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# 1 Introduction

Reflekt has been requested by the Petroleum Safety Authority (PSA) to carry out a review of technology development related to permanent plugging and abandonment (P&A) of wells. The purpose of the review is knowledge sharing and information gathering about the qualification process for new technology for P&A of wells in various operating companies. The method PWC (Perforate, Wash and Cement) has been chosen as an example of qualification of new technology and new methods.

Three operating companies (Equinor, AkerBP, ConocoPhillips) have provided information on their qualification processes and how the development, testing and use of the method PWC for establishing well barriers is qualified with associated documentation, verification processes and potential further development of technology and method.

The development and application of PWC has also been discussed with the main technology suppliers in Norway; Archer and Hydrawell, and has received their insight into both the cup-type and jet-type PWC operations and tools, their limitations and expected further development.

Reflekt would like to thank the companies involved in the review for their cooperation, for making personnel available for discussions and providing relevant information as required. The people involved have shown a thorough knowledge of both PWC and the qualification process and have in general displayed an enthusiasm and engagement that has made the task an interesting learning experience for Reflekt.

# 2 Summary

PWC is used in the permanent plugging and abandonment (P&A) of wells or plugging/preparing for a side-track where there is for example, poor annulus cement or uncemented casing. PWC is an alternative to section milling as a methodology for establishing a verifiable well barrier according to NORSOK D-010. For permanent P&A operations it is important that the barrier is verified in an eternal perspective.

Reflekt has reviewed the processes for qualification of PWC in AkerBP, ConocoPhillips and Equinor. The three companies have different strategies and approaches to the development, and use of PWC are influenced by their plans for P&A and slot recovery. These strategies have influenced the requirements for qualification and hence the scope of qualification is different in each company. All three companies have carried out a qualification process that is appropriate for the application of PWC in their respective operations. The qualification processes follow the recommendations in DNV-GL-RP-A203, are approved by the respective "technical authorities" in the three companies and are documented accordingly. The qualification processes also include demonstration of how to establish a 'track record' for each PWC application. All three companies have established clear criteria for the use of PWC and for the requirements for verification of the cement plug installed as a barrier or as part of the cross-sectional well barrier. The status of the technology with respect to API 17N Technology Readiness level definitions has also been noted.

A key factor in the qualification of PWC is the understanding of the limitations in its application and assessment of the requirements for drilling out and logging the cement plug to verify its integrity. One company has qualified PWC for use, however requires that the plugs are drilled out and logged irrespective of previous experience. Two companies have qualified PWC for use in specific casing sizes and configurations, with specific fluids (wash fluid, spacer, cement) and an established best practice for each application. This best practice reflects the 'track record'



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intention in NORSOK D-010. For applications with an established track record, drilling out and logging is not necessarily required to verify the integrity of the barrier. Deviation from the best practice or qualification matrix requires either a repetition of the operation (circulate out cement) or drilling out and logging of the annulus cement plug. For each application outside the limits established in the best practice a new qualification is required to verify the application, develop a qualification matrix and potentially allow for verification without drilling out and logging. This is important for the future application of PWC and for more extensive use in the industry. PWC therefore cannot be considered qualified on a general basis.

The history of PWC is well documented with information that is readily available. There has been a focus on information sharing within the industry, and particularly experience transfer and learning between the operators on the development and application of PWC. Reflekt's view is that PWC is a good example of what the petroleum industry can do if the participants, for example the operators, make a conscious effort to cooperate in the development of new technologies and methodologies. All three companies and the two service providers have contributed to this process through published materials including SPE papers and conference presentations.

# 3 Abbreviations

ABBREVIATION	FULL DESCRIPTION
ВНА	Bottom Hole Assembly
ВОР	Blow Out Preventor
CFD	Computational Fluid Dynamics
CRI	Cuttings, Re-Injection
P&A	Plug and Abandonment
PSA	Petroleum Safety Authority
PWC	Perforate, Wash and Cement
SME	Subject matter experts (technical authorities)
SPE	Society of Petroleum Engineers
TFA	Total Flow Area

# 4 Methodology for review

Reflekt organized initial meetings with the three operators to describe the review and to obtain an overview of the use of PWC in their respective operations. Follow up meetings were arranged to discuss the PWC methodology, its development and details of how it is applied in the different operations and the processes used by the companies to qualify the technology. The operators



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contributed with relevant information on PWC including SPE papers, conference presentations and qualification reports.

