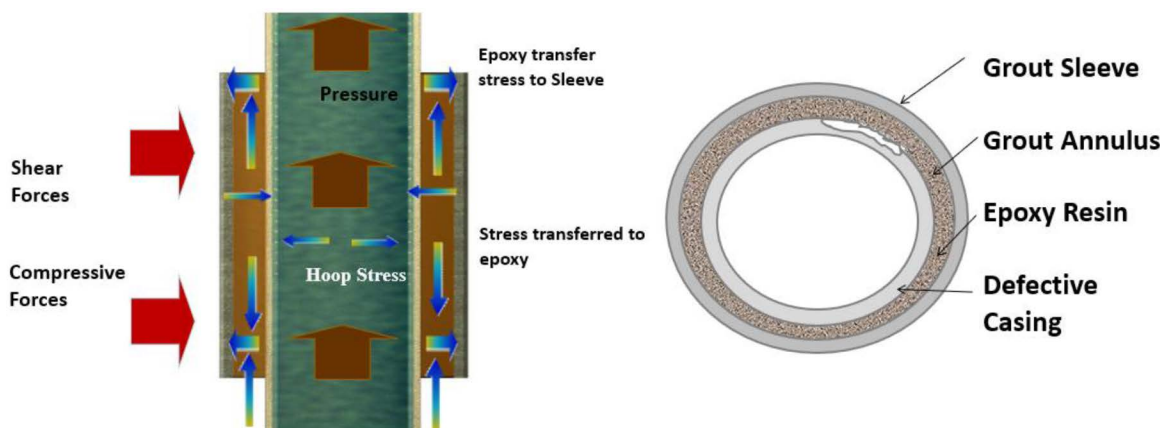


Figure 3(c)—Cross-sectional view of composite repair systems and their sealing mechanism.

## Leak Rectification Methodology

A complete understanding of leak characteristics and behaviors is crucial in determining the next course of action. In this paper, the authors have outlined the following steps to achieve a better understanding of the leaks' issues for each Well Barrier Element (WBE) and the methods to stop the leaks. These steps are documented in the form of a Work on Paper (WOP), detailing data gathering and analysis, diagnostic plans, proposed System Integrity Test (SIT), and rectification plans.

### Data gathering and leak analysis

During this process, leak categorization is implemented, as seen in [Table 1](#). This summary can help determine what data should be gathered for analysis. Data required for wellhead leak issues can usually be extracted from the operator's wellhead preventive and corrective maintenance reports. In this case, the operator's vendor performing Critical Device Functions Test (CDFT) triggers the WBE failure and flags a requirement for further diagnostics and maintenance. Wellhead stack-up and schematic are also crucial in understanding the potential leak path since there are many isolation barriers in the wellhead tree itself.

Conductor leaks at the body usually occur due to corrosion or cement grouting degradation. Conductor leak issues require casing completion history to understand the type and material of the conductor installed in the facility. However, leaks on conductors are not independent since the conductor was not supposed to sustain any pressure. During this study, the authors found out that the existence of Sustain Casing Pressure (SCP) also contributed to the problems.

Packer leaks are the most challenging leak issues encountered during this campaign. This type of leak requires further understanding of well completion and packer installation guidelines. Control Line (CL) plugging requires a simple dataset such as well schematic, CL physical properties like maximum operating pressure, diameter, and wall thickness. CLs are installed to operate downhole equipment such as SCSSV, CIV, ESP, and PDG. The authors found the importance of understanding the equipment connected to the CL so that sealant deployment can be properly assessed.

An example of typical data required for further analysis is shown in the [table 2](#) below:

Table 2—Summary of typical data and report for analysis

Leak category	Typical Data Requirement
Wellhead	Well Schematic, Wellhead/Tree Drawing, CDFT Report, Wellhead Preventive & Corrective Maintenance Record (PM&CM),
Conductor	Well Schematic, Wellhead/Tree Drawing, Annulus Pressure Monitoring
Packer	Well schematic, Wellhead/Tree Drawing, Intervention History, Annulus Pressure Monitoring
Control Line	Well Schematic, Wellhead/Tree Drawing, CL Properties, Downhole Equipment Operating Manual

The purpose of this step is to gather all data and summarize each leak potential based on operator data. When studying the data, the authors understand the potential leak path as shown in figure 4 and potential affected Well Barrier Elements (WBEs), and sometimes the severity of the leaks for better diagnostic and repair plan.

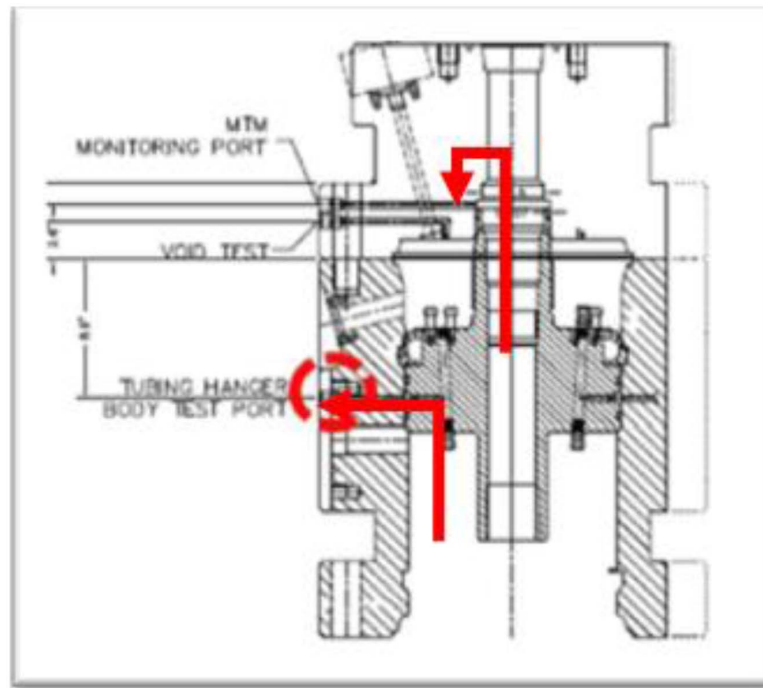


Figure 4—Potential leak path visualization using wellhead tree diagram or drawing.

When a leak is too severe and deemed unsuitable for a sealant solution, the data can be relied upon to explore other options for well leak repair, such as mechanical changeout or perhaps working over the well. If the leak is manageable, the data is reliable to be used for Management of Change (MOC) writing after several risk assessments are completed.

### Leak Diagnostic Plan

Qualifying and quantifying the potential of a leak is another important step for a successful leak sealing procedure. As discussed by Saharuddin et al., 2020, a well-thought-out leak diagnostics plan is important in understanding a leak problem and determining the right approach and selection of sealant to be used for rectification. From data gathering and analysis, the integrity status of each potential leak must be confirmed

on-site. Qualifying a leak is important by confirming the potential leak of each Well Barrier Element (WBE), while quantifying the leak involves measuring the severity of the leak by performing several pressure manipulation tests.

Performing Pressure Build-Up (PBU) and pressure tests at the wellhead seal provides insight into the seal integrity. Additionally, these tests confirm if the potential WBE is leaking and the severity of the leak, which aids in deciding the suitable chemical sealant for repair.

Understanding the well barrier element's working principle, installation running procedure, and testing methods of the leak component is crucial for designing diagnostic and rectification procedures. For example, if a tubing hanger was tested at a testing port with allowable pressure drop tolerance using hydraulic oil as the medium, the diagnostic procedure should be similar since the method will be used to quantify post-rectification performance. This ensures consistency and accuracy in evaluating any potential leaks and verifying the effectiveness of rectification efforts.

Downhole leaks require additional diagnostic methods to qualify the leak depth location. Common approaches such as use of acoustic logging tools are necessary to detect noise at depth via performing several logging passes under different conditions or pressure manipulations on the well annulus and tubing. Figure 5 shows examples of leak confirmation by performing acoustic logging.

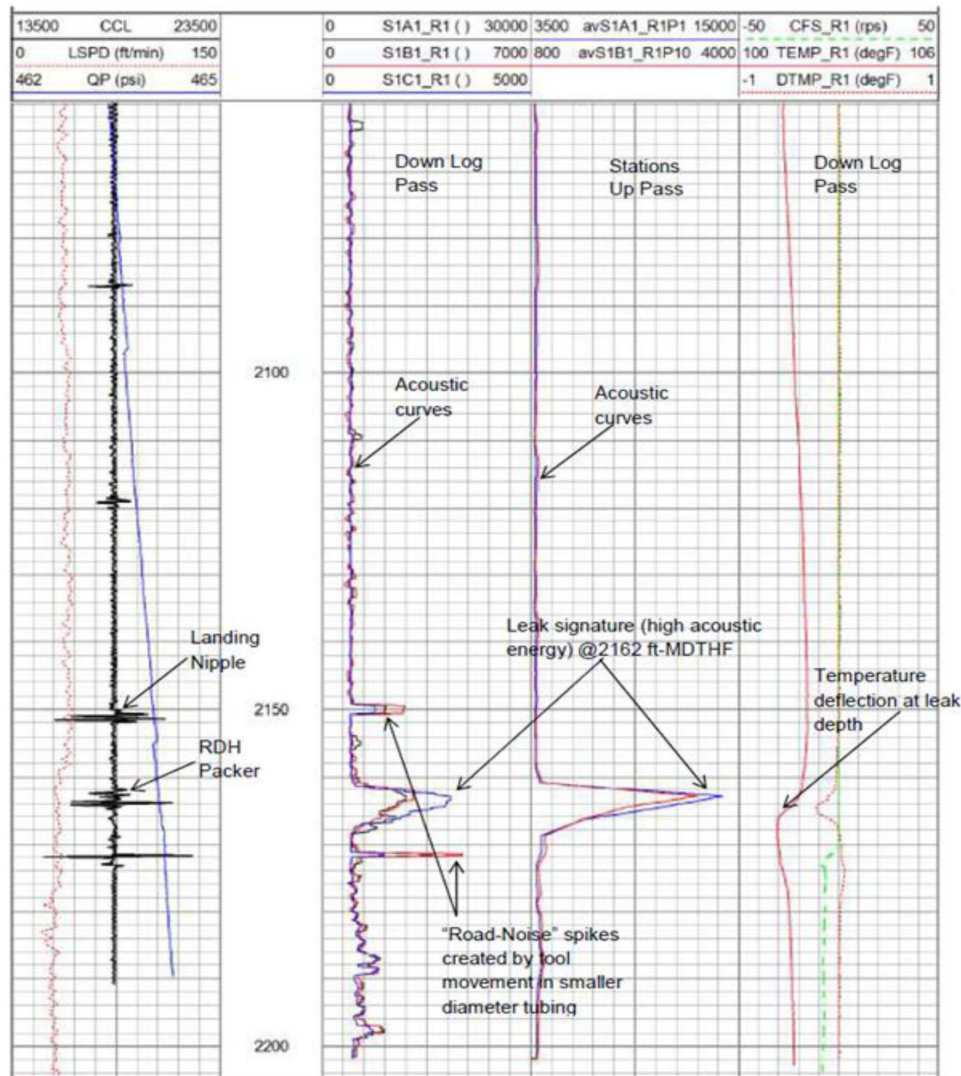


Figure 5—Leak confirmation on packer depth for well P3 using acoustic logging intervention.

