Perforate, Wash, and Cement: A Review of Practices and Where to Go Next

M. A. Jaculli[1]*, M. Iuell[1], E. Engelsgjerd[1], E. A. Knudsen[1], S. Amdal[1], P. Andersen[1], S. I. Haukelid[1], and S. Vemmestad[1]

[1]HydraWell Intervention

Summary

Installing qualified cross-sectional cement barriers is a difficult task. One needs to ensure that cement is displaced evenly along the required length and fills the annulus completely, which may prove difficult in some scenarios such as unknown annular content and wells with eccentric casings. Traditional methods, such as section milling and cement squeeze, have been ineffective in delivering good results in terms of time, cost, and quality, and as such, new techniques have been developed. In this review article, we discuss perforate, wash, and cement (PWC), a method of installing a cross-sectional cement barrier that is being deployed widely around the world for remediating poor cement and performing plugging and abandonment (P&A) jobs. Abandoning wells will be an enormous undertaking in the short term, thus installing safe and cost-effective barriers is of utmost importance. In this context, we review PWC in terms of reported field deployments, modeling techniques with computational fluid dynamics (CFD), qualification processes according to existing standards, the establishment of track records, and the efforts to go rigless. We conclude that establishing track records through qualification matrices is fundamental for reducing costs without incurring reduced safety as well as that performing rigless P&A through PWC could save significant costs and time in the context of thousands of wells to be plugged in the near future.

Introduction

Decommissioning is expected to become a large part of the industry efforts in the upcoming decades with significant costs attached, which encompass P&A of wells (Chukwuemeka et al. 2023). Wells are to be plugged when they reach the end of their life cycle, which could be caused by a lack of commercial viability or integrity issues; such a procedure must be carried out safely and provide a lasting solution considering the long-term perspective of well abandonment (Khalifeh and Saasen 2020).

NORSOK D-010 (2021) dictates how to evaluate safety during abandonment activities according to the two-barrier philosophy. A well must have in place two well barrier envelopes—a primary one closest to the fluid-bearing formation and a secondary one on top of that as a redundancy—that must close all potential leak paths along the wellbore. NORSOK D-010 (2021) also lists element acceptance criteria (EAC) for various well barrier elements (WBE) used to accomplish that, with one of them being the cement plug placed using the PWC technique. A dedicated EAC table to this WBE was added in its latest (fifth) revision. PWC is a method that has evolved over the last 15 years since its inception (Delabroy et al. 2017; Ferg et al. 2011; Hovda et al. 2020; Leeson and Larsen 2020; Pollard 2021) to ensure that a cement plug of the best quality—compared with traditional section milling and squeeze methods—is placed at the desired depth. Offshore Norge, a major organization for the oil industry in the Norwegian Continental Shelf, has this technique marked as field-proven in their P&A roadmap (https://pa-roadmap-app.collabor8.no/), confirming its status as a mature method for annular remediation. Nevertheless, as new challenges arise, the method must evolve continuously to cover wider operational windows while improving deployments and barrier verification.

In this article, we present a literature review on the evolution of PWC practices and discuss where the technique should aim next in this new P&A-demanding context. We present existing practices for installing a cement plug downhole, discuss barrier verification philosophies, and illustrate the method with field deployments and their validations using numerical modeling and logging. Finally, we conclude that a natural evolution for the method is to go rigless using coiled tubing, which can reduce upcoming P&A costs significantly by the reduction in rig time. Also, establishing a track record is necessary to reduce drilling out and logging activities while giving confidence in the quality of the deployed barriers.

Cement Plug Placing Practices

Several methods exist for placing cement plugs downhole, namely section milling, cement squeeze operations, and PWC. The latter has evolved and is now mainly split into cup-based PWC and jet-based PWC. We address them next.

Section Milling. Fig. 1 illustrates the main steps of the section milling method for installing a cross-sectional cement barrier. The idea behind this technique is to mill a section of casing (typically 50 m)—in front of a consolidated rock formation—to open a window where a cross-sectional cement barrier can be placed. After the casing is milled, an underreamer removes the annulus content (cement, debris, etc.) to clean the wellbore and prepare for cementing. Finally, the cementing job is performed to create the well barrier. The verification process may change depending on the goal. In some cases, verification is done by tagging the cement plug and pressure testing it; this is typical for cross-sectional cement plugs used in P&A. Otherwise, if PWC is used for annulus cement remediation, the plug is drilled out, and logging is performed to verify the new cement. Note that drilling out and logging may be done for verification in P&A as well, which later entails re-establishing the cement plug inside the casing.

The section milling method is qualified and included in NORSOK D-010 (2021, EAC Table 60). It is a popular method among operators due to its simplicity. However, it is known to be an expensive method due to long operational times and uncertainties—thus

*Corresponding author; email: mj@hydrawell.no

Original SPE manuscript received for review 18 January 2025. Revised manuscript received for review 14 March 2025. Paper (SPE 226204) peer approved 31 March 2025.

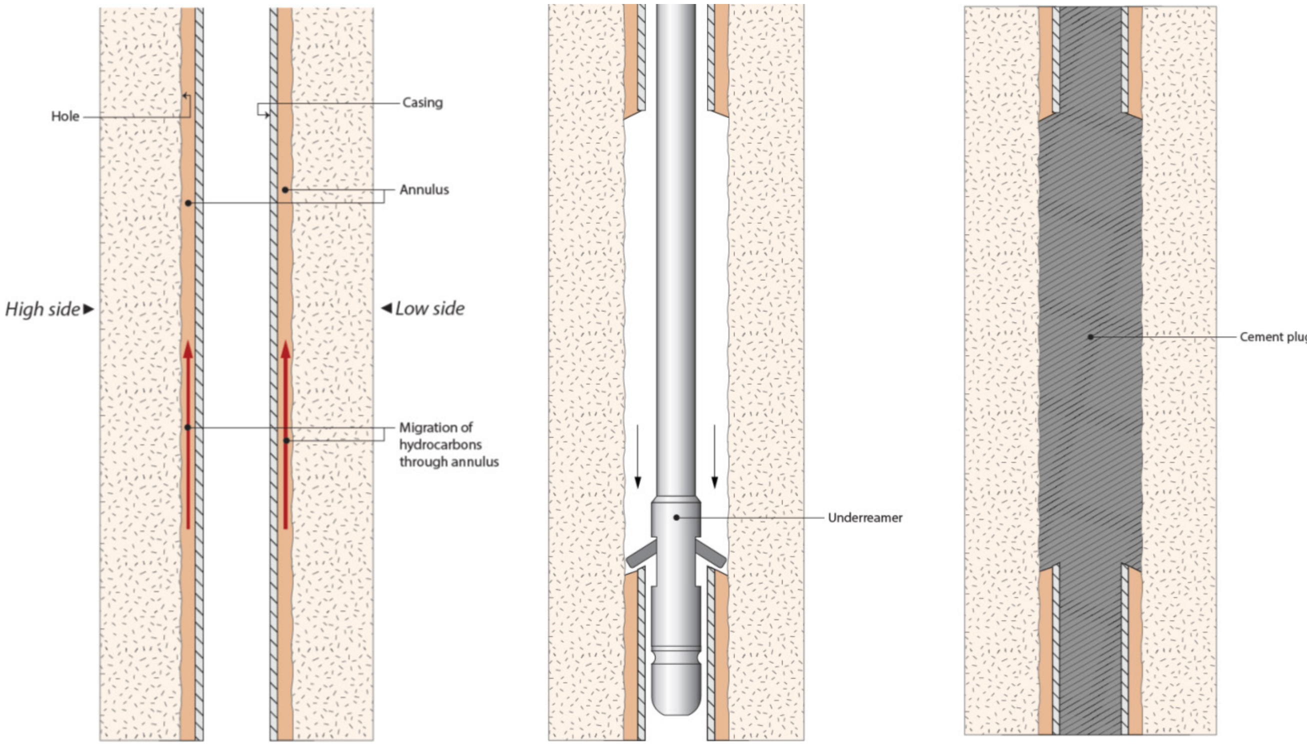

Fig. 1—Main steps in a section milling operation (after Ansari et al. 2017).

consuming significant rig time and generating significant swarf from the milled casing, which can lead to wellbore cleanup problems even if circulating it is attempted. Furthermore, the handling and discarding of swarf—including its movement to shore—is a cause of further concerns in terms of health, safety, and environment.

Cement Squeeze. **Fig. 2** illustrates the main steps of the cement squeeze method for installing a cross-sectional cement barrier. In this technique, the casing is instead perforated using tubing-conveyed guns at two depths spaced according to barrier length requirements. A cement retainer is positioned between the two perforations, and then cement is pumped through the pipe, entering through the lower perforation and exiting through the upper one. A spacer/wash fluid may be pumped beforehand to try and clean wellbore contents that may contaminate the cement later. The subsequent verification of annular cement must take place by drilling out the internal cement and running cement bond log (CBL) tools. If the logging tools show inadequate cement, the cement squeeze operation must be performed again until satisfactory results are achieved.

