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Public Summary Report

TKI2021-06-GE Field Pilot P&A Using Bentonite

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TKI2021-06-GE Field Pilot P&A Using Bentonite

Public Summary Report

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Contents

1 Introduction

Hundreds of existing wells and new wells, planned for the production of sustainable energy in the Netherlands and necessary to achieve the goal of minimal 15PJ geothermal exploitation in 20301, will undergo P&A in the future. Durable and cost-efficient solutions for annular sealing and well plugging can save billions of predicted P&A costs and will strongly contribute to the economic competitiveness of promising sustainable geo energy options, like CCUS, geothermal energy or gas and energy storage2.

Within the existing geo energy sector in the Netherlands a consortium of operators and a salt production company, together with TNO as coordinator, initiated a research program in 2014 to investigate the use of natural sealing materials for deep wellbore sealing to restore the initial caprock with wireline or gravitational methods. The program "Natural formation sealing" (NFS) runs under the TKI Geo energy Theme Decommissioning & Abandonment. The aim of this program is to develop solutions that can provide long-term containment and cost-effective options for sustainable future re-use of existing wells and for final plug and abandonment of wells required for sustainable geo energy provision. The general concept of natural formation sealing (NFS) is illustrated in Figure 1.

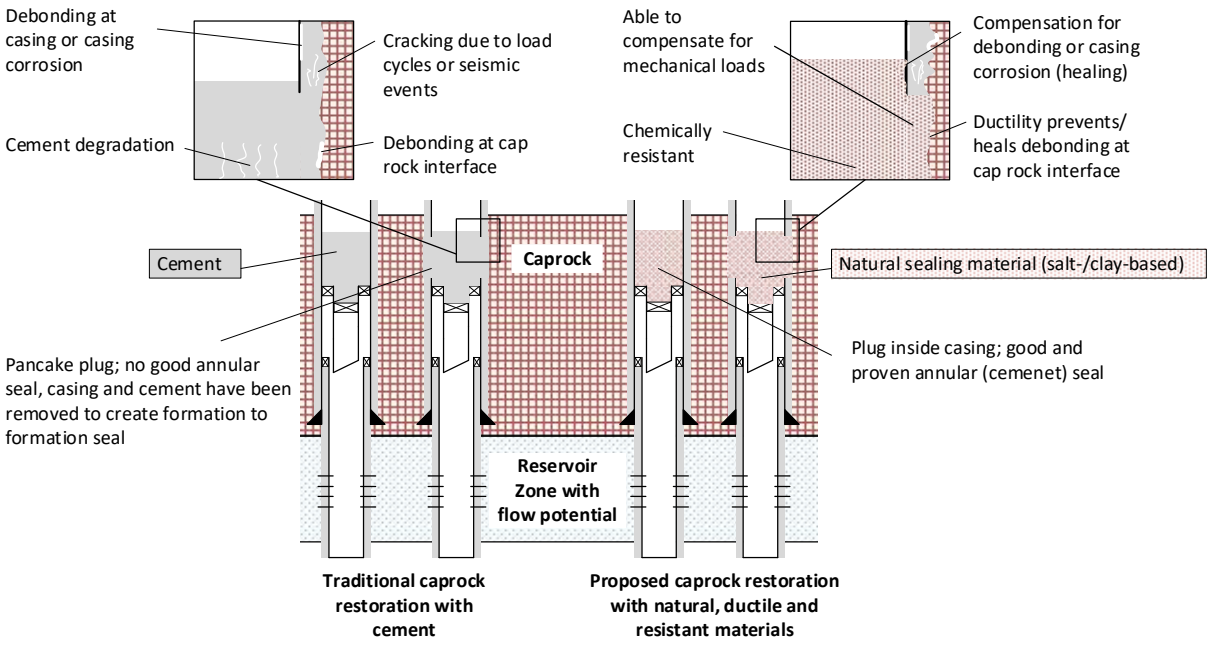

Figure 1 - The concept of natural formation sealing with and without milled-out casing: Schematic comparing properties of salt- and clay-based sealing materials (right) with conventional cement-based materials (left).

The R&D program Natural Formation Sealing has investigated the functional bentonite sealing performance in the light of the P&A application for geo energy wells using cost-efficient wireline or gravitational options to place the plug. Bentonites are natural, swellable

[1] EBN, DAGO, Platform Geothermie, (2018): Masterplan Aardwarmte Nederland
[2] Nexstep Re-use and decommissioning rapport, 2019 (link)

clays (mostly smectites) which are chemically stable, ductile and highly impermeable under downhole conditions[4]. Following feasibility studies[3,4], successful small[5] and large-scale[6] lab tests, as well as full-scale rig-test[7] in previous years, the logical final step for the program is to conduct a P&A field trial as final step of this program line before operators can perform necessary qualification and pilot testing of this sealing technology as final demonstration to the regulator(s).