Conductor leaks, however, require a different approach. A bubble test is used to qualify the leak location, while Lower Explosive Limit (LEL) measurement is used to quantify the leak severity. The inability of the conductor to bleed off pressure or reduce the Sustain Casing Pressure (SCP) requires a holistic leak sealing and repair solution that must be performed while the annulus is under pressurized condition.

Diagnostic testing for control line leaks is similar to that of wellhead leaks. However, determining the leak depth relies solely on volume calculations of fluid during pressure manipulation on the surface. During this campaign, control line leak conditions were diagnosed primarily to understand the leak severity and injectability for the sealant deployment. Proper displacement is critical since over-injection of sealant might result in excess sealant exposure toward the MCX Valve underneath the Tubing Retrievable Safety Valve (TRSV) depth. An example of depth determination for volume calculation is shown in figure 6 below.

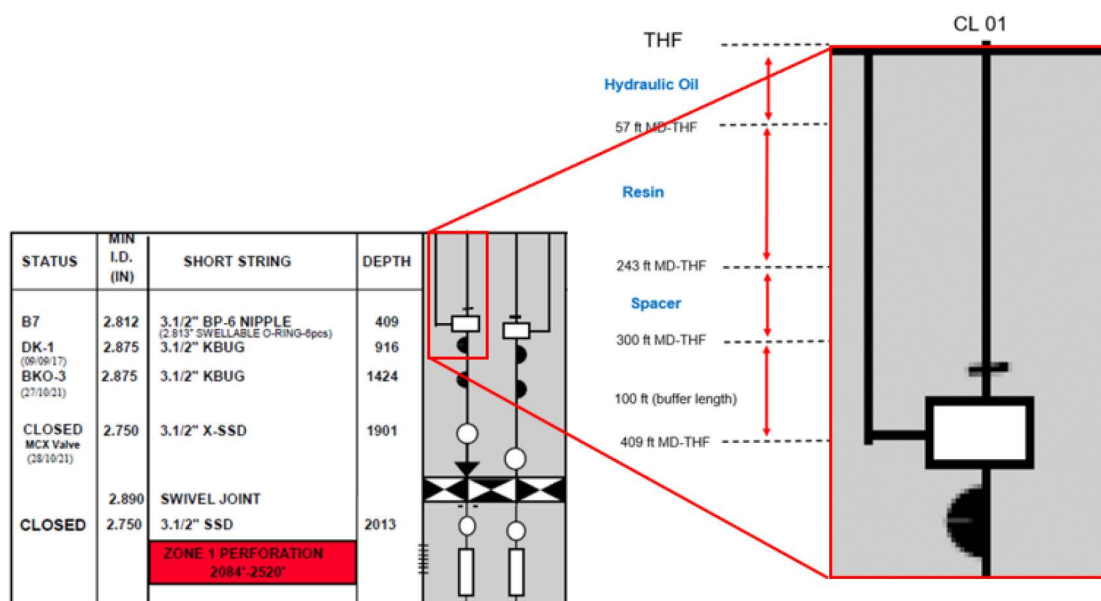


Figure 6—Typical CL schematic (zoom in) with depth in well CL 1

### System Integrity Test (SIT)

After understanding the leak information and diagnostic plan, a methodology for sealant deployment and sealing principle needs to be tested on a laboratory scale. Each leak category requires several System Integrity Tests (SITs) to be performed prior to actual sealant deployment using different types of sealant principles.

**Wellhead Leak.** Elastomeric seal damage in the wellhead is usually the culprit for any wellhead leak issues. The capability of the sealant to be injected into the wellhead monitoring port and seal the leak is simulated using a pressure-rated test fixture with an actual damaged wellhead seal complete with an injection cavity, as shown in Figure 7 below.

The results from this SIT provide us with confirmation of TAS's ability to seal the simulated leak flow path, indicated by the green arrow at 55 ml/min at 1500 psi. TAS was cured under a 600-psi curing pressure and created a competent seal capable of withstanding 2000 psi pressure during the integrity test. TAS was seen to cover the injection cavity of the test fixture, as shown in Figure 5, and thus did not excessively bleed out of the simulated leak cavity, as depicted in Figure 6. This further confirms the requirement of high pressure to ensure successful TAS application, in line with the sealant's working principle.

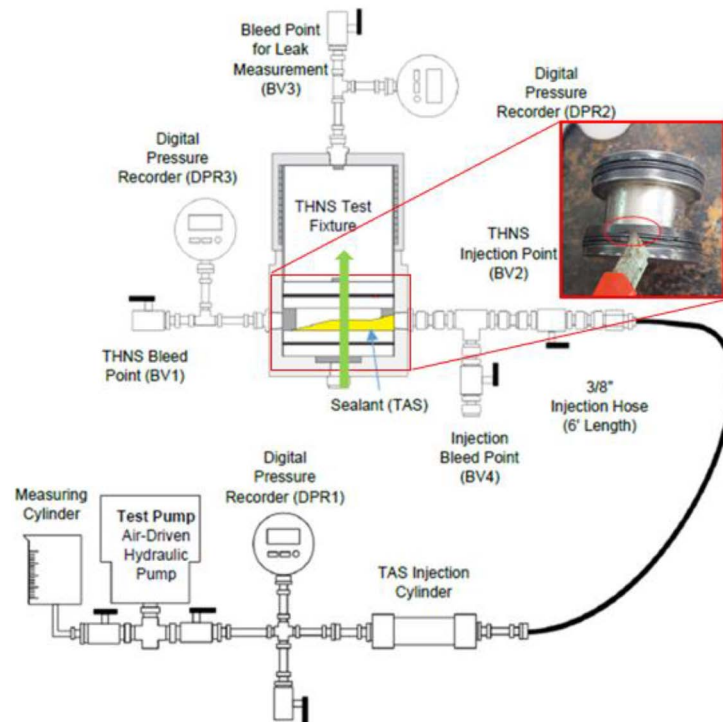


Figure 7(a)—Sealant injection setup for simulated wellhead seal leak rectification using TAS.



Figure 7(b)—A competent seal was observed when removing the simulated injection cavity.

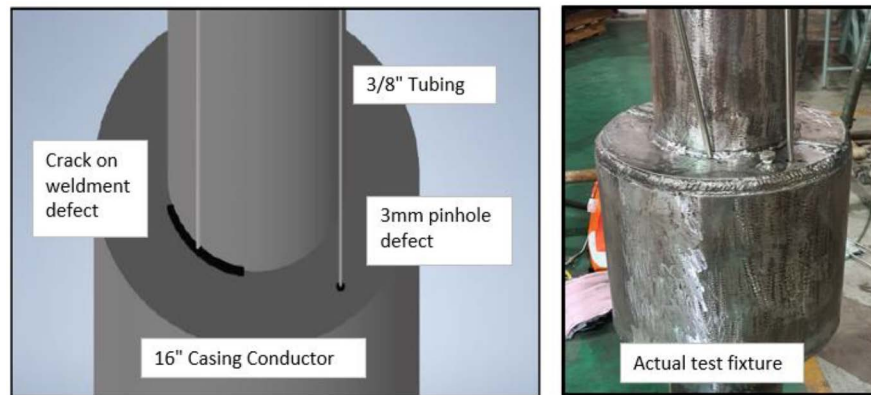


Figure 7(c)—No excessive sealant was squeezed outside of the injection cavity.

**Conductor Leak.** The proposed repair method aimed to divert fugitive gas emissions while reinstating the conductor's structural strength to prevent future gas leak emissions from the nearby surface. Investigation into surface preparation, metal putty applications, epoxy grouting on active gas leaks, and pressure testing

was conducted in this System Integrity Test (SIT). The detailed repair step procedure was demonstrated to further understand the feasibility of the proposed methodology. The authors acknowledges that the leak source in the conductor may be coming from a shallow zone, which may require other repair solutions; however, this SIT proved that conductor leaks can be solved by reinstating the outermost barrier.

Referring to [Figure 8\(a\)](#), the test fixture was fabricated to replicate the repair application as closely as possible, thereby verifying the leak sealing methodology. A special Polyurethane (PU) sleeve served as a conduit for epoxy grouting, encapsulating the defect area. Prior to performing the final pressure test or integrity test after the curing process for 12 hours, as shown in [Figure 8\(b\)](#).



**Figure 8(a)—Initial SIT proposal vs actual test fixture fabrication to simulate casing conductor leak with pinhole damage and weldment defect.**



**Figure 8(b)—Conductor leak test fixture condition after tubing diverter installation and cured epoxy grout.**

**Downhole Packer Leak.** Reinstating permanent downhole packer integrity was possible after understanding the working principle of a downhole packer. Main purpose of several SITs performed was to investigate the feasibility using sealant as in-situ leak repair solution. Below are the summarize the several SIT's objective and method.