While cement squeeze is not presented as a standalone NORSOK D-010 (2021) EAC table, cross-sectional cement barriers installed using this technique may be validated using the separate EAC tables for annulus cement (EAC Table 22) and cement plug (EAC Table 24). Cement squeeze is also a popular technique due to its relative simplicity and being less time-consuming than section milling, as well as eliminating the problem of swarf. However, uncertainties regarding wellbore cleanup and annulus content (e.g., debris and settled barite) may result in cement contamination and/or channeling, thus hindering full circumferential annulus coverage.

Cup-Based PWC. **Fig. 3** illustrates the cup-based PWC method. The cup-based method is the original PWC method discussed by Ferg et al. (2011). As the PWC name implies, installing the cross-sectional cement barrier consists of three steps; these may be performed in separate trips (i.e., perforating, retrieving the gun, and then a wash/cement trip) or combined onto a single trip. The schematics shown in **Fig. 3** assume the latter. In this scenario, first a tubing-conveyed gun—attached to the bottom of the wash/cement tool—is lowered and perforates the whole barrier interval. Then, the gun is dropped to the rathole before washing starts. Washing is carried out by pumping washing fluid into the A-annulus, trapping it between two cups, and forcing it into the perforations and the B-annulus. The tool runs from top to bottom, washing the annular content from the top perforation to the bottom perforation and then back up to the top of the interval. With the wash phase concluded, the tool is run back down to the bottom perforation again to pump a spacer, displacing the washing fluid. Finally, the cups are released and placed below the bottom perforation as a cement base, and cement is pumped through the string to displace the spacer, filling the A- and B-annuli to create the cross-sectional barrier.

The cup-based method was developed to remediate the problems observed with section milling and cement squeeze operations, such as generated swarf and cement contamination due to poor annulus cleaning, especially in eccentric wellbores. Washing and cementing are done with a pump-and-pull method, which manages to displace fluids and debris to some extent but may not be able to deal with significantly bonded annulus content (Delabroy et al. 2017).

Jet-Based PWC. **Fig. 4** illustrates the jet-based PWC method. The jet-based method is an evolution of the original cup-based method, as discussed by Delabroy et al. (2017) and Hovda et al. (2020). The principle behind the technique is still the same, that is, the cross-sectional cement barrier is installed using the three aforementioned steps, performed in a single trip. The difference lies in the tool configuration, which now jets the washing fluid and cement instead of simply pumping them through the string and constraining their path using cups. Again, a tubing-conveyed gun perforates the whole barrier interval and is dropped to the rathole. Washing is now carried out by jetting

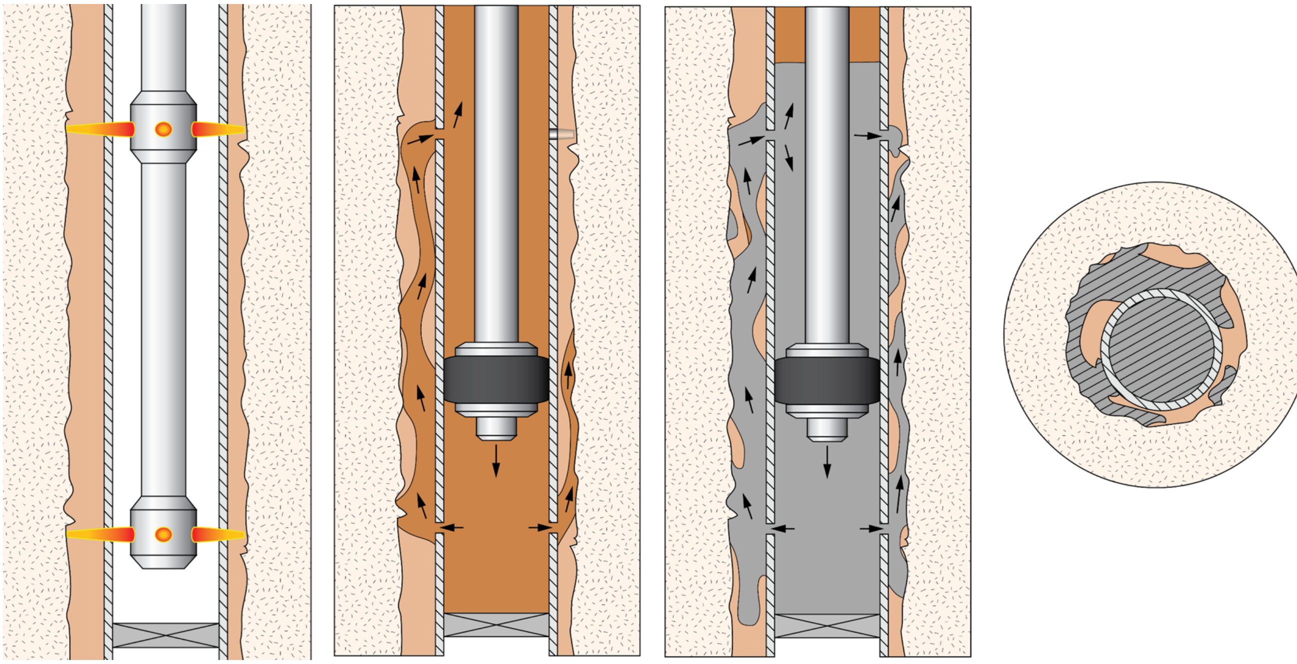

Fig. 2—Main steps in a cement squeeze operation (after Ansari et al. 2017).

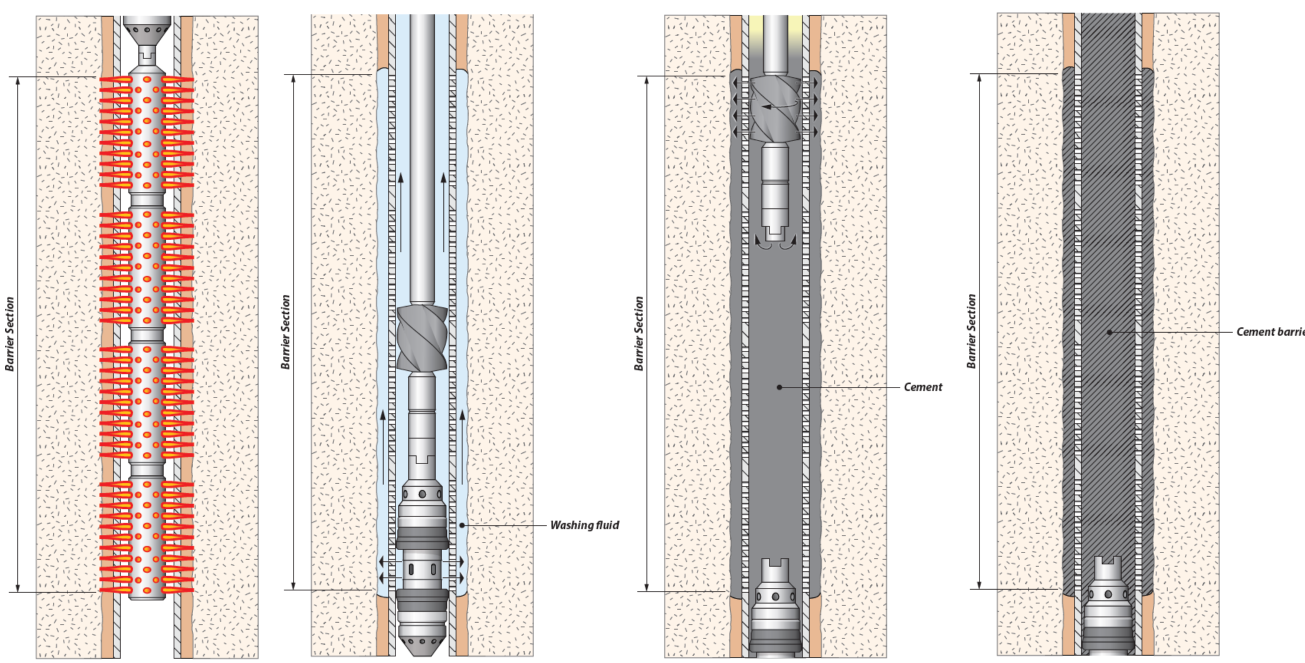

Fig. 3—Main steps in a cup-based PWC operation.

with nozzles into the A- and B-annuli, displacing and circulating the annulus content. A spacer is also jetted into the annulus to displace the washing fluid. Finally, the jetting tool is run in hole to the bottom perforation, and a cement valve jets cement through the perforations with high energy, from bottom to top, leaving a cross-sectional cement barrier.

High-velocity jet nozzles are used instead of squeezing the various fluids (washing fluid, spacer, and cement) through the perforations and annuli with cups. The use of jetting through a pump-pull-rotate method improved operations significantly in terms of wellbore cleanup (Delabroy et al. 2017; Hovda et al. 2020) compared with squeezing fluids with cups, yielding reduced fluid losses during the wash phase, more bonded cement after the cement phase, and reduced overall time to install and verify the barrier. Operators in the North Sea have been more prone to using this method for their P&A needs (Delabroy et al. 2017; Pollard 2021), performing lengthy qualification processes to establish track records as per NORSOK D-010 (2021).