Natural caprocks have been proven to effectively seal and trap pressurized hydrocarbon gas and (acid) fluids in the deep subsurface for millions of years[8]. The engineered well construction, essential to provide hydrocarbons or sustainable geo energy, presents a potential leak path through the initially impermeable natural caprock barrier and requires to be sealed during operations and beyond. In recent years, studies on safe and durable P&A options identified bentonite as a promising material for deep wellbore sealing[9]. The advantages of using natural downhole materials over cement are their long-term sealing capacities, their stability and equal or even lower permeabilities compared to cement[10]. Recent P&A industry practices explicitly allow alternative sealing materials to cement, such as bentonite, if they perform as good or better compared to the standard sealing material[10]. Unlike cement[11], the conventional sealing material of choice, natural downhole material like bentonite is ductile, self-healing and chemical stable under (acidic) downhole conditions and is considered more cost-efficient[12], which can result in costs-savings of up to 70% compared to conventional P&A operations if placed rig-less[13].

Clay-based materials, such as bentonites, have been used as sealing materials for decades for shallow subsurface applications such as storage of radioactive wastes[14,15] or to seal water wells[16]. Lately bentonite gained more and more attention in the oil and gas industry

[3] H. Fischer, B. Orlic, K. Geel, P. Pipilikaki, J. Wollenweber (2016) The phenomena of the ductile properties of shales and salts. TKI Plugging wells by enhanced formation ductility – Deliverable report D3.1 TNO 2016 R11749
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[5] P. Hopmans, H. Fischer, J. Wollenweber (2019). Results of small-scale bentonite well sealing experiments. TKI Using Bentonites for zonal isolation and well abandonment, deliverable report D1.1, TNO 2019 R10162
[6] C.J.K. Castelein, P. Hopmans, H. R. Fischer, J. Wollenweber (2019). Results of large-scale bentonite well sealing experiments. TKI Using Bentonites for zonal isolation and well abandonment, deliverable report D1.2 TNO 2019 R10813
[7] C.J.K. Castelein et al. (in prep.). Full-scale and well testing of bentonite sealing properties for plugging O&G wells. TKI Natural Sealing Research and Test Well. Deliverable report D4.1 (in prep.).
[8] Vincent Vandeweijer, Bert van der Meer, Cor Hofstee, Frans Mulders, Daan D'Hoore, Hilbrand Graven, "Monitoring the CO2 injection site: K12-B," *Energy Procedia*, vol. 4, pp. 5471–5478, 2011
[9] Towler, B. F., Firouzi, M., Mortezapour, A., Hywel-Evans, P.D. (2015): Plugging CSG Wells with Bentonite, Review and Preliminary lab Results, SPE 176987 (2015)
[10] NOGEPA 45 Well decommissioning/het buiten gebruik stellen van putten (link)
[11] Bachu S and Bennion DB. Experimental assessment of brine and/or CO_2 leakage through well cement at reservoir conditions. International Journal of Greenhouse Gas Control 2009; 3, 494-501
[12] Clark, J. and Salbury, B. (2003) Well abandonment using Highly compressed sodium bentonite, an Australian Case Study. SPE 80592
[13] P. Hopmans and J. Wollenweber (2018). Business case for using bentonite for O&G wellbore sealing. TKI Using bentonites for zonal isolation and well abandonment, deliverable report D3.1, TNO 2018 R11235
[14] Le Seine Saint-Germain Organisation for Economic Co-Operation and Development - Nuclear Energy Agency - OECD/NEA 12 boulevard des Iles, F-92130 Issy-les-Moulineaux (France), *Self-sealing of Fractures in Argillaceous Formations in the Context of Geological Disposal of Radioactive Waste*. Nuclear Energy Agency of the OECD (NEA): Organisation for Economic Co-Operation and Development - Nuclear Energy Agency, 2010
[15] R. Pusch, "Use of bentonite for isolation of radioactive waste products," *Clay Minerals*, vol. 27, no. 03, pp. 353–361, Sep. 1992
[16] B. F. Towler et al. (2008). Plugging wells with hydrated Bontine, part 2: Bentonitne bars. SPE-115524

for well abandonment of e.g. coalbed methane wells down to ~1500 m[17,18] but has not been investigated sufficiently for well sealing and P&A of deeper geo energy wells which would be representative for the Netherlands or the North Sea. Verification is required at relevant conditions for Dutch hydrocarbon, CO_2 storage, deep geothermal or energy storage wells with respect to pressure, temperature, salinity and present well/P&A fluids, applying recently developed, specialized placement techniques, tailored to the use at deeper depths, such as coated pellets, preventing premature swelling of the bentonite[7,8,19].

Therefore, the crucial next step for the implementation of this alternative sealing methodology is to test plugs set by newly developed placement technologies for the deep subsurface (i.e. coated pellets) and investigate the performance at depths of 1500 m and deeper under (hydrostatic) conditions relevant for the geo energy sector and validate the operational feasibility.