#### *Packer Sealing Simulation Test*

This test aimed to assess the effectiveness of the sealant (PAS) in sealing elastomeric packing seals within a simulated environment. This involved damaging the packing seal, as shown in Figure 9(a), and subjecting it to pressure tests within a controlled pressure chamber. The test measured the injectivity of the sealant both before and after the simulation, demonstrating its capability to seal the simulated leak effectively. As shown in Figure 9(b), the inactivated sealant in the pressure chamber remained in liquid form, proving that the sealant only activates at the leak path, as depicted in Figure 9(c). The excess sealant will not solidify if not activated. Additionally, the investigation delved into potential contamination effects, crucial for understanding real-world application scenarios and ensuring the reliability of the sealant under various conditions which yield similar results.

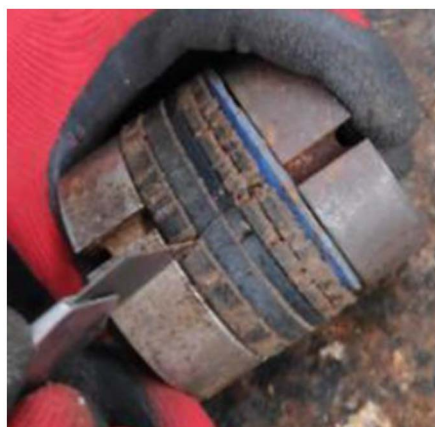


Figure 9(a)—Damage at elastomeric packing seal induce the simulated leak rate.



Figure 9(b)—Inactivated sealant in liquid form remain after depressurise pressure chamber for leak sealing simulation.



Figure 9(c)—Activated sealant in solid form observed across the leak path created competent seal.

*Sealant Fall Rate Test*

This test focused on evaluating the deployment sequence of the sealant. PAS was injected into a translucent pipe, and the time it took for the sealant to reach a certain length was measured. This provided insights into its flow dynamics in the annulus liquid. Moreover, tests were conducted at different angles to simulate real well deviations, enhancing the understanding of how the sealant behaved under varying well geometries, a crucial aspect for successful deployment in actual field conditions. The time taken data was used to estimate the slickline operation working window to close the Sliding Side Door (SSD) after reverse circulating the sealant down to the SSD depth, as shown in Table 3(a) and Table 3(b). Another finding that the authors discovered was the immiscibility issue of sealant dilution with annulus fluid or travel medium. This led the authors to investigate a new fluid deployment system designed for the next SIT.

Table 3(a)—Average fall rate result of 9.2 ppg PAS in 8.6 ppg CaCl<sub>2</sub> brine at different angles.

SIT attempt	55°		73°	
	Time (s)	Fall rate (s/m)	Time (s)	Fall rate (s/m)
1	12.41	6.21	10.47	5.24
2	12.22	6.11	10.28	5.14
3	12.56	6.28	10.87	5.44
Average	12.4	6.2	10.54	5.27
Fall Rate Average	5.74 sec/meter			

Table 3(b)—Tabulated depth sealant fluid head to SSD based on estimated slickline operation duration for Well P2.

Slickline Operation Duration (minutes)	Travel distance of Sealant (meter)	Estimated Sealant Head Distance from SSD (SSD at 2262.3 m-MDTHF)
60	627.2	1635.1
120	1254.4	1007.9
180	1881.5	380.8
216	2257.8	4.5

MDTHF : Measured Depth Tubing Head Flange

### Sealant Flipping and Flow Suspension Test

The objective of this test was to investigate the fluid train's capability to suspend the sealant during deployment. PAS was deployed within a translucent tube, and its behavior under static and dynamic flow conditions was observed. An example of perfect sealant suspension can be observed in Figure 10(a).

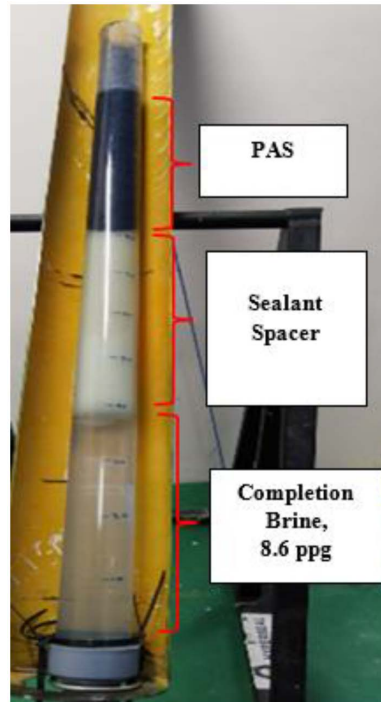


Figure 10(a)—Example of perfectly suspended sealant above the Sealant Spacer.

The sealant's suspension properties between lead and tail spacers were tested, as shown in Figure 10(b). The fluid train investigated was started with lead 8.6 ppg Spacer > 9.5 ppg Spacer > Pressure Activated Sealant > Tail 8.6 ppg Spacer.

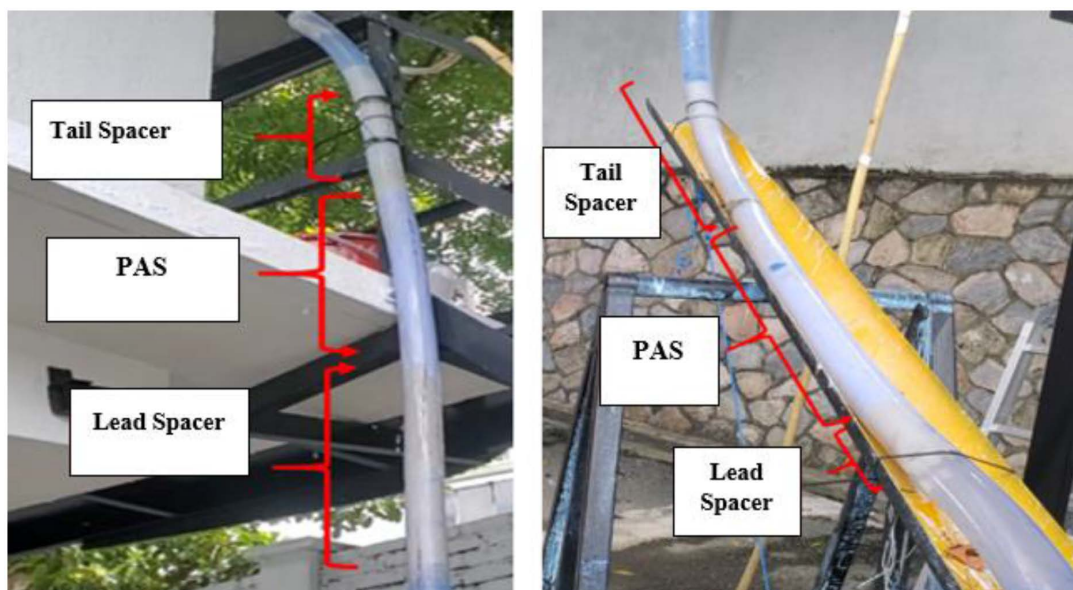


Figure 10(b)—Comparison of sealant deployment fluid slurry on vertical static condition (on left) versus dynamic flow scenario under simulated deviation angle (on right).

The best volumetric ratio of the fluid train was concluded to be at a ratio to 2:2:1, since this volumetric deployment ratio could avoid the contamination of the encapsulated fresh sealant in the fluid train, as summarized in Table 4.

Table 4—Summary observation of contamination effect by volumetric percentage during static and flow test.

Condition	55° Inclination			
	Test 1 (1:1:0.5)		Test 2 (1:1:1)	
	Head	Tail	Head	Tail
Static	No contamination	10% contamination	10% contamination	No contamination
Dynamic	No contamination	20% contamination	50% seepage of PAS	10% contamination

Condition	73° Inclination			
	Test 1 (1:1:0.5)		Test 2 (1:1:1)	
	Head	Tail	Head	Tail
Static	No contamination	No contamination	Large portion displaced by PAS	No contamination
Dynamic	Very small contamination	20% contamination	Dilution of PAS	No contamination

#### Sealant Compatibility and Thermal Stability Test

The test focused on verifying the compatibility of the sealant and spacer fluid with crude oil and production treatment chemicals. It was performed in accordance with a simplified version of ASTM G170, the standard guideline for evaluating and qualifying oilfield chemicals in the laboratory. Test fluids underwent vigorous shaking and exposure to well temperatures to observe any emulsion formation, good phase separation, precipitation, or other physical changes. This ensured that the sealant and spacer fluid maintained their integrity and functionality when exposed to the harsh conditions encountered in oil and gas production environments. Figure 11 below shows an example of accepted test result of the sealant and crude oil compatibility under well temperature.

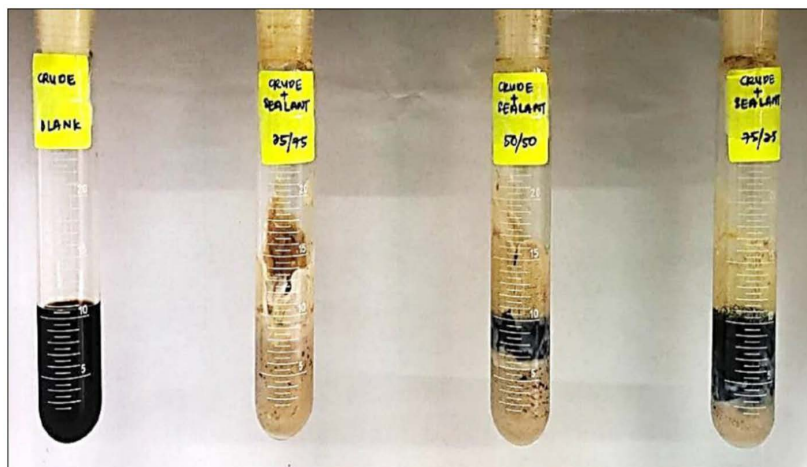


Figure 11—Example of sealant (PAS) compatibility test with crude oil under 90 degrees temperature.