Summary. Table 1 summarizes the strengths and weaknesses of each method discussed in this section. These have been noted based on the technological developments and observations made during field deployments (Ansari et al. 2017; Delabroy et al. 2017; Hovda

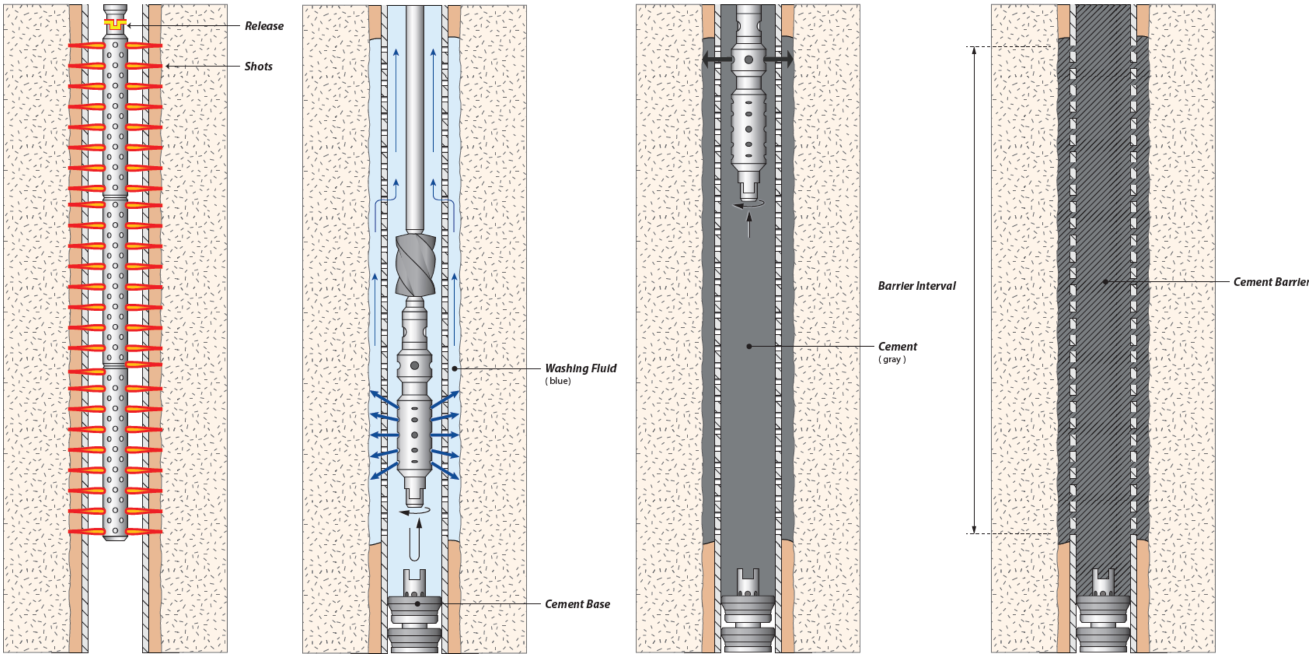

Fig. 4—Main steps in a jet-based PWC operation.

et al. 2020; Leeson and Larsen 2020; Lucas et al. 2024; Tayar et al. 2024; Torvestad et al. 2022). Naturally, no absolute, one-size-fits-all method can be applied in all wells under all conditions, but still, there is a clear evolution among them regarding the achieved sealability and quality of the cement job. One important aspect to highlight is that the jet-based tool was developed as an improvement over the cup-based tool, and for this reason, the later technology retains the original advantages while eliminating some of its weaknesses. Removing annulus content—such as settled barite—requires circumferential coverage with the fluid being pumped, the flow of which will provide enough energy over time to displace these contents. Thus, a higher shot density and larger entry holes improve the annulus material removal. However, the cup-based tool requires dimensioning the entry hole size and shot density to ensure that the selected flow rate yields a sufficient pressure differential across the perforations between the cups and that the flow energy is spread equally among all the exposed perforations. A consequence of this concept is that a path of least resistance is created in the wellbore if the flow energy is not spread adequately across all perforations, leading to washing only the wide side of the wellbore while the narrow side remains unwashed. Another one is that if some of the perforations are blocked—such as in the presence of cement content—the pressure may spike during pumping, causing complications in the operation such as the sealing cups losing their integrity. This requires a reduction in flow rate to reduce these pressure spikes, compromising the original parameters selected for the job and, consequently, the washing efficiency. The jet-based tool ensures that uniform and sufficient energy is delivered throughout all perforations, open or blocked, without the need to monitor and adjust the flow rate on the surface or at the risk of imposing damage to the tool.

Method	Advantages	Disadvantages
Section milling	• Simple yet effective technique • Restores the annular barrier by installing new cement • Underreaming extends knives to “virgin” formation	• Unable to circulate • Multiple runs are needed due to worn knives • Difficulties in handling swarf • Unknown effectiveness of annular cleaning • Need for a post-job blowout preventer cleaning • May cut two casings in high-eccentricity wellbores • No ability to drill out cement and confirm bonding between cement and formation
Cement squeeze	• Simple technique • Generally lower cost than section milling and PWC • Works fairly well in centralized wellbores with no annular cement or barite settlements	• Sometimes unable to break circulation between perforations • Unknown effectiveness of annular cleaning • Difficulties in squeezing through annular debris • Uncertain cement coverage in the annulus, especially low side • Need to drill out to log and verify annulus cement

Table 1—Summary of cement plug installation techniques, highlighting advantages and disadvantages of each method. USIT = Ultrasonic Imager Tool. CBL = Cement Bond Log.

Method	Advantages	Disadvantages
Cup-based PWC	• Reduced operational time over section milling • No milling swarf generated, eliminating handling by rig personnel and potential of swarf in the blowout preventer • Casing left intact should further interventions be required • Ability to drill out and log to confirm bonding between pipe and formation	• Need to carefully consider the pressure differential during washing for 360° coverage • Perforation size setup needs to be calculated based on equivalent circulating density expectations • Cannot handle narrow operating margins (pore pressure vs. fracture gradient) without inducing losses • Requires a swivel to rotate string during washing • Difficulties washing unknown annular cement contents • Requirement to drill out and relog annular cement in some regions • Not established as a method for remediating microannuli • Contamination of fluids generating (large) volumes of slop, especially when using spacer
Jet-based PWC	• All the advantages of the cup-based PWC • Significant reduced operational time over section milling and cup-based PWC • Improved wellbore cleaning by continuous rotation while washing (no swivel required) • Larger total flow area for washing and cement • Handles unknown annular contents • Handles eccentric wellbores • Improved washing efficiencies over cup-based PWC • Reduced operational risk over section milling, cement squeeze, and cup-type PWC • Handles narrow operating margins (pore pressure vs. fracture gradient) without inducing losses • Largest track record of successful PWC jobs to date	• Unknown effectiveness in wells with significant annular cement • Requirement to drill out and relog annular cement in some regions • Not established as a method for remediating microannuli • Contamination of fluids generating (large) volumes of slop, especially when using spacer • Larger total flow area creates more noise on USIT/CBL logs

Table 1 (continued)—Summary of cement plug installation techniques, highlighting advantages and disadvantages of each method. USIT = Ultrasonic Imager Tool. CBL = Cement Bond Log.

Some of the limitations of the PWC tools may be remediated. In particular, Lucas et al. (2024) commented on how existing PWC tools have difficulty cleaning the annulus during the wash phase if there is well-bonded cement to the casing, thus proposing an improved tubing-conveyed gun design that can crack the well-bonded cement and improve efficiency in the washing phase. Meanwhile, the need for drilling out and logging—and then re-establishing the cement plug—can be mitigated by establishing a track record (Delabroy et al. 2017; Pollard 2021; NORSOK D-010 2021), which we discuss further in the following sections.

Field Deployments

PWC has been successfully deployed in several regions across the globe: the Norwegian (Delabroy et al. 2018; Govil et al. 2024; Hovda et al. 2024; Thomson 2018; Torvestad et al. 2022) and UK (Joneja 2018; Lucas et al. 2018) portions of the North Sea, Southeast Asia (Azihar et al. 2022; Ho 2018; Kueh et al. 2018; Mohd Mokhtar et al. 2019; Othman et al. 2018; Razak et al. 2021; Teo et al. 2018, 2020; Yang et al. 2019; Yusof et al. 2018; Zulkipli and Saw 2019; Zulkipli et al. 2018), Middle East (Adawi et al. 2024; Ansari et al. 2016a, 2016b, 2017; Hurtado et al. 2024), West Africa (Allapitchai et al. 2021, 2023), the Netherlands (Dahmani et al. 2022, Mohamad and Joppe 2022), Gulf of Mexico (Gulf of America) (Kehlenbeck and McNicol 2023), and Australia (Bothamley et al. 2020). Applications include remediating poor annulus cement, deploying cross-sectional cement barriers, and slot recovery.