Reflekt has used DNVs recommend practice for technology qualification to assess the companies technology development and approval processes, Ref. 1. Reflekt has also reviewed the qualification against API 17N Technology Readiness level definitions, Ref. 2.

# Three factors that were important for the review:

- An assessment of what is the 'new' technology and/or methodology that will set the
  expectations to qualification. PWC as an application is 'new', however it uses some
  conventional technology, some established methodologies and in some cases the
  annulus cement plugs are verified using a conventional technique, i.e. drilling out and
  logging of the quality of cement behind the casing. Computational Fluid Dynamics (CFD)
  is used to optimize the design of the equipment and the operational parameters. While
  CFD is not new in itself, its application in PWC is considered 'new'.
- The understanding of the limitations of PWC and how the operators have created a 'track record' including an envelope with clear boundaries. The track record and envelope have to consider several variables including the casing configuration and sizes, well inclination, the fluid properties and the operational parameters, (drill string rotation rate, pull out speed, stand-pipe pressures, circulation rates, etc.).
- The verification of the annulus cement plug barrier and the requirement for drilling out and logging the annulus cement plug. This is also influenced by the type of PWC applied since the larger perforations used in the jet-type makes interpretation of the cement bond logging information more challenging. The verification by drilling out and logging demonstrates the technologies 'proven in the field' status. However, 'proven in the field' is for only a limited application where a track record including a qualification matrix has been established.

Reflekt has received and reviewed sufficient information to complete the review as specified by PSA.

# 5 Strategy

The companies have different strategies for PWC, mostly determined by their current and near future requirements for permanent plugging of wells. These strategies have influenced the technology development, verification of the well barriers and the drive for experience transfer/knowledge sharing and learning.

# 5.1 ConocoPhillips

ConocoPhillips recognized the potential for PWC for slot recovery and P&A for fields in the Ekofisk area. PWC has significant operational advantages over traditional section milling, including setting of balanced cement plugs. ConocoPhillips made a strategic decision to develop PWC together with the relevant contractors and has been a driver in the development of technological and operational aspects of both cup-type and jet-type. ConocoPhillips main focus is the jet-type due to the particular challenges with the wells in the Greater Ekofisk area, including casing deformation caused by subsidence and fluid losses to the formation.



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ConocoPhillips made a strategic decision to actively promote experience transfer and learning related to use of PWC. This decision had two main drivers:

- Assurance of the credibility of the PWC technology/methodology and its application in the petroleum industry.
- Encouragement in the use of PWC to extend the market and reduce the cost of the slot recovery and permanent plugging and abandonment of wells.

#### 5.2 AkerBP

AkerBP has also recognized the benefits of PWC for slot recovery and P&A and has used both the cup-type and jet-type. Most of the applications have been in the Valhall field where there are similar challenges to those experienced by ConocoPhillips in the Greater Ekofisk Area, hence it is mainly the jet-type that has been used. AkerBP has performed extensive CFD modelling to help optimize the PWC process, corroborate the field observations and confirm the robustness of the PWC process within the operating window that is defined. AkerBP is not involved in actively developing PWC since they are already close to what they see as the technical limit performance. AkerBP's strategy is to build on industry experience, mostly from ConocoPhillips, establish a 'track record' and to optimize the operational aspects of PWC. The main focus in AkerBP is following the established best practice for the casing configurations where PWC has been qualified and the quality of the application to provide assurance on the integrity of the barriers.

The original work on PWC was carried out by BP Norge and there was close cooperation with BP in the UK and US and their expertise with CFD. AkerBP has maintained contact with BP as a technical expert in CFD.

#### 5.3 Equinor

Equinor has used both types of PWC and has qualified both types for use within specified operating conditions. Equinor do not currently see a significant requirement for PWC and are therefore not actively pursuing its development and application. Equinor has not established a 'track record' for PWC so all cement plugs set are drilled out and logged to verify the barrier integrity. Based on post-PWC log results, the cup-type PWC is the preferred method. In the event that Equinor extends the use of PWC, including more extensive application of the jet-type, then Equinor intend to carry out further internal reviews in order to qualify the application, develop a 'track record' including a best practice and corresponding qualification matrix.