**Control Line Leak.** The Control Line (CL) is typically used for transferring hydraulic pressure to operate downhole hydraulic equipment. In this System Integrity Test (SIT), the CL was subjected to permanent abandonment since it had lost its function, additionally creating problems by having sustained pressure at the surface. The SIT was designed to demonstrate the application of sealant deployment via the spacer system and the plug's ability to hold pressure for a 1-meter plug length.

This SIT proved that the sealant was able to suspend between the spacer systems with minimal to no contamination of the sealant length, as seen in Figure 12(a). The sealant train was followed by hydraulic oil, and perfect separation of the hydraulic oil from the spacer system ensuing that the deployment method is accepted.

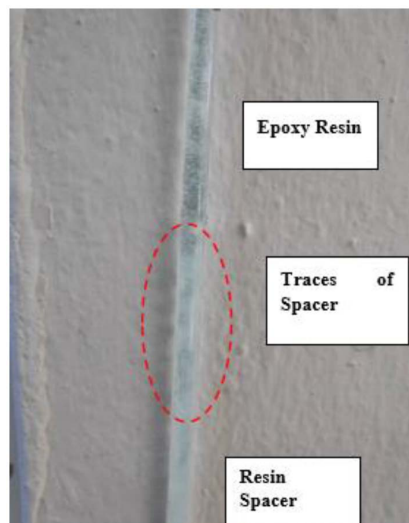


Figure 12(a)—Minimum traces of viscous spacer system observed not effecting the sealant deployment and curing process.

Thermal stability of resin sealant fluid train consists of sealant spacer, sealant plug and hydraulic oil chase fluid showing no immiscibility issues after submerged on 40° Celsius water bath as seen in figure 12(b). Again, the test was repeated using crude oil sample and subject to the vigorous shaken prior to simulate worst case scenario. Figure 12 (c) showed solidified section of the plug length proven the resin sealant capability to cure under contaminated environment, with some hydraulic oil separate at top of the plug. This further strengthens the deployment methodology to use spacer system during resin sealant deployment.

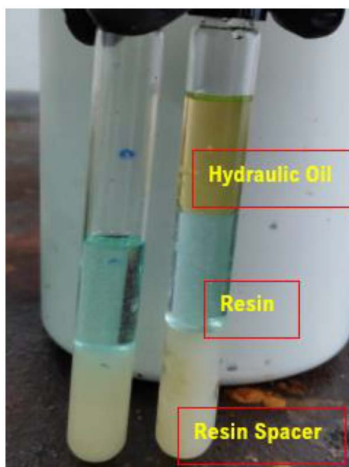


Figure 12(b)—Visible phase separation between spacer system and hydraulic oil chase fluid.



Figure 12(c)—From left to right, mixture of sealant spacer, neat resin sealant and crude oil, followed by shaken process and sealant plug condition after 24 hours curing process in 40° Celsius water bath.

Figure 12(d) depicts the final SIT setup, aimed at simulating resin injection pressure or back pressure inside the control line. The test involved simulating sustained pressure at one end of the control line and confirming the plugging capability of a column length of epoxy resin sealant in a 0.25-inch control line.

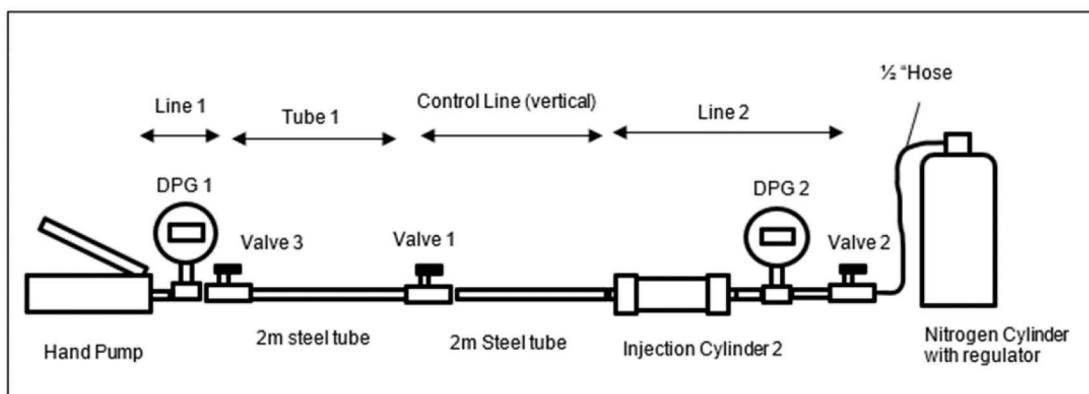


Figure 12(d)—Test setup for resin injection simulation with simulated downhole pressure using nitrogen gas.

Pressure test from both end of test setup was performed, and 1-meter cured epoxy resin plug can hold up to 1400 psi as shown in figure 12(e), thus meet the acceptance criteria of this resin plugging methodology. It is essential to note that the plugging of control lines (CL) typically involves a one-time application, and there is no turning back after the injection of epoxy resin sealant. Once the resin sealant has cured, it becomes inert to any fluid, leaving no option to reinstate the functionality of the control line back to normal.

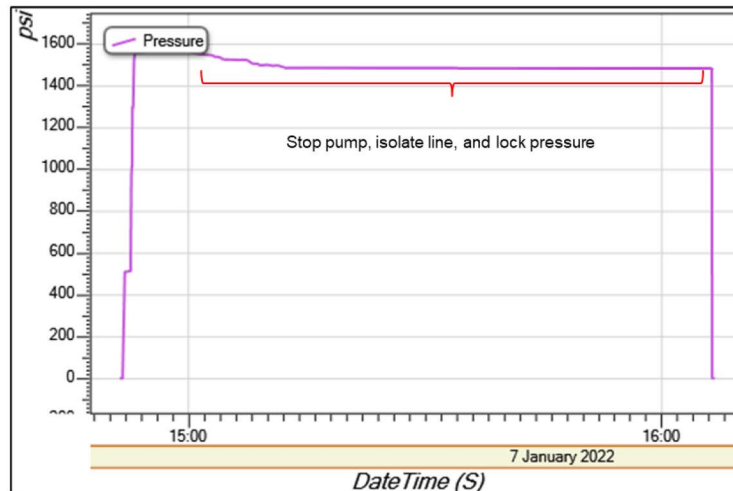


Figure 12(e)—Pressure test on 1 meter of cured epoxy sealant plug can hold up to 1400 psi.

### Leak Rectification Plan

During this step, it became evident that robust chemical sealant alone was not sufficient for successful leak rectification. Appropriate deployment strategies suitable for sealant deployment were studied and discussed. Thanks to the numerous SITs performed prior to job execution, an understanding of suitable deployment strategies could be developed.

**Wellhead and Control Line Leak Repair.** For example, rectifying a wellhead leak often involves utilizing a small pumping package capable of deploying liquid sealant at a certain flow rate and injection pressure. PAS requires a high-pressure and high-flow-rate pump to activate the sealant, whereas TAS requires the opposite. This can be achieved using an air-operated pneumatic pump. A typical sealant deployment for a wellhead leak can be seen in Figure 13.

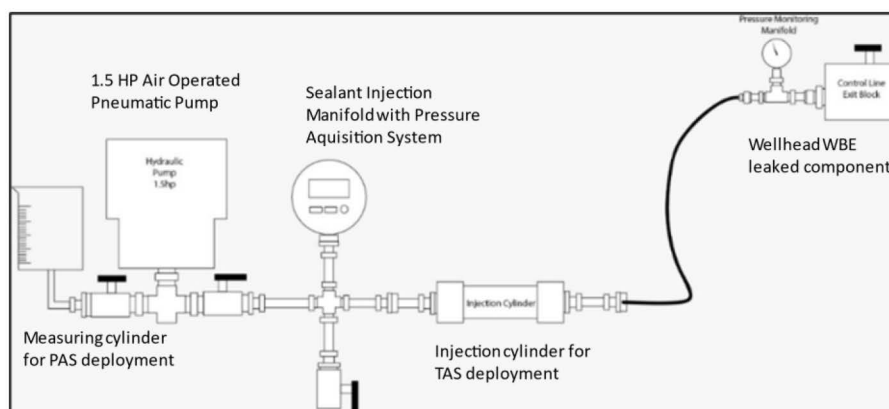


Figure 13—Typical layout of air operated pneumatic pump connection to wellhead WBE leak component for pressure and time activated sealant deployment.

**Downhole Packer Leak Repair.** Packer leak rectification, however, requires a full fleet of wireline or slickline units to operate the Sliding Side Door (SSD) or retrieve the valve at the downhole orifice or Side Pocket Mandrel (SPM) for fluid circulation purposes. Fluid circulation is necessary to ensure that a good length of uncontaminated sealant reaches the top of the packer. SIT results dictate the importance of having a good sealant deployment procedure. A positive displacement pump, often a triplex pump, is required to deploy the sealant inside the annulus and take returns at the tubing cap.

A proper sequence of sealant deployment procedures is crucial in orchestrating packer leak repair. Figure 14 shows a typical packer leak repair equipment setup with a fluid pumping fleet on a workboat and a sealant injection pump on the platform. The need for two separate pumps is to cater to a higher fluid injection rate during circulation using the triplex pump and a low-rate sealant injection pump to avoid sealant pre-activation at the pumping manifold.