Ansari et al. (2016a, 2016b, 2017) discussed the use of PWC to remediate high pressure in the B-annulus, while Adawi et al. (2024) and Hurtado et al. (2024) also reported using PWC to remediate sustained annulus pressure. Delabroy et al. (2018) discussed the deployment of PWC in a larger casing size and the challenges associated with that; up to that point, the majority of the deployments had been carried out inside 9 5/8-in. casing, but they successfully deployed it inside a 13 5/8-in. casing. Thomson (2018) reported a PWC deployment using coiled tubing, though with more trips into the well than expected for the conventional drillpipe-deployed cup- and jet-based methods. Joneja (2018) used PWC to abandon a well with multiple permeable zones by deploying two plugs at different depths. Lucas et al. (2018) evaluated the efficiency of cup-based PWC deployments, including comparison and calibration with CFD analysis and verification with logging. Ho (2018), Kueh et al. (2018), Mohd Mokhtar et al. (2019), Othman et al. (2018), Yusof et al. (2018), Zulkipli and Saw (2019), and Zulkipli et al. (2018) reported the decision to choose PWC to perform the first few subsea P&As in Malaysia over the traditional section milling method. Teo et al. (2018, 2020) presented a novel application to install an environmental plug across two casing strings, which posed new challenges in terms of washing and securing a cross-sectional cement barrier. Azihar et al. (2022) recommended that smaller-sized guns be used when installing PWC cement plugs between two casings (i.e., when there is no intention to perforate the second one), as there is a risk of puncturing the second casing behind, later leading to shallow gas problems. Bothamley et al. (2020) presented a case study on the remediation of an uncemented liner using cup-based PWC; they reported that the cups were worn and damaged due to the presence of paraffin synthetic-based mud damaging the elastomers. Kehlenbeck and McNicol (2023) also reported similar issues with the swab cups, though the job could still be completed. Allapitchai et al. (2021) reported a P&A job using PWC in which the plug quality was validated using the qualification matrix approach. Torvestad et al. (2022) reported the use of PWC to remediate the annulus cement by washing previous cement and pumping new cement in a slot recovery operation. Mohamad and Joppe (2022) and Dahmani et al. (2022) presented a P&A campaign that was carried out using grid electricity to power the tools, in which PWC was one of the abandonment technologies used. Yang et al. (2019) and Razak et al. (2021) also reported similar deployments, but in offshore Malaysia, illustrating that rigless operations are possible with PWC, even offshore. Allapitchai et al. (2023) summarized lessons learned from a P&A campaign, in which PWC was used to install plugs in some of the wells. Hovda et al. (2024) compiled the lessons learned through 150 deployments of jet-based PWC in Ekofisk, Norway, accompanied by CFD to understand the role of key parameters of the operation. Govil et al. (2024) proposed a new approach to interpret logging data from PWC deployments since the perforations (shot density and entry hole size) may affect this judgment; they commented that the blank sections between guns are good additional checks of log quality.

Barrier Verification Philosophy

Barrier verification and validation differ around the globe according to local regulations. Chukwuemeka et al. (2023) summarize the barrier length requirements for different countries, which in general vary between 15 m and 100 m, also depending on casedhole or openhole conditions. Some countries are stricter than others in terms of barrier length and validation, but the verification typically involves a combination of tagging, pressure testing, and/or logging. Following, focus is given to the barrier philosophy provided by NORSOK D-010 (2021) in the Norwegian North Sea due to the PWC methodology being conceived and developed in this context. Nevertheless, we also discuss it in light of other guidelines from other regions such as the UK (OEUK 2022), Brazil (IBP 2022), and the US (*API RP 65-3* 2021), as we understand that the method finds applicability in many regions of the globe.

According to NORSOK D-010 (2021), well barriers placed for permanent P&A shall extend across the full cross section of the well, effectively sealing it both vertically and horizontally. A horizontal seal means that all annuli are closed [i.e., both Annulus A (inside the casing string, with an internal WBE) and Annulus B (between rock and casing, with an external WBE)]. The aforementioned barrier placing methods involve communicating both annuli before installing the cement plug (e.g., by cutting or perforating the casing) and as such, a single barrier is placed along both annuli; such an approach is also deemed valid. The external WBE is labeled annulus cement, and its acceptance criteria are presented in EAC Table 22 of NORSOK D-010 (2021); its sealing ability is later checked by formation integrity tests, while logging tools typically check its length. Meanwhile, the internal WBE is labeled cement plug, and its acceptance criteria are presented in EAC Table 24 of NORSOK D-010 (2021); its verification is done by tagging and pressure testing.

In this context, the PWC technique has its own EAC Table 61, as reproduced in **Table 2**. The technique is further mentioned in Section 10.6.9 of NORSOK D-010 (2021) as an alternative method to establish a permanent barrier, with provisions for establishing single or combined (primary + secondary) barriers, as seen in **Fig. 5**. Including a dedicated EAC table in NORSOK D-010 (2021) is a significant step toward widespread use of the technique, as it provides custom-tailored criteria that are simple to follow for successful deployment

Features	Acceptance Criteria
A. Description	This element consists of cement placed in the single annulus between the casing/liner and the borehole wall while also forming a cement plug inside the wellbore by using the PWC technique. Note: This EAC table does not apply to dual-casing PWC operations.
B. Function	The purpose of the element is to provide a continuous, permanent seal across a perforated interval in the casing annulus and inside a wellbore to prevent the flow of formation fluids between formation zones and/or to the surface/seabed.
C. Design, construction, and selection	1. A program shall be issued for each PWC operation, covering the following as a minimum: a. Foundation requirements in casing and annulus b. Perforation hole size and density, relative to casing/hole sizes c. Parameters for washing perforations, and placement of spacer and cement d. Properties of mud and spacer, relative to formation and cement slurry design 2. The cement plug shall a. Be designed as per EAC Table 24 Paragraph C b. Cover the perforations and the logged/verified interval in the annulus c. Extend 50 m measured depth above the top perforation 3. Planned perforation interval length shall be sufficient to obtain, as a minimum, 30 m measured depth of cement bonding, verified by logging, for the element to act as a single barrier.
D. Initial test and verification	1. The annulus cement length shall be verified by one of the following: a. Bonding logs: Logging methods/tools shall be selected based on the ability to provide data for verification of bonding. The measurements shall provide azimuthal/segmented data. The logs shall be verified by qualified personnel and documented. • Actual cement length verified by bond logs shall be a minimum of 30 m measured depth per barrier. b. If the element has previously been qualified for the same casing/borehole geometry, lithology, and fluid system, by drilling out cement and running CBLs, and a successful and auditable track record has been established, using a qualification matrix with a documented parameter set is considered sufficient for subsequent wells. • In the event of losses or the inability to perform the PWC operation according to the parameter set defined in the qualification matrix, the cement plug shall be drilled out, and cement bond logging shall be performed. • A minimum of three successful jobs, verified by drilling out and logging the cement behind the perforations, shall be completed prior to establishing a track record and a qualification matrix. 2. The internal cement plug shall be verified as per EAC Table 24, Paragraph D, and, if applicable, G. a. If the element has previously been qualified for the same casing/borehole geometry, lithology, and fluid system, by tagging the internal cement plug, and a successful and auditable track record has been established, tagging may be omitted for subsequent wells. • The cement plug shall be verified by pressure testing.
E. Use	None
F. Monitoring	The annulus pressure above the annulus cement shall be monitored at a defined frequency when access to this annulus exists.
G. Common WBE	See relevant requirements in Section D of this table.

Table 2—EAC table for the PWC technique (NORSOK D-010 2021).