Equinor is aware of the PWC experience in ConocoPhillips and AkerBP and can build on this if and when the time comes for a more extensive use of PWC and in particular the jet-type.



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Technology Qualification

DNV standard DNVGL-RP-A203 is the standard appropriate for the qualification of PWC and is referenced in the PSA's Facilities Regulations § 9 Qualification and use of new technology and new methods. The technology process outlined in the standard can be summarised in figure 6.1.



Figure 6.1 Overview of the technology qualification process (DNVGL-RP-A203)

API 17N has Technology Readiness level definitions and describes what needs to be in place to achieve these and how the technology can then be applied, Ref. 2. See Appendix 2.

The three operators involved in this review have followed the general lines of the DNV standard. For the PWC technique, the drilling fluids, spacer and cement are existing technology, as are the perforating, jetting and cementing tools with some optimisations for the jet-type. The new technology is the application of the method of setting a cement plug behind a string of casing to form a barrier when plugging a well, either temporarily, or permanently. For PWC, CFD is used to model the behaviour of the fluids given the tools and parameters used, and this is a new application for existing technology.

The general verification criteria for cement plugs set by the PWC method are set out in NORSOK D-010 Well Integrity in drilling and well operations, Rev 5/2021 table 61, Ref. 3. The standard clearly states what is required to qualify the application of PWC for setting a cross-sectional cement plug as a well barrier to stop flow and refers to the DNV recommended practice, Ref. 1. The experience that ConocoPhillips and AkerBP have gained during the years of qualification and use of PWC indicate that the application of the technology in achieving a high quality barrier





needs to be strictly controlled. The quality assurance of the process is essential to achieve the required well barrier integrity.

All the companies have carried out qualification of the PWC methods that is appropriate for the application in their respective operations. All the companies have set limitations to the qualification and have described criteria for further qualification for both the application of PWC and the verification of the annulus cement plug barrier. All three companies recognize that qualification of PWC cannot be a general qualification for all potential cases or well configurations.

# 6.1 ConocoPhillips

ConocoPhillips started a qualification process in 2010 based on the development and application of the cup-type PWC [4]. ConocoPhillips has also had continuous development of the jet-type PWC culminating in a best practice for 9 5/8" and 10 <sup>3</sup>/4" casings from 2H 2017, Ref. 5. Drill-out and logging verifications were carried out in several wells and PWC jet-type was considered a fully-qualified abandonment technique on the condition that the best practice parameters were strictly followed. ConocoPhillips subject matter experts (SMEs) were involved in the qualification process. ConocoPhillips emphasizes that PWC is an example of a new method based on existing technology.

The ConocoPhillips qualification process emphasizes the need to build a 'track record' for each application and the limitations of the qualification process for that application. This means that significant changes require establishing a new track record. This will require drilling out and logging to verify the annulus cement plug integrity to gain confidence in the application and may require a revised best practice.

In 2018 ConocoPhillips initiated a process to document the history and development work on PWC, both cup-type and jet-type over the previous 10 years to support the qualification of the technology. The process was in accordance with ConocoPhillips governing documents. This work included the development of the best practice, the application of CFD and the verification of the method through drill out and logging. This work is contained in a single report that is acknowledged by the ConocoPhillips Global Drilling Chief. Reflekt has reviewed this report and is of the view that it demonstrates a thorough qualification of PWC within certain described limitations. The qualification process used by ConocoPhillips, is based on the main steps in the Technology Qualification Process described in DNV-RP-A203. PWC has been qualified in ConocoPhillips to a level equivalent to TRL 7 in API 17N, Ref.2.