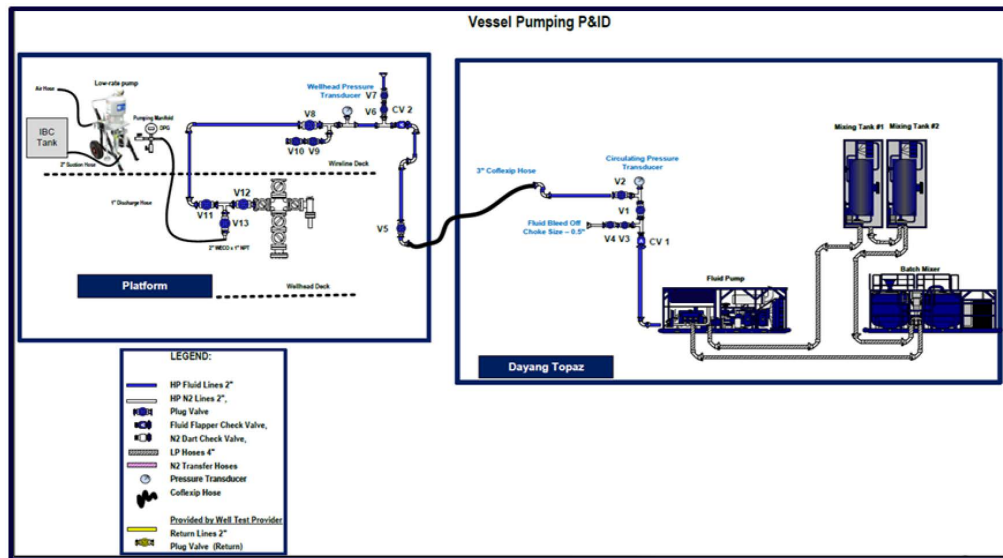


Figure 14—Typical sealant pumping setup for downhole packer leak repair via workboat assisted operation.

**Conductor Leak Repair.** The repair plan for conductor leaks differs slightly from other chemical sealant deployment plans. Since this repair method falls under composite repair, no injection is required as part of the methodology. However, the success factor for this sealant application lies in the sealant's ability to cure and adhere to the casing conductor surface while active gas emissions are diverted to a safe zone.

A surface cleaning tool is an important tool to achieve the SA 2.5 of surface preparation standard on the casing surface prior to the epoxy sealant grouting process. For example, on well C2 where the conductor is cemented up to the surface, 1 meter length of cement needs to be removed prior to vent line installation and epoxy sealant grouting process, as shown in Figure 15. This is to ensure that the composite repair can withstand high sustained casing pressure.

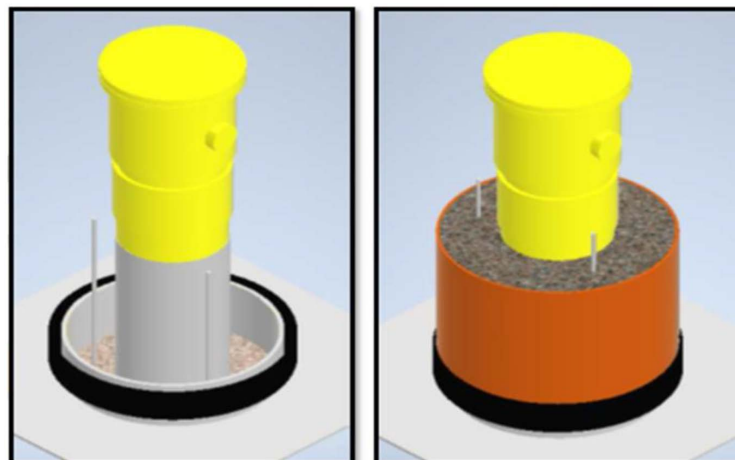


Figure 15—Rectification plan for conductor leak by removing existing cement, installation of gas diverter tubing line and completed with high adhesion epoxy sealant grout.

## On-site Well Leak Diagnostic and Rectification Campaign

Apart from the operator's well management and maintenance schedule, it is impossible to avoid sudden well integrity problems. The best practice to reinstate well integrity is to perform mechanical change-outs. However, this option is rather expensive and takes a long lead time to execute. This is where well leak repair can reduce the cost and lead time gap in order to achieve optimum well integrity at all times.

After understanding the well integrity issues and the capability of chemical sealant to reinstate well barrier element reliability, a non-routine well integrity campaign was executed. The deployment strategy followed the SIT but on a larger scale and using bigger volumes and equipment. Proper procedures were discussed and approved before sealant treatment could proceed. During diagnostics, several parameters were recorded before and after, which were used to measure the performance of the chemical sealant. The acceptance criteria set by the operator were also followed when performing the rectification work.

Referring to Table 5, all 10 WBEs have been categorized into surface and downhole as primary categories and 4 sub-categories to differentiate leak types: wellhead or tree leak, conductor leak, downhole packer leak, and control line plugging.

Table 5—Simplified generic procedure based on primary and secondary leak category.

Category	Sub-Category	Well	Well Barrier Element	Generic Procedure
Surface	Wellhead	W 1	Tubing Hanger Void	Wellhead Diagnostic & Repair
	Wellhead	W 2	Tubing Hanger Neck Seal	
	Wellhead	W 3	PRL / Tubing Hanger Neck Seal	
	Wellhead	W 4	Tubing Hanger Body Seal (THBS) & MTM	
	Conductor	C 1	Conductor Leak (SCP)	Conductor Diagnostic & Repair
	Conductor	C 2	Conductor Leak (SCP)	
Downhole	Packer	P 1	Production Packer	Packer Leak Diagnostic & Repair
	Packer	P 2	Production Packer	
	Packer	P 3	Production Packer	
	Control Line	CL 1	Control Line (Sub-Surface)	Control Line Plugging

### Generic Diagnostic and Repair Procedure for Different Leak Category

The generic procedure outlined below serves as a structured approach for addressing leaks in wellhead test monitoring port, conductor casing, downhole packer, and control line, aiming to ensure the integrity and safety of oil and gas well operations. This systematic process includes pressure testing, injectivity assessments, and sealant deployment, all designed to identify, mitigate, and repair leaks effectively while adhering to industry standards and safety protocols.

#### *Wellhead Diagnostic & Repair.*

1. Record initial pressure data for all test ports, casing annulus, and tubing.
2. Perform pressure buildup tests on all test monitoring ports using casing, tubing, or control line pressure.
3. Conduct pressure tests on all test monitoring ports following equipment or Well Barrier Element (WBE) recommended test pressures.
4. Conduct injectivity tests at various leak rates and pressures. Open additional test ports if needed to achieve higher leak rates.
5. Verify leak path and severity using wellhead drawings or schematics and onsite pumping data.

6. Deploy Pressure Activated Sealant (PAS) or Time Activated Sealant (TAS) based on onsite diagnostic data. The leak rate limit for PAS application is 1.2 LPM @1500 psi; TAS is used for higher leak rates. Ensure compliance with each sealant's leak sealing principle.
7. Allow sealant to cure under pressure for a minimum of 12 hours to enhance mechanical strength.
8. Perform post-sealant deployment sealant integrity tests according to acceptance criteria.

### ***Conductor Diagnostic & Repair.***

1. Record initial pressure data for all test ports, casing annulus, and tubing pressure.
2. Perform a Pressure Build-Up (PBU) test and measure Lower Explosive Limit (LEL) readings as baseline data.
3. Remove conductor cement and prepare casing metal surfaces.
4. Install leak containment or tubing diverter for active gas emission.
5. Apply a polyurethane (PU) sleeve molding to encapsulate the repair area.
6. Inject epoxy sealant grout into the encapsulated area.
7. Allow the sealant to cure at ambient condition for a minimum of 12 hours to enhance the cured sealant's mechanical strength.
8. Perform a PBU test and measure LEL readings post-sealant application.

### ***Packer Leak Diagnostic & Repair (Example using well P3).***

#### *Pre-Treatment (Optional)*

1. Perform Annulus Pressure Diagnostic (APD) and Echometer Survey.
2. Conduct Slickline Logging for Leak Detection.

#### *Pre-Treatment*

1. Conduct platform site survey to assess crane capability and main deck area arrangement.
2. Rig up equipment and hoses on casing valve for pumping.
3. Perform surface pressure test, set plug on LS and SS, and close SSD LS.
4. Perform Tubing Integrity Test on Long String (LS) and Short String (SS).
5. Conduct wireline activity: open Sliding Sleeve Door (SSD)-LS at 2,121 ft.
6. Conduct Casing-Tubing Liquid Displacement with XX bbls of Treated Sea Water (TSW).
7. Close SSD-LS.

#### *Leak Diagnostic*

1. Perform Injectivity Test against packer leak.
2. If the leak is below 0.25 bbls/min with MASTP XXXX psi, proceed with main treatment.
3. If the leak is above 0.25 bbls/min with MASTP XXXX psi, proceed with contingency.

#### *Main Treatment – Sealant Deployment via Reverse Circulation Method*

1. Open SSD-LS.
2. Pump XX bbl of Spacer fluid + XX bbls of downhole sealant (PAS) + XX bbl of Spacer fluid into the annulus.
3. Displace annulus with TSW for XX bbls.
4. Conduct wireline activity to close SSD-LS.
5. Pump XXX bbls TSW and pressure up casing to xxx psi until seal indication.
6. Lock surface curing pressure and let sealant cure under pressure for 24 hours.

### *Packer Integrity Test*

1. Bleed off all annulus pressure until 0 psi.
2. Allow pressure to stabilize for 10 minutes, then monitor and record any pressure build-up for 1 hour, with 10-minute intervals.
3. Report results to engineer in charge.

### *Contingency*

1. Mix XX bbls of Spacer with CaCO<sub>3</sub> powder for plugging.
2. Pump mixture and displace with XX bbls of TSW.
3. Perform Injectivity Test against packer leak.
4. If leak is below 0.25 bbls/min with MASTP xxx psi, proceed with Main Treatment.
5. If leak is above 0.25 bbls/min with MASTP xxx psi, report results to town.