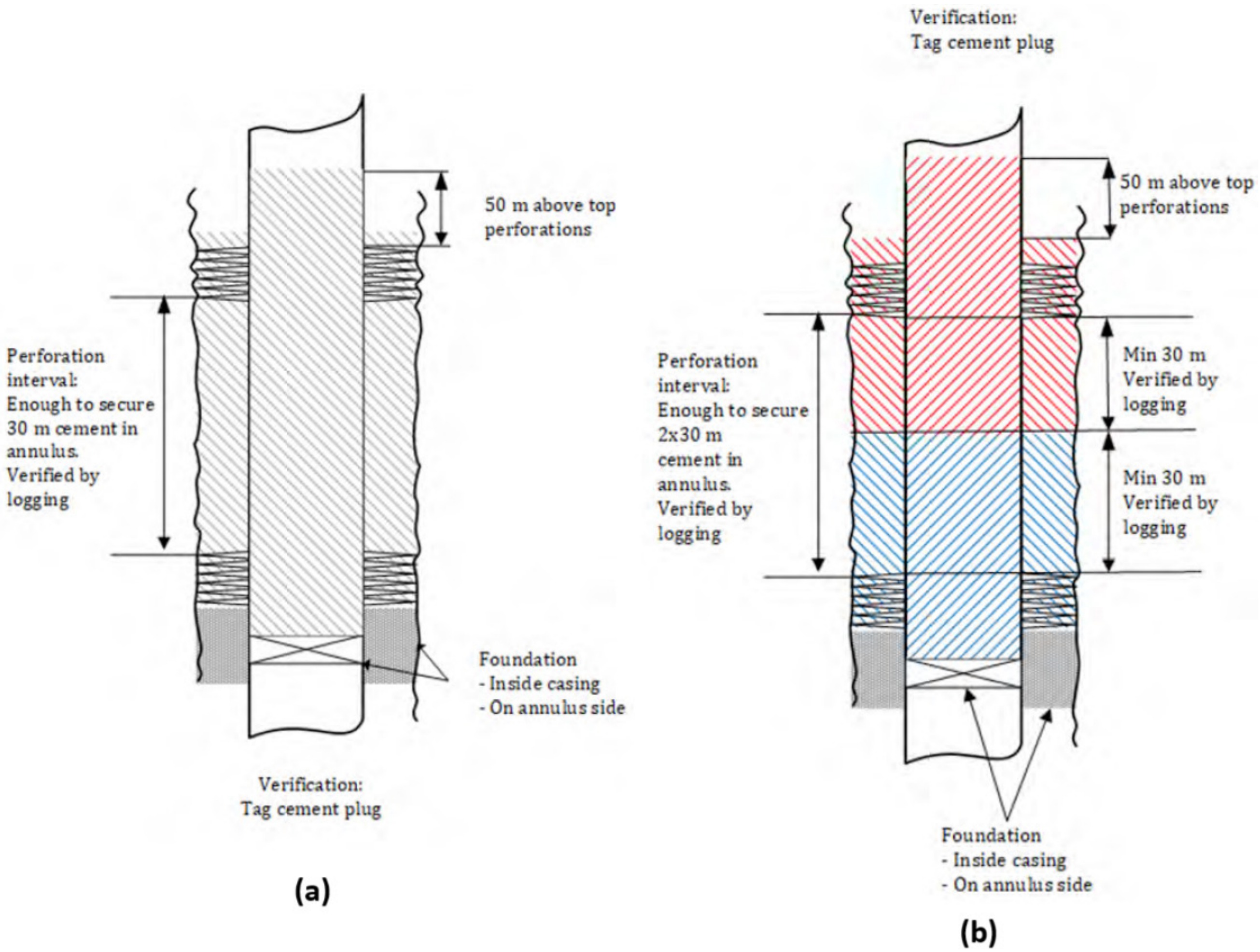

Fig. 5—PWC cement plug placed as a (a) single or (b) combined barrier element (after NORSOK D-010 2021).

and validation of the WBE. Other emerging P&A technologies, such as alternative materials, only possess general criteria [e.g., EAC Table 55 of NORSOK D-010 (2021)], thus currently requiring more extensive qualification processes for WBE acceptance.

In the OEUK (2022) guidelines, there is no explicit mention of the PWC method, but cross-sectional cement barriers are covered in the barrier envelope integrity section, including when performed in front of perforated intervals. It lists root causes for barriers to fail and includes a list of leakage paths for this scenario; from their schematics, it can be seen that cross-sectional barriers installed on perforated intervals can eliminate some of the leakage paths compared with traditional cement plugs inside the casing, such as leakage through holes in the casing, cement cracks, and the casing-cement interface. Verification is done based on the correct barrier positioning, tests to verify integrity (typically a pressure test but also alternative methods such as tracers), and good practices followed during deployment to ensure that the pre- and post-job criteria have been met. In this sense, these guidelines are less prescriptive than NORSOK D-010 (2021), providing alternatives for the verification. Meanwhile, the IBP (2022) guidelines mention PWC explicitly, providing a similar table as seen in NORSOK D-010 (2021). Similar to the OEUK (2022) document, verification—both of the barrier position and its integrity—can be done using one of the listed options, which can be direct pressure testing, logging, or simply adequate operational parameters if there is an established track record.

According to Delabroy et al. (2017) and Pollard (2021) [and as stated by *NORSOK D-010* 2021], establishing a track record for specific well characteristics (wellbore geometry, casing size, lithology, and fluid system) may relinquish the need for drilling out and logging altogether and replace it with a qualification matrix. This is corroborated further by the PWC EAC table, as reproduced in **Table 2**; in this sense, a track record is defined as a minimum of three successful jobs under the specified well conditions. Delabroy et al. (2017) suggested what a qualification matrix should contain; essentially, all parameters that may change in a PWC operation, such as

- PWC tool (type, size, number of nozzles, nozzle size, nozzle configuration, nozzle standoff, total flow area, jetting speed, and number of jet impacts)
- Casing (size and type)
- Hole geometry (drill-bit size and inclination along the zone of interest)
- Perforating guns (gun size, perforation size, shot density, and percentage of casing removal)
- Minimum expected length of perforated interval (for single or combined barrier)
- Fluid properties for washing fluid, spacer, and cement slurry (type, density, and rheology)
- Flow rates during each phase (washing, spacer placement, and cementing)
- Tool rotational speed during each phase
- Tripping in/out speed during each phase
- Volume of spacer and cement pumped relative to total flow area
- Gains and losses during and after cementing

- Foundation requirements in both A- and B-annuli
- Operational events

Validation and Verification of PWC

Validation and verification of the deployed plug can be achieved using numerical modeling through CFD and logging tools. In this sense, CFD works both as a design tool (i.e., to confirm the operational window before the job is executed, based on relevant input parameters) and as a validation tool (i.e., to confirm that the washing and cementing phases managed to displace the annular content and install cement correctly at the desired position). Note that validation through CFD requires a robust methodology to reduce the inherent uncertainties of displacing fluids downhole. Then, logging tools verify that cement has been correctly placed in the annulus, as per current NORSOK D-010 (2021) requirements for PWC as seen in **Table 2**.

Furthermore, as PWC operations consolidate over time, alternative ways to verify and validate jobs may be promoted in the future. Currently, we rely on robust engineering by using CFD, correct job execution, and verification by logging to deem a deployment as successful; then, we could move toward good engineering + good execution + track record (instead of logging), or even good engineering + good execution only—if we become sufficiently confident in their robustness.

Using Numerical Modeling. Pollard (2021) mentioned that operators have performed extensive CFD modeling to validate their PWC deployments, emphasizing the importance of numerical modeling as a complementary tool. Some of these modeling attempts have been reported in the literature.

Hovda et al. (2020) and Phadke et al. (2020) provided a comprehensive description of their CFD modeling approach using Ansys Fluent. The analyses used the Reynolds-averaged Navier-Stokes-based unsteady multiphase volume of fluid model, with multiple interacting phases or fluids. Separate simulations were carried out for the wash and cement phases. The bottomhole assembly had a prescribed motion (running/pulling trip speed), which affected the fluid motion and was simulated by means of a moving-deforming-layering mesh approach. A reduced and representative length was selected since it would be impractical to discretize and simulate the whole domain of an actual PWC operation. All fluids involved in the operation were modeled as non-Newtonian, using either Bingham plastic or Herschel-Bulkley formulations, with their rheologies obtained from laboratory tests. The fluids were considered immiscible but possessed an interface that was captured. The authors recognized that direct validation was not straightforward since it was difficult to compare field-measured parameters with the CFD results. Instead, they suggested comparing washing fluid and cement displacement efficiencies obtained from the software with logging results—performed after the operation had been carried out.

Lucas et al. (2024) also proposed a CFD model to evaluate the wash and cement phases. Washing performance was determined by injecting spherical particles into the model and calculating whether they were transported out of the domain by the flow, while the cementing performance was evaluated similar to Phadke et al. (2020). The authors performed a design optimization to find the best operational parameters suitable for the intended operation. These results were used as a basis for a wider scope of improving perforating guns for the perforate phase.

Other works in the literature include Teo et al. (2018, 2020), who performed CFD analyses to validate the cup-based tool applied to dual-casing PWC operations, and Phadke et al. (2023), who performed a sensitivity analysis to improve operational parameters for the wash phase. Overall, the CFD works reported above have concerned themselves with the displacement phenomenon, ensuring that the wash fluid manages to remove the annular content and that the cement slurry replaces the wash/spacer fluid, covering the whole wellbore adequately. These simulations show that PWC can typically deal just fine with old mud and barite settings with an adequate choice of job parameters. An aspect not considered is partially cemented annuli; the efficiency of PWC jobs against well-bonded cement in the annulus is unknown. Based on operational experience, some weak, old cement may be washed away if the perforations manage to crack it down further, especially when the jet-based-type tool is used, but that is not guaranteed, as stated in **Table 1**. More studies are necessary on this issue and intended for future work, being outside the scope of this article. Finally, job design is fundamental for a successful PWC job; as such, previous works have all taken care to investigate the effect of varying operational parameters, looking for the best choices of shot density, entry hole diameter, pumping rate, fluid rheology, well inclination, casing eccentricity, and rotational speed of the tool. These, combined with the annulus content considerations discussed in **Table 1**, will determine if a PWC job is a feasible alternative for a particular well.

Using Logging. Several of the aforementioned works also presented logging results for validation of the PWC job (Allapitchai et al. 2021, 2023; Delabroy et al. 2017, 2018; Ferg et al. 2011; Govil et al. 2024; Hurtado et al. 2024; Joneja 2018; Lucas et al. 2018, 2024; Torvestad et al. 2022; Yang et al. 2019; Yusof et al. 2018; Zulkipli and Saw 2019; Zulkipli et al. 2018). **Fig. 6** provides an example of logging results before and after a PWC job. In most of these works, the results serve merely to confirm the success in deploying a cross-sectional cement barrier; however, some of them provide interesting takeaways about logging challenges.