# 6.2 AkerBP

AkerBP started the qualification process in 2013 through BP Norge. AkerBP has a process for technology qualification in their business management system that has been applied to PWC. The process follows the main steps in DNV-RP-A203 and states clearly the involvement of technical experts and the requirement for approval from the people that are technically responsible in AkerBP. AkerBP has actively involved the relevant technical experts and the equipment and technology providers in the qualification process. The qualification of PWC considers two key factors. Firstly, the design, construction and selection for the barriers installed with PWC method. Secondly, the qualification of the verification for PWC well barriers. AkerBP has developed a set of criteria for where PWC can be applied and has also developed a best practice for carrying out these operations. AkerBP has performed extensive CFD modelling to validate the criteria used to develop the Qualification Matrix and to test the robustness of the PWC process when operating within the envelope of the Qualification Matrix criteria. To this end



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AkerBP has limited the application of PWC to within certain conditions and parameters and has put in place strict quality control of the way the PWC operations are carried out. AkerBP has drilled out and logged several annulus cement plugs in different wells to verify the annulus cement plug barrier integrity to provide assurance on the application. As long as the operational parameters are confirmed for the application of PWC then drill out and log is not necessarily required. AkerBP drill out and log at least 10% of the cement plugs set by PWC as a quality control on the application. PWC has been qualified in AkerBP to a level equivalent to TRL 7 in API 17N, Ref. 2.

# 6.3 Equinor

Equinor started the PWC technology qualification process in 2015. Equinor has an internal process for technology development, TDI (Technology Development and Implementation). Two separate qualifications have been established for the cup-type and jet-type respectively. Both qualifications are at the 'Technology Readiness Level 4 (TRL4). Approval for TRL4 and TRL7 is from the Equinor Chief Engineers in Drilling and Well. There are two Chief Engineers that are involved in the approval process, Drilling Technology and Well Technology.

Equinor has not approved PWC for application and verification without drilling out and logging the annulus cement plug. Further internal work would be required here and no plans are in place to pursue this work since Equinor does not have a need for extensive use of PWC at this time. PWC has been qualified in Equinor to a level equivalent to TRL 4 in API 17N, Ref. 2.

### 7 Description of PWC

Permanently plugging and abandoning a well requires permanent barrier(s) to be set above each zone containing hydrocarbons and/or other fluids with over-pressure and/or flow potential. The barriers shall extend across the full cross section of the well and they shall be installed and tested with an eternal perspective, Ref. 3. PWC was developed as an alternative to section milling in situations where the wellbore barrier needs to be placed across a section of poorly cemented or uncemented casing. The three stages in the operation are perforating, washing and cementing and the PWC tools have been developed such that all stages can be integrated into one BHA and carried out in a single run. Section milling is time consuming and results in exposing the BOP to swarf from the milling operation that in turn can compromise the BOP operation. Handling of swarf on surface also presents safety and operational risks.

There are two types of PWC that are used, the cup-type and jet-type. The type used is dependent on several factors including the condition of the casing in the well to be plugged. In the cup-type the washing sequence uses swab cups to force the fluid through the perforations creating a high velocity fluid to clean the annulus. The wash tool is then positioned at the bottom perforation's depth and cement spacer is pumped between the swab cups, through the perforations and into the annulus, as the tool moves upward. Cementing is done over the swab cups or as a balanced plug/squeeze technique. In the jet-type, the washing and cementing is carried out through a large open area from perforations and high velocity jet nozzles on the washing tool before pumping cement.

The cup-type requires 'conventional' perforations that provide the 'nozzles' for the jetting of the fluids/cement behind the casing. Conventional perforations do not significantly interfere with interpretation of the cement bond logging information. The jet-type requires significantly larger perforations giving a greater total flow area (TFA) than the 'cup' type and required the development of special perforating guns. The larger casing perforations make interpretation of



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the cement bond logs more challenging, however the blank section from the gun connector will provide a short but undisturbed log response every 20 ft [6].

CFD is used for both jet-type and cup-type to optimize the design of the equipment and the operational parameters for carrying the work. The use of CFD is an important part of the PWC development and further information on this application can be found in published material [7].

The history of PWC is described in several publications including SPE papers and a detailed description of this history is therefore not included in this report. Appendix 1 has an overview of these papers for information and for follow up for anyone interested in the details.

### 8 Application of PWC

This section gives an overview of the operations with PWC in the respective companies.

#### 8.1 ConocoPhillips

ConocoPhillips has carried out more than 200 operations with PWC over a period of approximately 10 years, and will pass the 100 plug milestone for jet-type operations as per the Best Practice in Q4 2021. A significant number of cement plugs have been drilled out and logged either as part of establishing a track record or due to deviations from the best practice during execution.