### *Control Line Plugging.*

1. Record initial pressure data for all test ports, casing annulus, and tubing.
2. Perform a pressure buildup test on the control line to estimate sealant injection back pressure.
3. Conduct a pressure test on the control line to confirm leaks. If the test pressure holds, sealant deployment is not possible.
4. Conduct injectivity tests at different leak rates and pressures. If no injectivity is observed, sealant deployment is not possible.
5. Verify the leak path and severity using wellhead drawings or schematics.
6. Deploy epoxy resin sealant into the control line:
7. Deploy 210 ml of sealant spacer, followed by 670 ml of epoxy resin sealant (more than 150 ft of plug length), and chase with 210 ml of hydraulic oil.
8. Allow the sealant to cure under pressure for a minimum of 12 hours to enhance mechanical strength.
9. Perform a sealant integrity test post-deployment according to acceptance criteria.

### **Leak Repair Acceptance Criteria**

During well operations and maintenance, it is imperative to maintain the integrity of the well barrier envelope (WBE) for safe operations. According to NORSOK D-010, Rev. 4, June 2013, monitoring the status of WBEs involves registering tubing and annulus pressures, temperatures, flow rates, fluid compositions, and conducting pressure/leak tests.

The acceptance criteria for each WBE must be established to ensure well integrity. In this campaign, the authors simplified the acceptance criteria for each WBE based on operator and local petroleum governance WIMS, as outlined in [Table 6](#).

**Table 6—Simplified acceptance criteria of all WBE according to leak category.**

Leak Category	Acceptance Criteria
Wellhead leaks	<ul style="list-style-type: none"> <li>- WBE withstands supplier-recommended test pressure.</li> <li>- Typical test pressure: 2000 - 5000 psi (except MTM: 500 psi if tested from port).</li> <li>- Rectification work reinstates or agrees upon test pressure and confirms sealed leak path.</li> <li>- Consider de-rated pressure test due to aging and corrosion.</li> </ul>
Conductor Leak	<ul style="list-style-type: none"> <li>- No external leaks in conductor annulus.</li> <li>- Gas leaks diverted to safe zone (e.g., back into system, flare).</li> <li>- Rectification work sustains casing pressure.</li> <li>- Assumption: subsequent annulus pressures 400 psi (Well C1) and 700 psi (Well C2).</li> </ul>
Packer Leak	<ul style="list-style-type: none"> <li>- Production casing annulus pressure does not exceed 15 scf/min leak rate.</li> <li>- Rectification work closes leak at MAWOP (800 psi) and maintains PBU &lt; 50 psi for 24 hours.</li> </ul>
Control Line Plugging	<ul style="list-style-type: none"> <li>- Control Line has no sustained pressure in shut-in condition.</li> <li>- Cured sealants plug inside control line records no PBU or sustained pressure at surface post-deployment.</li> </ul>

### Leak Diagnostic and Chemical Sealant Solution

During the diagnostic of all the Well Barrier Elements (WBE), a pattern of leak conditions was observed. The leak intensity at the wellhead WBE was typically very small compared to leaks at the production packer. This discrepancy arises from the necessity to maintain the effective volume of the WBE. Wellhead leaks usually manifest internally and are only detectable through pressure changes during diagnostics. However, instances of leaks to the environment were rare, but one such occurrence was noted at well W3, as illustrated in Figure 16 (a).



Figure 16(a)—Unknown plug leaked when performing pressure test diagnostic on well W3.

The leak on the conductor was very small, preventing the possibility of conducting pressure tests or negative tests. The severity of the leak could only be assessed by observing bubble formation at the surface and using a gas tester to measure Lower Explosive Limit (LEL) percentage readings. Surface leak conditions for wells C1 and C2 are illustrated in Figure 16 (b).



Figure 16(b)—Active gas emission at conductor surface area for well C1 and C2.

Table 7 shows the summary and rectification work using chemical sealants for all 10 WBEs.

**Table 7—The summary of leak path and type confirmation with baseline diagnostic result prior to sealant solution application.**

Category	Well	Well Element	Barrier	Leak Path & Type	Diagnostic Baseline	Sealant Solution
Surface	W 1	Tubing Void	Hanger	Communication with PCP and CL at 132 psi	Injectivity rate 1.6 LPM & PBU 82 psi/hr.	PAS & TAS
	W 2	Tubing Neck Seal	Hanger	Communication with Tubing Pressure,	PBU 1-4 psi/ 30 min	TAS
	W 3	PRL / Tubing Hanger Neck Seal		Communication with Tubing Pressure,	Leak rate of 150 ml/min with PBU 600 psi/sec	PAS & TAS
	W 4	Tubing Body Seal (THBS) & MTM	Hanger	One way leak from THV into THBS,	Leak rate of 12 ml/min.	PAS
				One way leak from THP to MTM,	Leak rate of 5 ml/min	
	C 1	Conductor (SCP)	Leak	Gas seepage on wellhead adaptor (pinhole)	LEL:13%	Composite Repair
C 2	Conductor (SCP)	Leak	Gas seepage on surface cement.	LEL: 5%	Composite Repair	
Downhole	P 1	Production Packer		Sustain Pressure Casing	Injectivity rate of 0.25 barrel/min and PBU <b>13scf/min.</b>	PAS
	P 2	Production Packer		Sustain Pressure Casing	Injectivity rate of 0.2 barrel/min and PBU 100psi/hr, calculated <b>70scf/min</b>	PAS
	P 3	Production Packer		Sustain Pressure Casing	Injectivity rate of 0.2 barrel/min and PBU 30psi/hr calculated <b>24scf/min</b>	PAS
	CL 1	Control Line (Sub-Surface)		CL communication with Tubing Pressure	Injectivity rate of 850ml/min and PBU 300 psi/ 30sec	Epoxy Resin Plug

PAS: Pressure Activated Sealant  
 TAS: Time Activated Sealant  
 MTM: Metal to Metal  
 THBS: Tubing Hanger Body Seal  
 SCP: Sustain Casing Pressure  
 PCP: Production Casing Pressure  
 PBU: Pressure Build Up  
 CL: Control Line  
 LPM: Liter per minute  
 TWCV: Two-way check valve  
 SIP: Sealant Injection Pump (Small Footprint)  
 HPWLP: High Pressure Pump & Wireline Package  
 GPD: Grouting Package with Diverter Tubing

**Wellhead Leak Diagnostic and Repair.** The leak rate often serves as a determining parameter in selecting the appropriate sealant. Pressure Activated Sealant (PAS) is typically used in low leak rate conditions, while Time Activated Sealant (TAS) is reserved for severe leak rate scenarios, where building up pressure for activating PAS becomes impractical. In reference to the baseline diagnostic data presented in Table 7, all wellhead test ports were diagnosed to have pressure communication with to its nearby well pressure i.e. production casing pressure, tubing pressure control line and others. It can be observed that the leak in wellhead is interrelated.

Different injection methods are required in line with the sealant activation mechanism. When using PAS to address leaks, high injection pressure is necessary to activate the PAS in-situ at the leak path. Pressure cycling is introduced to expedite the intertwining process of active polymer in PAS, as depicted in Figure 16(c). The sealing improvement becomes evident after each cycle.

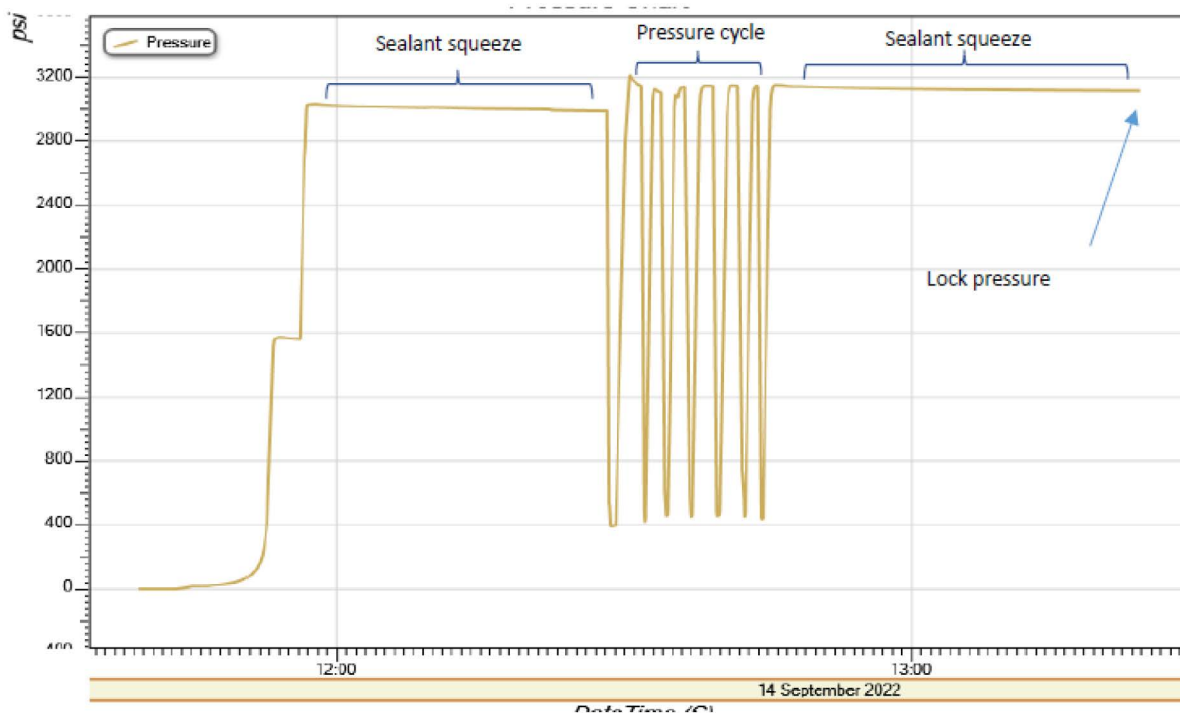


Figure 16(c)—PAS sealant deployment demands high squeeze pressure and pressure cycle.

Injecting TAS into damaged seals also requires high injection pressure due to the viscosity of the sealant. Figure 16(d) illustrates the TAS injection process, where the pressure drop indicates TAS liquid propagation into the circumference of the test port seal cavity. Each port allows for a different amount of sealant to be injected, depending on varying leak conditions. Upon completion, TAS is left to cure under pressure for 12 hours.