According to Pollard (2021), verification of annulus cement quality using logging is particularly difficult for the jet-based method due to the large and continuous perforations disrupting the signal. In these cases, alternatives are checking the response in the blank sections between guns to obtain a more undisturbed log response or using the track record as previously discussed. However, we have noted through experience that even the blank sections may not yield good results depending on the annulus content.

Delabroy et al. (2017) claimed that drilling out and logging right after the operation has been performed (typically 1–2 days) may lead to conservative results in terms of cement coverage in the annulus. The authors explained that the complex flow of multiple fluids during the operation may cause cement contamination that delays it from building the intended compressive strength. Experience in the North Sea has confirmed that one well had two barriers (primary and secondary) installed separately and verified independently. After the primary barrier was completed, the internal cement was drilled out, and the annulus cement was logged within the typical 2–3 days after placement. Then, the secondary barrier was placed, and the internal cement was once again drilled out all the way down to the bottom of the first interval. This allowed relogging the primary barrier, now 6–7 days after the first log. The difference between the two log results showed a 20% improvement in the length of verified cement over this period. This indicates that the results obtained when logging a PWC job within a few days after the cement is placed are quite conservative, as contaminated cement is still curing at this stage, and bonding is expected to increase further over time.

Lucas et al. (2018) and Yang et al. (2019) remark that logging may not always be the most effective way of qualifying the cement barrier since the quality of results relies on their interpretation, even claiming that annuli have been known occasionally to develop sustained casing pressure despite a well-executed cementing job followed by a positive log interpretation. Considering this context, Delabroy et al. (2018) remarked that an increased density of perforation holes may compromise logging quality. Govil et al. (2024) went further and

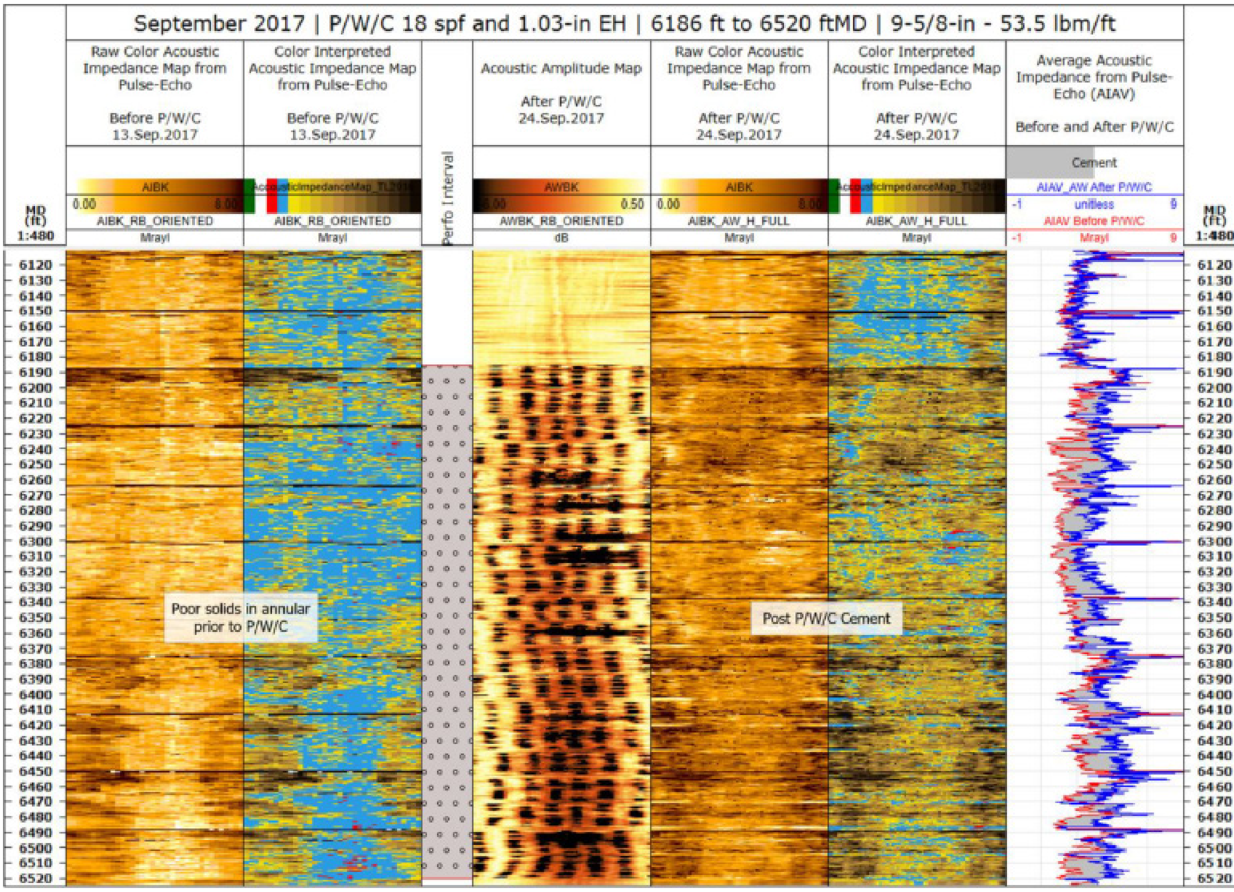

Fig. 6—Example of a logging result obtained prior (left) and after (right) performing a PWC job. Logging is typically run before the job is executed to serve as a benchmark for post-job analysis (Govil et al. 2024).

evaluated the impact of hole size and shot density on the quality of CBL and variable density log. CBL was not affected for a hole size of 0.5 in. at 12 shots per foot but was heavily affected for a hole size of 1.0 in. at 18 shots per foot. Meanwhile, variable density log was not affected for either of the aforementioned parameter sets, but the authors remarked that using larger hole sizes and shot densities will affect the variable density log as well. Considering these limitations in the logging technology and interpretation, other methods, including CFD analysis and track record, can be beneficial for barrier verification.

We conclude this section by posing the following question: If a logging result yields a negative for bonded cement, is it a problem with the PWC, or is it a problem with the logging itself? As aforementioned, it is not unusual for logging results to be assessed incorrectly under unique circumstances. In this sense, alternative ways of verification—CFD and track record—are necessary to complement logging. Furthermore, emerging techniques could be used, such as through-barrier diagnostics (Solovyev et al. 2020; Volkov et al. 2021; Yeleussinov et al. 2021) and tracer-based monitoring (Palisch and Zhang 2021; Silva et al. 2023).

Using Track Record and Qualification Matrix. The idea of establishing track records and a qualification matrix was first proposed by Delabroy et al. (2017), which led to its eventual incorporation into NORSOK D-010 (2021). Allapitchai et al. (2021) adopted this methodology in a P&A campaign, recognizing that drilling out and logging every PWC job is expensive, time-consuming, and may jeopardize the quality of the PWC-installed barrier. Pollard (2021) recognized, based on talks with operators in the North Sea, that establishing a track record and qualification matrix is a challenging but necessary endeavor and that good CFD validation is fundamental for extending and trusting this procedure.

Fig. 7 illustrates a qualification matrix for a jet-based PWC tool using a combination of track record and CFD validation. The casing size of 9 5/8-in. is simply an example of a typical casing size in which PWC is performed. After establishing several plugs for this combination of casing size and set of parameters and validating them using CFD analysis, the table is filled with standardized operational conditions, which are then reproduced for further wellbores that fall within this same classification. Finally, this would waive the drilling out and logging and tagging verification criteria stated for the annulus cement and the cement plug, respectively, in **Table 2**.

It is important to point out that the inclusion of CFD as a tool in the qualification matrix is valuable to extending operational windows, by performing worst-case scenario analyses that can cover a wider range of well parameters than those established by the track record. This means that if a cross-sectional cement barrier is placed subject to a set of parameters more benign than another set that has been qualified already, then there would be no need to drill out and log that particular PWC job, even if the job is being performed subject to those parameters for the first time. This would enhance the feasibility of establishing meaningful track records and reduce costs significantly without incurring reduced safety.

Next Steps

Based on the experiences and lessons learned from reported field deployments, our discussions on barrier verification and validation, and the technological needs for upcoming P&A activities, we may affirm that two main drivers exist for the future of PWC—the compatibility

			Jet-based PWC tool
	Annulus Area	*in2*	*(60)*
Application	Casing size	in	9 5/8
	MAX Casing ID	in	8.835
	MAX Annulus ID	in	13.0
Uncemented Annulus	SPF (minimum)	ea	
	EHD (minimum)	in	
	Steel removal	%	
Partially Cemented	SPF (minimum)	in	
	EHD (minimum)	ea	
BHA	OD body	in	
	Tool standoff	*in*	
	Nozzle size (W/S)	ea	
	Nozzle qty (W/S)	ea	
	Nozzle size (C)	ea	
	Nozzle qty (C)	ea	
Washing [↓]	Passes	ea	
	Pump rate	gpm	
	Movement speed	ft/min	
	Rotational speed	rpm	
	Effective vol./annulus	gpf/in2	
Spacer [↑]	Pump rate	gpm	
	Movement speed	ft/min	
	Rotational speed	rpm	
	Vol/distance	*gal/ft*	
	Effective vol./annulus	*gpf/in2*	
Cement [↑]	Pump rate	gpm	
	Movement speed	ft/min	
	Rotational speed	rpm	
	Vol/ft	*gal/ft*	
	Effective vol./annulus	*gpf/in2*	
Validation	Wash		Track record Optimizations by CFD
	Spacer		Track record Optimizations by CFD
	Cement		Track record Optimizations by CFD
Fluid Requirements			Fluids densities windows Jetting rotational speed

Fig. 7—Example of a qualification matrix for a jet-based PWC tool. SPF = shots per foot; EHD = entry hole diameter.

with rigless interventions and the establishment of wider track records as an alternative verification method, alongside emerging verification techniques.