There is a review process for each job and detailed analyses of jobs that have failed are carried out in order to understand and correct the causes of failure (DP washout, BHA integrity failure, twist off, other). There is good documentation and transparency of this work.

CFD has been used extensively since 2016 and ConocoPhillips has internal expertise in this area, and has established long term contracts with service providers. ConocoPhillips has given other operators access to their PWC CFD models and best practice on the condition that the results of any simulations and operations are made available. In this way ConocoPhillips maintains a good understanding of the success and failures of PWC operations carried out by other operators and is in a position to influence the perception of PWC in the industry.

ConocoPhillips also recognizes the limitations in the application of PWC and has continually emphasized this in published papers and in any dialogue with other operators that are considering its use. The company has participated in several SPE papers that describe in detail the PWC application and verification. This has contributed to the industry knowledge and understanding of PWC and its limitations. ConocoPhillips continues to develop the PWC methodology and stimulate the industry to develop the individual parts, for example the development of interpretation of cement bond log raw data to account for larger perforations and hence improve the verification of annulus cement plug integrity. ConocoPhillips can also see significant potential in PWC related to further development of fluids and fluid properties.

# 8.2 AkerBP

AkerBP has performed over 40 PWC operations over a period of approximately 7 years (initially as BP Norge, and then as AkerBP from 2017). AkerBP started with PWC in Norway using the cup-type. The initial PWC operation in a 9 5/8" casing was successful but proved to be a lot more challenging and time-consuming than originally anticipated, which is why AkerBP switched to the jet-type technique. AkerBP has since used the jet-type PWC in casing sizes up to and including



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11 <sup>3</sup>/<sub>4</sub>" and has had a focus on quality of operational and development of the qualification matrix in order to build up the track record. AkerBP has developed and documented a verification process to assure the quality of the PWC operation and acceptance of the integrity of the cement plug barrier [8]. AkerBP drilled out and logged about 50% of the cement plugs in the initial phase to verify their annulus integrity and zonal isolation. In the future AkerBP anticipate drilling out and logging at least 10% of the cement plugs set by PWC.

When part of BP, AkerBP used BP competence (SMEs) in cement bond logging for the interpretation of the logging data and advice on criteria for acceptance. AkerBP is still using BP as a SME in CFD.

### 8.3 Equinor

Up to 1<sup>st</sup> August 2021 Equinor has carried out 29 operations using PWC. Most of these have been performed in conjunction with slot recovery. Every PWC operation is verified by drilling out cement and logging the annulus cement plug. Over the past 3 years, only the cup-type has been used. There have been 9 PWC operations in this period, and all the operations have been successful.

Equinor uses internal log interpretation expertise for evaluating the cement bond logs. Log interpretation is more challenging in relation to jet-type applications due to the size and number of perforations.

Equinor has no major P&A campaigns planned that would be suitable for application of PWC, hence the technology or methodology is not a focus area for further development and application.

#### 9 Environmental Considerations

The main environmental consideration in P&A is the assurance of the integrity of the well barriers in an eternal perspective [3]. The integrity of the well barriers is best assured through the quality of the PWC application. This should be the paramount factor in any environmental assessment of the PWC operation. Leakage of hydrocarbons from abandoned wells is not acceptable neither environmentally nor economically. Re-entry to wells that have been plugged and abandoned is complicated and hence would result in a costly drilling operation or relief well drilling.

The wash and cement processes result in waste fluids being generated. There are alternative ways of disposing with these waste fluids and each well needs to be assessed individually. The following sections mainly covers the disposal of the waste fluids.

# 9.1 ConocoPhillips

ConocoPhillips recognizes that most future P&A operations will not have access to waste injection wells. ConocoPhillips has extensive experience in the assessment of disposal of waste fluids and has had correspondence with the authorities on potential discharges to sea. The assessment process used considers the following factors:

- Availability and suitability of any waste injection well (CRI)
- Analyses of the fluids that may be discharged. The wash and cement fluids are known and the key factor here is the potential volumes. The composition of the fluids behind the



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annulus is determined from well records and experience from previous wells. An overview of the chemical content of all fluids is therefore determined.