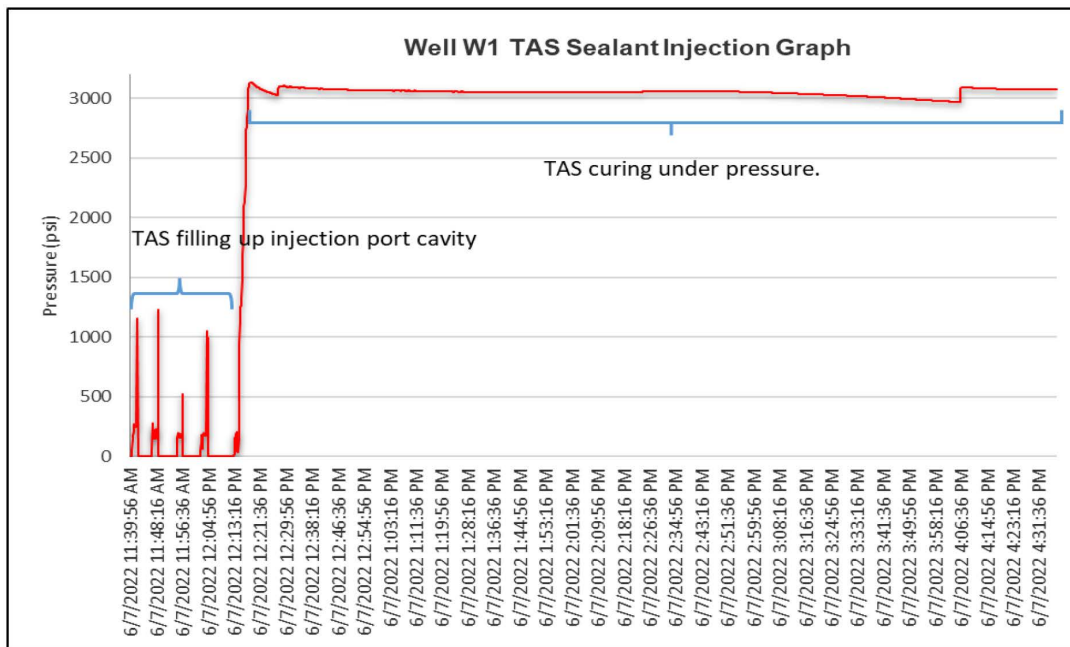


Figure 16(d)—Example of TAS sealant injection graph for W1.

**Packer Leak Diagnostic and Repair.** The injectivity rate test was an important step procedure for determining the leak severity of the packer. The injectivity rate vs injection pressure data plot as figure 16 (e), will be used to set maximum pumping rate and sealant pumping duration.

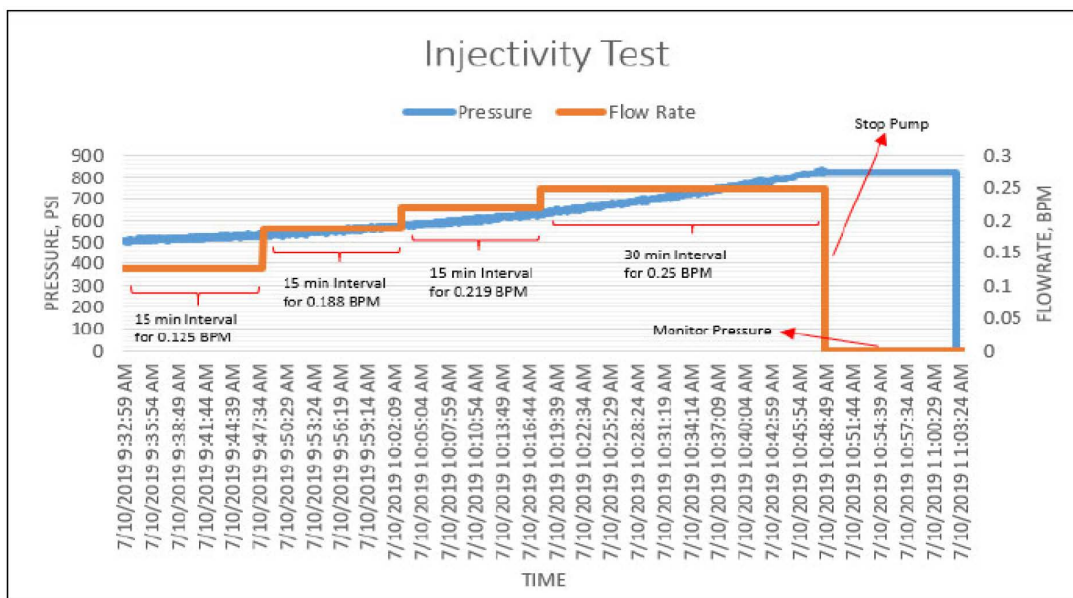


Figure 16(e)—Injectivity rate test for packer in well P1 before reaching maximum allowable pumping pressure.

The authors emphasize the importance of having a circulation point in the tubing for PAS deployment due to two reasons:

- i. It offers the capability to deploy sealant in cases where injectivity is insufficient, and when spot sealing on top of the packer is time-consuming.
- ii. It effectively minimizes sealant contamination compared to relying solely on gravity flow.

Figure 16(f) below shows the actual PAS pumping sequence together with wireline entry to close the SSD. During circulation down the annulus, a constant pumping pressure was registered, indicating only friction pressure between the sealant fluid train completion. After closing the SSD, it can be observed that injection pressure starts to increase, indicating the sealant reached and attempted to seal the leaking packer. An adequate chase fluid volume is required to squeeze the sealant onto the leaked packer.

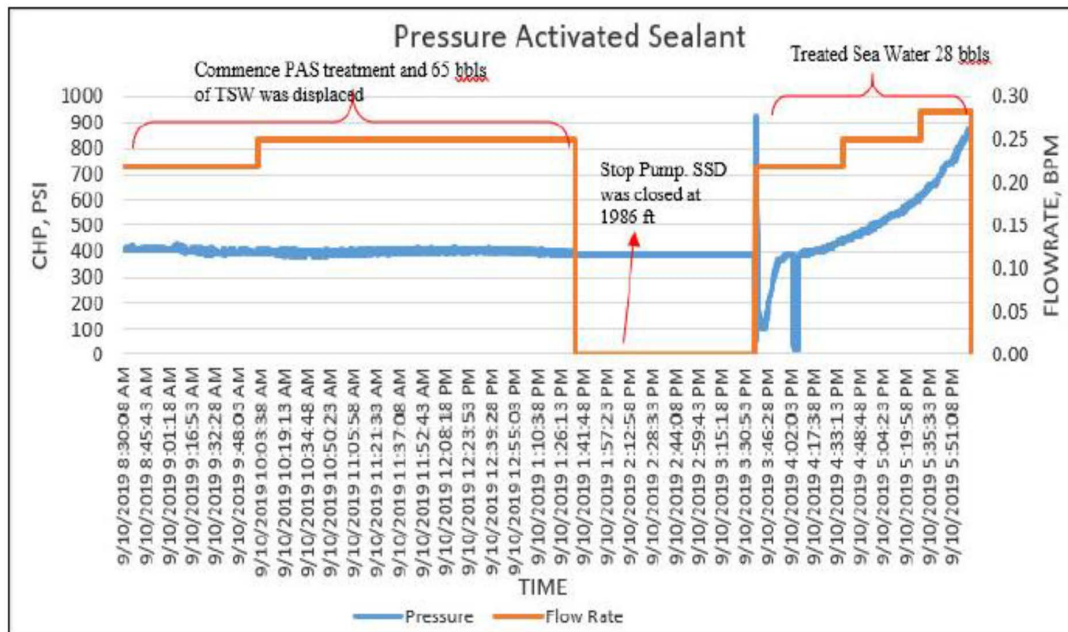


Figure 16(f)—Injectivity rate test for packer in well P1 before reaching maximum allowable pumping pressure.

**Conductor Leak Diagnostic and Repair.** The application of conductor leak diagnostic and rectification is straightforward. The leak was diagnosed through physical observation, and LEL% readings were measured to assess the risk. The composite repair system, utilizing epoxy grout chemical sealant widely employed in the pipeline industry, was applied to this production well. Successful conductor leak repair was achieved on both well C1 and C2 after deploying 500 Liters of epoxy resin grout, respectively as depicted in figure 16(g).



Figure 16(g)—Successful composite repair work using epoxy grout chemical sealant with tubing diverter installation for pressure management.

**Control Line Plugging.** Well CL1 was diagnosed with injectivity up to 850 ml/min, considered very severe. Additionally, the Pressure Build-Up (PBU) rate showed instantaneous pressure built up to 300 psi in 300 minutes, aggravating the issue. Since this well completed with MCX flow control valve, permanent plug

needs to be deployed carefully to avoid over injection on top of valve mechanism. A total of 180 ft of plug was designed and deployed into the control line body, and the integrity test was successfully accepted.

### Sealant Performance Test Result

All diagnostic and rectification work was carried out as per plan. Table 8 shows the results of all well integrity repair work using chemical sealant. It's worth mentioning that the total workdays taken for all remedial jobs were short and precise. The longest workdays were recorded when executing packer leak jobs, suited to the complexity of the rectification work, which required pumping and slickline vendors to work in hand.