Onshore, PWC can be combined with hydraulic power units to perform rigless abandonment operations, thus saving costs while also reducing emissions due to the electrification of these tools. Dahmani et al. (2022) and Mohamad and Joppe (2022) reported such usage in the onshore Netherlands, where PWC was one among other P&A technologies used. Meanwhile, Yang et al. (2019) and Razak et al. (2021) reported the same combination of PWC and hydraulic workover units to perform rigless operations but in an offshore environment in offshore Malaysia. This demonstrates that rigless PWC is possible, but initiatives are still incipient and adapt existing solutions instead of developing tailored ones.

Given their flexibility, a possible path is using coiled-tubing units over hydraulic workover units. Thomson (2018) reported an early coiled-tubing PWC deployment, although a total of 10 runs were needed to install and verify the plug, which is prohibitively expensive; coiled-tubing PWC systems in development are expected to perform it in a single trip or in two trips (perforate, then wash-cement); that is, in the same way regular PWC jobs are currently carried out. Meanwhile, Kverneland (2023) successfully performed a jet-based PWC operation using coiled tubing in a test rig in Norway. A recently developed coiled-tubing PWC tool has conducted 16 successful plug deployments in Alaska and Australia, proving the method in the field and enabling rigless operations; these deployments will be the subject of future publications. We understand that such a tool is fundamental to push forward rigless P&A by adding more flexibility and reducing costs.

Regarding the use of track records, we reaffirm the claims from the previous section "Using Track Record and Qualification Matrix". Proposing qualification matrices—by combining track records and CFD analyses—for standardized sets of operational parameters is a feasible way of reducing verification by logging, thus saving cost and time. For this approach to be successful, it is necessary to establish that worst-case scenario analyses using CFD are valid tools in this process if they have been properly validated for a wide range of scenarios. Furthermore, if a track record has not been established and one resorts to verification by logging, then emerging methods may be used to circumvent the logging limitations previously discussed.

Final Remarks

The present work provides a comprehensive and novel literature review on PWC techniques. Throughout this article, we have addressed the main advantages and disadvantages of the cup-based and jet-based types of PWC and how they compare against the traditional section milling and cement squeeze techniques. We have collected and discussed reported field deployments, highlighting success cases and operational challenges faced. Finally, we discussed how the cross-sectional cement barrier created by the PWC methods may be validated and verified, thus addressing the contributions of CFD, the challenges of logging, the need to establish a track record, and the potential of going rigless in the future. It is our understanding that multiple data sources should be combined to ensure that cement isolation was achieved along the desired interval and that adequate job execution, adequate operational parameter selection, and CFD validation, combined with an extensive track record on similar conditions, may be enough to verify jobs without the need to drill out and log.

As further work, we intend to delve into a comprehensive CFD validation approach undertaken during jet-based deployments, which has been developed internally over the last couple of years. The developed CFD methodology is rooted in field experience, sensitivity studies, and laboratory testing of critical variables, enabling the optimization and validation of existing and new PWC technologies. Two approaches have been developed that are to be applied depending on the study objectives and the scope of the wells. Furthermore, we would also like to discuss recent deployments around the world presented as case studies. These include coiled-tubing PWC, dual-casing PWC, and challenges and alternatives associated with logging PWC jobs performed with high shot densities.

References

Adawi, A. A., Mahrooqi, M. A., Mahruqi, I. et al. 2024. Innovative Techniques for Managing Sustained Annulus Pressure in Highly Fractured Carbonate Field. Paper presented at the SPE Symposium - Well Integrity Management, Al-Khobar, Saudi Arabia, 21–22 May. https://doi.org/10.2118/220593-MS.

Allapitchai, M. S. M., Johan, A. L., Heboul, E. K. M. M. et al. 2021. Annulus Perforate, Wash and Cement: Establishing Barrier Verification Process for Deepwater Subsea Wells Abandonment and Its Lessons Learnt. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Virtual, 30 November–2 December. https://doi.org/10.2118/208492-MS.

Allapitchai, M. S. M., Johan, A. L., Liew, W. S. Y. et al. 2023. A Systematic Approach in Methodology for Permanent Plug Placement in Deepwater Subsea Plug and Abandonment Campaign. Paper presented at the International Petroleum Technology Conference, Bangkok, Thailand, 1–3 March. https://doi.org/10.2523/IPTC-22892-MS.

Ansari, A., Al-Azizi, B., and Larsen, A. G. 2017. Innovative Remediation Techniques for Restoring Well Integrity by Curing High Annulus-B Pressure and Zonal Communication. Paper presented at the SPE Bergen One Day Seminar, Bergen, Norway, 5 April. https://doi.org/10.2118/185911-MS.

Ansari, A. A., Libdi, Z., and Larsen, A. G. 2016a. Innovative Planning and Remediation Techniques for Restoring the Well Integrity by Curing High Annulus-B Pressure and Zonal Communication. Paper presented at the International Petroleum Technology Conference, Bangkok, Thailand, 14–16 November. https://doi.org/10.2523/IPTC-18894-MS.

Ansari, A. A., Ringrose, D., Libdi, Z. et al. 2016b. A Novel Strategy for Restoring the Well Integrity by Curing High Annulus-B Pressure and Zonal Communication. Paper presented at the SPE Russian Petroleum Technology Conference and Exhibition, Moscow, Russia, 24–26 October. https://doi.org/10.2118/181905-MS.

API RP 65-3, Wellbore Plugging and Abandonment. 2021. Washington, DC, USA: American Petroleum Institute.

Azihar, A. A., Abu Mukhtar, M., Yang, S. et al. 2022. Biggest Wells Plug and Abandonment Campaign – Effective Management & Best Practices Implementation. Paper presented at the Offshore Technology Conference Asia, Virtual and Kuala Lumpur, Malaysia, 22–25 March. https://doi.org/10.4043/31403-MS.

Bothamley, R., Haigh, M., and Soudi, M. 2020. Installation of Annulus Cement Plugs Using Perforation, Wash and Cement Technique, a Lookback from a First for Australia. Paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Virtual, 17–19 November. https://doi.org/10.2118/202430-MS.

Chukwuemeka, A. O., Oluyemi, G., Mohammed, A. I. et al. 2023. Plug and Abandonment of Oil and Gas Wells – A Comprehensive Review of Regulations, Practices, and Related Impact of Materials Selection. *Geoenergy Sci Eng* **226**: 211718. https://doi.org/10.1016/j.geoen.2023.211718.

Dahmani, L., Joppe, L. C., and Dekker, V. 2022. A Low Impact Rigless Well Abandonment Solution for Complex Wells. Paper presented at the SPE/ICoTA Well Intervention Conference and Exhibition, The Woodlands, Texas, USA, 22–23 March. https://doi.org/10.2118/209047-MS.

Delabroy, L., Rodrigues, D., Norum, E. et al. 2017. Perforate, Wash and Cement PWC Verification Process and an Industry Standard for Barrier Acceptance Criteria. Paper presented at the SPE Bergen One Day Seminar, Bergen, Norway, 5 April. https://doi.org/10.2118/185938-MS.

Delabroy, L., Stokkeland, T. A., Åstrand, G. et al. 2018. Perforate Wash and Cement for Large Casing Sizes. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3–4 December. https://doi.org/10.2118/193945-MS.

Ferg, T. E., Lund, H.-J., Mueller, D. et al. 2011. Novel Approach to More Effective Plug and Abandonment Cementing Techniques. Paper presented at the SPE Arctic and Extreme Environments Conference and Exhibition, Moscow, Russia, 18−20 October. https://doi.org/10.2118/148640-MS.

Govil, A., Obando Palacio, G. A., Middleton, R. et al. 2024. Improved Logging Techniques and Interpretation Experiences to Evaluate Perforate-Wash-Cement Intervals. Paper presented at the IADC/SPE International Drilling Conference and Exhibition, Galveston, Texas, USA, 5−7 March. https://doi.org/10.2118/217712-MS.

Ho, C. Y. 2018. Malaysia's First Subsea Fields Abandonment. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/193959-MS.

Hovda, L., Mueller, D., Phadke, A. et al. 2024. Lessons Learned from 150 Jet-Type Perforate, Wash and Cement Well Abandonment Operations. Paper presented at the IADC/SPE International Drilling Conference and Exhibition, Galveston, Texas, USA, 5−7 March. https://doi.org/10.2118/217690-MS.