- Optimization of the operational procedures to minimize any discharge to sea
- Assessment of the total environmental impact for transport to an installation with a waste injection well or to shore for disposal.
- Estimate of volumes and chemical content of materials/fluids discharged to sea.

The suitability of a waste injection well includes an assessment of the required volumes and the injection well capacity. Injection wells have limited injection capacity and sidetracking of existing injection wells or drilling new injection wells is expensive.

### 9.2 AkerBP

AkerBP does not discharge any fluids to sea during the PWC operations. Excess cement pumped is normally left in the well and waste fluids are either injected in waste injection wells, or sent onshore for treatment and re-use.

AkerBP recognizes that the use of PWC in comparison with section milling results in lower emissions of  $CO_2$  since PWC is completed in less time. AkerBP also has a focus on deploying rig-less PWC that will result in further reductions in power requirements hence less  $CO_2$  emissions.

# 9.3 Equinor

Equinor does not inject or discharge fluids during the washing and cementing phases of PWC operations. Any residual fluids are treated as waste. Only waste with a chemical content and volume within the discharge permit are discharged. Any waste with traces of cement is not injected. Cement operations are included in the existing discharge permit, however PWC is not specifically mentioned. If there is no/little information on the composition of the waste, then the fluid is sent to shore for destruction or disposal.

### 10 Discussion

Reflekt has identified three factors that are key to the use and further development of PWC and are repeated from the text of the report to emphasize their importance.

#### 10.1 Experience Transfer and Learning

The development and application of PWC has been accompanied with a willingness by the operators and service providers to share experience and learn from each other. Detailed descriptions of application, verification and qualification of PWC have been presented at conferences and forums and been the subject of published technical papers and articles. The advantages, limitations and potential of PWC have been covered, and any operator that is considering the use of PWC for P&A and/or slot recovery has a good basis for getting started.

The experience transfer and learning demonstrated in PWC application and development has benefitted the operators using PWC and stands to significantly benefit other operators in the future. Operators should consider what other areas could benefit from this level of experience transfer and learning.

One of the concerns on sharing of best practices is that operators inexperienced with PWC and the application of NORSOK D-010 may assume that they have to do no work for their own qualification under their specific conditions.



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# 10.2 Application of NORSOK D-010

PWC is specifically covered in the 2021 version of NORSOK D-010 and a table for acceptance criteria for a PWC cement plug has been included, EAC Table 61. The description of the application of PWC and the verification of the cement plug reflect the ConocoPhillips and AkerBP experience. NORSOK D-010 emphasizes the limitations of the application of PWC and the importance of establishing a track record of success before cement plugs can be verified without drilling out and logging. NORSOK D-010 also references the use of DNV-GL-RP-A203 process to establish the track record and qualify different applications and different casing configurations and well designs.

NORSOK D-010 emphasizes the importance of establishing a best practice and a qualification matrix for PWC applications. In the event that the PWC operation is not carried out in accordance with the best practice then the cement plug shall be drilled out and cement bond logging shall be performed.

# 10.3 Further development of PWC

PWC has a potential to be used for rigless P&A through running the operation on coiled tubing. This could lead to significant cost reductions and more flexibility in P&A operations. There are however technical barriers that must be overcome to compensate for gun and BHA size, reduced flow capacity and lack of rotation which is inherent in a through tubing approach and or coil tubing spread. There is a lot of work currently being performed to model with CFD, and develop the coiled tubing version of PWC. A full test of PWC with coiled tubing was performed during the summer at Ullrig in Stavanger.

Improvements in cement bond interpretation of quality of cement with large perforations continue to give greater assurance of cement plug quality for the jet-type PWC and provide better verification information for establishing a track record. Specific processing techniques for PWC have been developed that compensate for signal loss due to the larger holes. As long as the perforation size is within the acceptable range then a high degree of confidence can be attributed to the logging results.

Developments in fluid technology can also potentially improve the efficiency of the PWC operation.

PWC could be developed to cover other casing configurations and well designs extending the application of the technology for both P&A and slot recovery.