**Table 8—Rectification work result summary complete with workdays and deployment method.**

Category	Well	Well Barrier Element	Result	Workday	Deployment
Surface	W 1	Tubing Hanger Void	No pressure communication with PCP and CL	5	SIP
	W 2	Tubing Hanger Neck Seal	No pressure communication with Tubing Pressure	6	SIP
	W 3	PRL / Tubing Hanger Neck Seal	Minor PBU of 2 psi/ hr from 597 psi/sec	7	SIP
	W 4	Tubing Hanger Body Seal (THBS) & MTM	No pressure communication with THBS & MTM	7	SIP + TWCV
	C 1	Conductor Leak (SCP)	Gas diverted to safe zone after epoxy grout. No gas seepage to surface	5	GPDT
	C 2	Conductor Leak (SCP)	LEL: 0%	5	GPDT
Downhole	P 1	Production Packer	PCP maintain below 30 psi with calculated <b>0.878 scf/min.</b>	10	HPWLP
	P 2	Production Packer	PCP maintain below 50 psi after 24 hrs. with calculated <b>0.98 scf/min.</b>	8 (24 hrs.)	HPWLP
	P 3	Production Packer	PCP maintain below 24 psi after 24 hr. with calculated <b>0.64 scf/min.</b>	8 (24 hrs.)	HPWLP
	CL 1	Control Line (Sub-Surface)	No PBU on surface recorded.	4	SIP

PAS: Pressure Activated Sealant  
TAS: Time Activated Sealant  
MTM: Metal to Metal  
THBS: Tubing Hanger Body Seal  
SCP: Sustain Casing Pressure  
PCP: Production Casing Pressure  
PBU: Pressure Build Up  
CL: Control Line  
LPM: Liter per minute  
TWCV: Two-way check valve  
SIP: Sealant Injection Pump (Small Footprint)  
HPWLP: High Pressure Pump & Wireline Package  
GPDT: Grouting Package with Diverter Tubing

As mentioned in the previous chapter, different well integrity rectification tasks require different deployment methods. Referring to the table for wellhead leaks, a hand-carried small footprint pump was sufficient to deliver the chemical sealant according to its leak sealing principles. However, complex jobs such as packer leaks usually require a full fleet well intervention pumping and slickline packages. For

composite repair work, the surface preparation tool and epoxy grout chemical were important equipment and materials.

After more than a year of robust chemical sealant application, only well W1, W4, and P3 require a second diagnostic and rectification work revisit. When this paper was published, it reported that W4 and P3 suffered from well integrity issues requiring further diagnostic and advanced rectification plans, while the rest of the well integrity remains intact.

## Conclusion

- Breach of well integrity barriers could lead to production loss and environmental issues.
- Comprehensive leak diagnostics are crucial to quantify and qualify leak type and severity.
- Various sealant activation mechanisms allow for fit-for-purpose solutions in solving complex surface and downhole leak issues.
- Successful leak remediation or well integrity restoration is the result of an established methodology and proper deployment of proprietary robust chemical sealant.

## Acknowledgment

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## SI Metric Conversions Factor

cP × 1.00	E-03 = Pa. s
in × 2.54	E-02 = m
psi × 6.894757	E+03 = Pa
ppg × 1.198264	E+02 = kg/m <sup>3</sup>
ml × 1.00	E-06 = m <sup>3</sup>
bbl (us) × 1.589873	E-01 = m <sup>3</sup>
Celsius + 274.15	E-0= Kelvin

**The SI Metric System of Units and SPE Metric Standard, the Society's official standard, is available on the SPE website, <http://www.spe.org>.**

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## Appendices

### A1. Summary of Well Candidate Information for Well Integrity Non-Routine Campaign

Well	W1	W2	W3	W4	C1	C2	P1	P2	P3	CL1
<b>Platform</b>	Mother Platform	Jacket	Jacket	Jacket	Jacket	Jacket	Jacket	Jacket	Jacket	Drilling Platform
<b>Well Type</b>	Single String Monobore Horizontal, Oil producer	LS – Active oil producer SS – Idle oil producer	Gas injector	Active oil producer			Oil producer	Oil producer (LS), Gas injector (SS)	Oil producer	Oil producer
<b>Current Status</b>	Flowing	Flowing	Shut in	Flowing	Idle	Idle	Idle	Idle	Flowing	Idle
<b>Production Casing Size</b>	9-5/8"	9-5/8"	9-5/8"	9-5/8"			9-5/8"	9-5/8"	9-5/8"	9-5/8"
<b>Surface Casing</b>					9-5/8" dual splitter	13-3/8"				
<b>Conductor Casing LEL</b>					26"	26"				
<b>Tubing Size</b>	2-3/8"	3-1/2" x 2-7/8"	7"	3-1/2"			3-1/2" (LS) 3-1/2" x 2-7/8" (SS)	3-1/2"	3-1/2"	3-1/2"
<b>Wellhead / X-mas Type</b>	FMC 2 <sup>nd</sup> Gen. Dualtree	3-1/8" FMC	6-3/8" McEvoy	3-1/8" Solar Alert SAE			FMC New Style Dual with Rotating Hangars			CIW dual
<b>TRSCSSV depth</b>	474 ft		426 ft	426 ft						409 ft, 1901 ft (MCX valve)
<b>Packer depth &amp; inclination</b>							2,021 ft, 35°	2,258 ft, 39°	2,161 ft, 45°	
<b>Current SITHP</b>	300 psi (18 April 2022)	195 psi (April 2022)	388 psi (June 2022)	392 psi (April 2022)			210 psi	419 psi (Sep 2020)	SS: 430 psi (Feb 2020) LS: 20 psi (Feb 2020)	303 psi
<b>Current CCP (date)</b>	55 psi (18 April 2022)	0 psi (April 2022)	262 psi (April 2022), MAASP: 485 psi, MAWOP: 388 psi	259 psi (April 2022), MAASP: 65 psi, MAWOP: 52 psi						
<b>Current CHP (date)</b>		19 psi (April 2022)	388 psi (June 2022)	390 psi (April 2022), MAASP: 1000 psi, MAWOP: 800 psi	650 psi	270 psi	310 psi	419 psi (Sep 2020)	440 psi (Feb 2020)	187 psi
<b>Current SCP (date)</b>		20 psi (April 2022)	389 psi (June 2022)	391 psi (April 2022), MAASP: 1000 psi, MAWOP: 800 psi	n/a	400 psi				

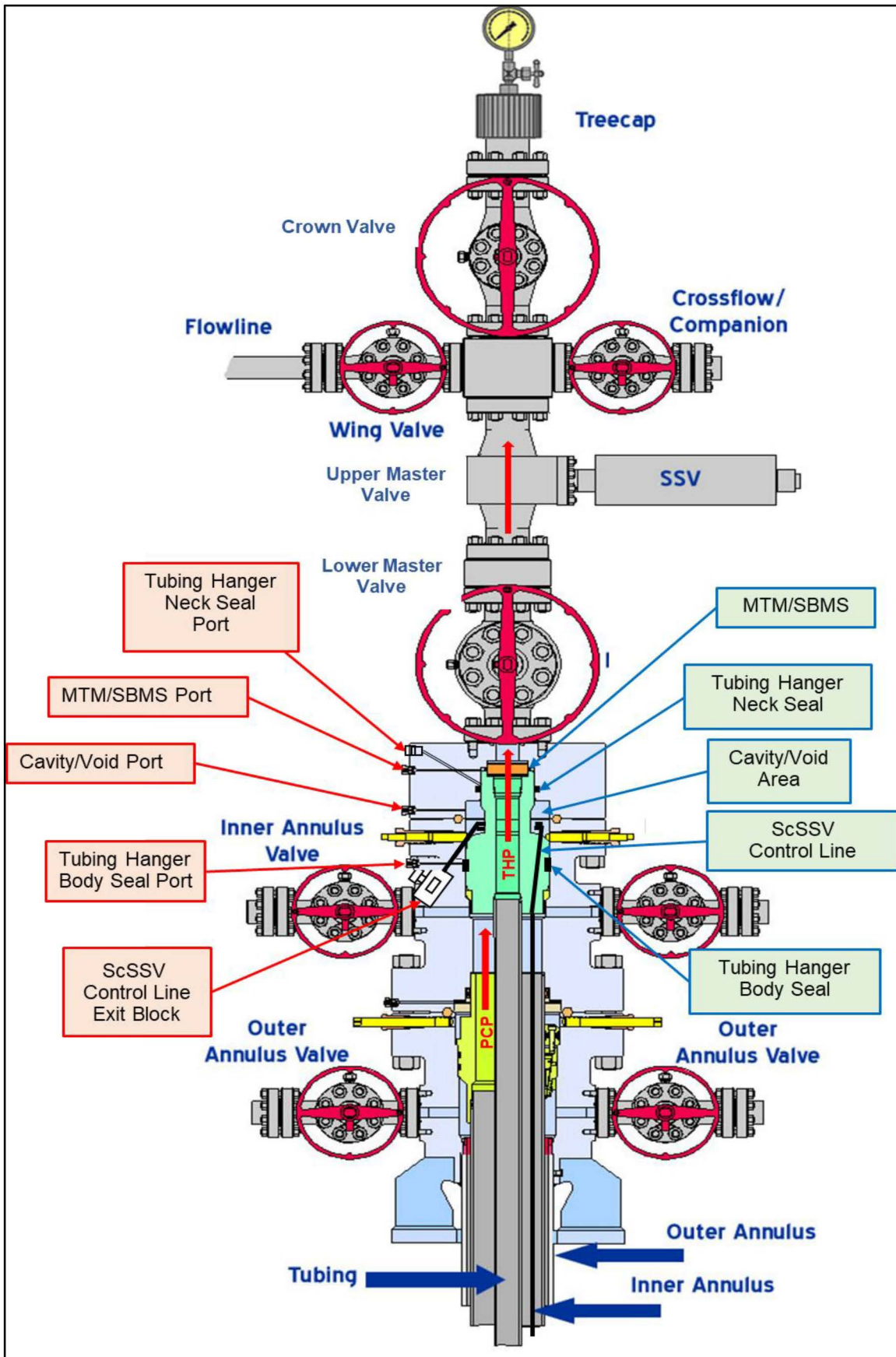
### A2. Sealant Injection Pump (SIP)– Hand Carried Small Footprint Unit



### A3. Packer Leak Rectification Campaign – High Pressure Triplex Pump and Wireline Unit



### A4. Typical Wellhead Diagram/Drawing complete with WBEs annotation



# A5. Example of Decision Tree for every remedial work using chemical sealant