Hovda, L., Phadke, A., Mueller, D. et al. 2020. Best Practice for Cementing and Zonal Isolation Using the Jet-Type Perforate, Wash and Cement Technique. Paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Virtual, 17−19 November. https://doi.org/10.2118/202397-MS.

Hurtado, N., Zapata, F., Alzaab, A. et al. 2024. Extending Well Life and Securing Well Integrity Efficiently. Paper presented at the ADIPEC, Abu Dhabi, UAE, 4−7 November. https://doi.org/10.2118/222408-MS.

IBP. 2022. *Diretrizes Para Abandono de Po¸cos (Well Abandonment Guidelines)*, second revision.

Joneja, J. 2018. Perf-and-Wash Cement Placement Technique as A Cost-Effective Solution for Permanent Abandonment of A Well with Multiple Permeable Zones: A Case Study from North Sea, UK. Paper presented at the IADC/SPE Drilling Conference and Exhibition, Fort Worth, Texas, USA, 6−8 March. https://doi.org/10.2118/189580-MS.

Kehlenbeck, D. and McNicol, J. 2023. Abandonment Barrier Placement with Novel Analysis Spells Success in Deepwater. Paper presented at the SPE/IADC International Drilling Conference and Exhibition, Stavanger, Norway, 7−9 March. https://doi.org/10.2118/212444-MS.

Khalifeh, M. and Saasen, A. 2020. *Introduction to Permanent Plug and Abandonment of Wells*, Vol. 12. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-39970-2.

Kueh, J. Z., Hassani, H., Zamzuri, M. D. B. et al. 2018. Cap Rock Restoration in Well Abandonment: Fit-for-Purpose Well Abandonment Design through Workflow Optimization and Integrated Assessment. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/193965-MS.

Kverneland, D. 2023. System Integration Test (SIT) of Technology Enabling Through-Tubing Rig-Less Plug and Abandonment. Paper presented at the SPE/IADC International Drilling Conference and Exhibition, Stavanger, Norway, 7−9 March. https://doi.org/10.2118/212548-MS.

Leeson, T. and Larsen, A. G. 2020. When Can Perforating, Wash and Cement PWC Reduce Abandonment Costs? Paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Virtual, 17−19 November. https://doi.org/10.2118/202344-MS.

Lucas, A., Smith, C., Ullbrand, B. et al. 2024. Advanced Perforation Technology for Enhanced Remedial and Casing Recovery Applications. Paper presented at the ADIPEC, Abu Dhabi, UAE, 4−7 November. https://doi.org/10.2118/222228-MS.

Lucas, A., Stokkeland, T. A., Jackson, D. et al. 2018. Improving the Understanding, Application and Reliability of the Perforate, Wash and Cement Technique through the Use of Cement Bond Logs, Tool Enhancements and Barrier Verification via Annular Pressure Monitoring. Paper presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, USA, 24−26 September. https://doi.org/10.2118/191528-MS.

Mohamad, S. I. and Joppe, L. C. 2022. An Electrifying Integrated Solution Towards a Safe and Environmentally Sound Well Abandonment in Urban Setting. Paper presented at the Offshore Technology Conference Asia, Virtual and Kuala Lumpur, Malaysia, 22−25 March. https://doi.org/10.4043/31394-MS.

Mohd Mokhtar, S. R., Wibisono, R., and Zakaria, M. Z. 2019. How Malaysia Late Life Field Benefited From Well Intervention Efficiency Improvements Through Integrated Operations. Paper presented at the SPE Annual Technical Conference and Exhibition, Calgary, Alberta, Canada, 30 September–2 October. https://doi.org/10.2118/195843-MS.

NORSOK D-010, *Well Integrity in Drilling and Well Operations*. 2021. Oslo, Norway: Standards Norway.

OEUK. 2022. *Use of Barrier Materials in Well Decommissioning Guidelines, Issue 3*. https://doi.org/OEUK.

Othman, F., Teo, C. H., and Bakri, F. 2018. Malaysia's First Subsea Development Well Plug and Abandonment. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/193980-MS.

Palisch, T. and Zhang, J. 2021. A Novel Method to Detect Cement through Direct Measurement – Case Histories. Paper presented at the SPE Annual Technical Conference and Exhibition, Dubai, UAE, 21−23 September. https://doi.org/10.2118/206019-MS.

Phadke, A., Hovda, L., Gonuguntla, P. et al. 2020. Application of Computational Fluid Dynamics for Parametric Optimization of Jet-Type P/W/C Technique. Paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Virtual, 17−19 November. https://doi.org/10.2118/202441-MS.

Phadke, A. C., Hovda, L., and Gonuguntla, P. 2023. Insight into Parameters Influencing Wash Displacement Efficiency Through CFD Modeling. Paper presented at the SNAME 28th Offshore Symposium, Houston, Texas, USA, 8−9 March. https://doi.org/10.5957/TOS-2023-014.

Pollard, M. 2021. Qualification Process for P&A Perforate, Wash, Cement (PWC). Technical Report. Reflekt AS, Stavanger, Norway.

Razak, M. A. A., Rajab, A. Z. A., Chew, J. S. et al. 2021. Pushing the Operational Envelope of a Cap-Rock Restoration Campaign Utilizing Perforate Wash Cement Technology and a Hydraulic Work Over Unit Offshore Malaysia. Paper presented at the International Petroleum Technology Conference, Virtual, 23 March−1 April. https://doi.org/10.2523/IPTC-21367-MS.

Silva, M., Brandvoll, Ø., Hubred, P.-A. et al. 2023. Tracer-Based Monitoring of P&A in Offshore Fields. Paper presented at the SPE EuropEC - Europe Energy Conference Featured at the 84th EAGE Annual Conference & Exhibition, Vienna, Austria, 5−8 June. https://doi.org/10.2118/214446-MS.

Solovyev, T., Ivanov, A., Soltanov, D. et al. 2020. Smart Completion Improvement in Horizontal Wells Based on Through-Barrier Diagnostics. Paper presented at the SPE Russian Petroleum Technology Conference, Virtual, 26−29 October. https://doi.org/10.2118/201896-MS.

Tayar, A. A., Betancourt Joya, M. G., and Aramco, S. 2024. Maximize Well Integrity During Plug and Abandonment Through Perforate and Wash Operation. Paper presented at the SPE Symposium - Well Integrity Management, Al-Khobar, Saudi Arabia, 21−22 May. https://doi.org/10.2118/220577-MS.

Teo, C. H., Bakri, F., Koh, Q. et al. 2020. Dual Casing Perforate Wash and Cement for Annular Isolation. Paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Virtual, 17−19 November. https://doi.org/10.2118/202292-MS.

Teo, C. H., Stokkeland, T. A., Matthews, P. et al. 2018. Dual Annuli Closed System Perforate, Wash and Cement. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/193989-MS.

Thomson, I. 2018. Successful Creation of Permanent Reservoir Isolation Barriers Using Coiled Tubing on the Norwegian Continental Shelf NCS. Paper presented at the SPE/ICoTA Coiled Tubing and Well Intervention Conference and Exhibition, The Woodlands, Texas, USA, 27−28 March. https://doi.org/10.2118/189956-MS.

Torvestad, B. T., Stokkeland, T. A., Fliss, A. et al. 2022. Perf, Wash and Cementing Technique Remediates Cemented Annulus to Achieve High Quality Bond Across the Entire Interval in Complex Slot Recovery Operation. Paper presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Adelaide, Australia, 17−19 October. https://doi.org/10.2118/210783-MS.

Volkov, M., Zaripova, A., Sikander, S. et al. 2021. Through Barrier Diagnostics to Locate Multiple Barrier Failures in Complex Well Failure Scenario and to Enable Successful P&A. Paper presented at the SPE Annual Technical Conference and Exhibition, Dubai, UAE, 21−23 September. https://doi.org/10.2118/205938-MS.

Yang, S., Yusoff, M. H. M., Abdullah, I. A. et al. 2019. Plugging & Abandonment of Multiple Zones in One Run Using Perforate Wash and Cement on Hydraulic Workover Unit. Paper presented at the Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE, 11−14 November. https://doi.org/10.2118/197149-MS.

Yeleussinov, D., Assangaliyev, A., Ospanova, A. et al. 2021. Vertical Fracture Monitoring by Multi-Rate Through-Barrier Diagnostics. Paper presented at the SPE Annual Caspian Technical Conference, Virtual, 5−7 October. https://doi.org/10.2118/207067-MS.

Yusof, V., Ros, M. I., and Omar, M. A. 2018. Well Decommissioning Campaign in Block SK305, Sarawak, Malaysia 7 Production Wells and 9 Suspended Subsea Mud Line Suspension Exploration Wells. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/194054-MS.

Zulkipli, S. N. and Saw, L. J. 2019. Knowledge and Experiences Combined under One Hood: Lessons Learned from Peninsular Malaysia Well Abandonment Campaign. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/199200-MS.

Zulkipli, S. N., Shuib, S. N., Saw, L. J. et al. 2018. Maximizing Value from Well Abandonment through Shallow Gas Hunting and Integrated Well Surveillance. Paper presented at the SPE Symposium: Decommissioning and Abandonment, Kuala Lumpur, Malaysia, 3−4 December. https://doi.org/10.2118/193974-MS.