# 11 References

Number	Title	
1.	DNV-RP-A203 Technology Qualification	Referenced in Facilities Regulations § 9 Qualification and use of new technology and new methods
2.	API 17N Subsea Production System Reliability, Technical Risk, and Integrity Management, Second Edition	
3.	NORSOK D-010:2021 Rev 5.	
4.	Novel Approach to More Effective Plug and Abandonment Cementing Techniques, SPE 148640	ConocoPhillips et al
5.	Best Practice for Cementing and Zonal Isolation Using the Jet-Type Perforate, Wash and Cement Technique SPE-202397-MS Published 12 <sup>th</sup> November 2020	ConocoPhillips
6.	Presentation – Cement Evaluation PWC (Perforate Wash & Cement)	Schlumberger
7.	Application of Computational Fluid Dynamics for Parametric Optimization of Jet-Type P/W/C Technique, SPE-202441-MS Published 12 <sup>th</sup> November 2020	ConocoPhillips Et al
8.	Perforate, Wash and Cement PWC Verification Process and an Industry Standard for Barrier Acceptance Criteria SPE-185938- MS Presented 5 <sup>th</sup> April 2017	AkerBP/Statoil (Equinor)



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# Appendix 1 List of Relevant Published Information

Forum	Title	Company
Presentation PACE meeting 15 <sup>th</sup> April 2021	Improving efficiency of jet-type P/W/C technique through application of CFD	ConocoPhillips
SPE-202441-MS Published 12 <sup>th</sup> November 2020	Application of Computational Fluid Dynamics for Parametric Optimization of Jet-Type P/W/C Technique	ConocoPhillips Et al
SPE-202397-MS Published 12 <sup>th</sup> November 2020	Best Practice for Cementing and Zonal Isolation Using the Jet-Type Perforate, Wash and Cement Technique	ConocoPhillips
SPE 148640 October 2011	Novel Approach to More Effective Plug and Abandonment Cementing Techniques	ConocoPhillips et al
Presentation DEA October 2014	Annulus plug update	ConocoPhillips
Presentation PAF October 2014	Annulus plug update	ConocoPhillips
Presentation October 2017	Fluid dynamics & casing design induces limitations for P&A operations	MI-Swaco (Schlumberger)
SPE Technology Focus	Cementing/Zonal Isolation	Schlumberger
Presentation	Cement Evaluation PWC (Perforate Wash & Cement)	Schlumberger
SPE-185938-MS Presented 5 <sup>th</sup> April 2017	Perforate, Wash and Cement PWC Verification Process and an Industry Standard for Barrier Acceptance Criteria	AkerBP/Statoil (Equinor)
SPE 191335 Presented 31 <sup>st</sup> May 2019	Evaluating Cement-Plug Mechanical and Hydraulic Integrity	AkerBP et al
SPE-200739-MS	Materials for Well Integrity – Short-term Mechanical Properties of Cement Systems	AkerBP et al
SPE-191528-MS Presented 24 <sup>th</sup> September 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	Archer et al
SPE 189580 March 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	Schlumberger
SPE 193945 December 2018	Perforate Wash and Cement for Large Casing Sizes	AkerBP and Archer et al



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# Appendix 2 Technology Readiness Level Definition – API 17N

Technology Readiness Level	Description
TRL 0	Unproven idea/proposal Paper concept. No analysis or testing has been performed
TRL 1	Concept demonstrated. Basic functionality demonstrated by analysis, reference to features shared with existing technology or through testing on individual subcomponents/subsystems. Shall show that the technology is likely to meet specified objectives with additional testing
TRL 2	Concept validated. Concept design or novel features of design validated through model or small scale testing in laboratory environment. Shall show that the technology can meet specified acceptance criteria with additional testing
TRL 3	New technology tested. Prototype built and functionality demonstrated through testing over a limited range of operating conditions. These tests can be done on a scaled version if scalable
TRL 4	Technology qualified for first use. Full-scale prototype built and technology qualified through testing in intended environment, simulated or actual. The new hardware is now ready for first use
TRL 5	Technology integration tested. Full-scale prototype built and integrated into intended operating system with full interface and functionality tests
TRL 6	Technology installed. Full-scale prototype built and integrated into intended operating system with full interface and functionality test program in intended environment. The technology has shown acceptable performance and reliability over a period of time
TRL 7	Proven technology integrated into intended operating system. The technology has successfully operated with acceptable performance and reliability within the predefined criteria