[17] B. F. Towler, M. Firouzi, H.G. Holl, R. Gandhi, A, Thomas (2016). "Field trials of plugging oil and gas wells with hydrated bentonite," presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, SPE-182199
[18] A. Mortezapour, "Plugging Coal Seam Gas Wells with Bentonite," The University of Queensland, Queensland, 2017
[19] P. Hopmans, H. Fischer, J. Wollenweber, K. Castelein (2020). Design Options for coatings to retard bentonite pellets swelling for placement and plugging of wellbores. TKI Encapsulation of bentonite pellets for controlled downhole placement and sealing, Deliverable report D5.2, TNO 2019 R11966

2 Scope

The overall goal of the project is to create a "downhole field lab" at ~2000 meters to conduct the essential testing with hydrostatic pressure, real downhole fluids and elevated temperature to validate the sealing performance of bentonite as barrier material for well sealing and plugging at operational conditions.

The presented approach including the development of dedicated placement technologies for bentonite placement at 1500 m is, to our knowledge, unique in the world. The main project result is a downhole placed and tested bentonite plug with a verified performance under actual hydrostatic and chemical conditions in relevant operational environments of ~2000m depths (TRL 6). This is the essential step to develop a new, innovative sealing and placement product for deep wellbores before the operators can apply this technology as a real P&A plug or actual zonal isolation in follow-up pilot projects (TRL 7-9).

A field trial using O&G infrastructure currently in use is extremely difficult to organize for obvious reasons such as timing, costs and liability arrangements. Therefore, the consortium is very pleased to have established the opportunity to conduct a research field trial in a typical Dutch onshore gas well (operated by NAM). This well is plugged for abandonment and, after subsurface abandonment is completed, the project installs (additional) bentonite plug(s) at relevant depth of ca. 1500 m and test the plug properties according to Dutch Mining Law requirements.

The specific activities in this project consist of design and preparatory (de-risking) activities of the proposed field trial, which is the central element in this project. After field trial execution the bentonite plug is evaluated and a finite element model is developed to forecast plug performance.

3 Methodology

This project applies a phased approach with three main phases: 1) Field test preparation, 2) Field test execution and 3) Detailed plug sample analysis, lab tests and modelling, as indicated in Figure 2.

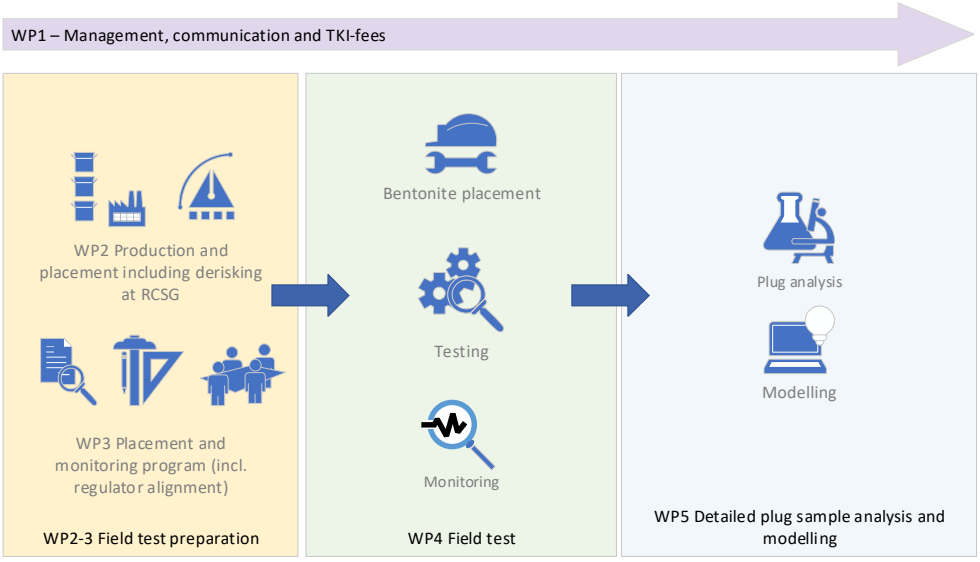

Figure 2 Project structure, including work packages and interconnections.

Key activities of this project comprise:

- Small and/or large-scale experiments specifically dedicated to de-risk the execution of the field trial, based on latest details of the exact well design and how the well is left by NAM (e.g. top of cement and fluid type in the well);
- Validation of placement concepts, incl. coating options, to ensure good plug performance;
- The final verification of a test and monitoring concept for the downhole sealing test based on the detailed preparation and planning provided in this proposal;
- The actual conduction of the field trial using the developed coated-bentonite pellets "STARNITE": placement, pressure testing of the plug including retrieving an aliquot for inspection in the lab;
- Microscopic (CT-scan), petrophysical evaluation, and/or density evaluations of the retrieved sample martial in the lab to confirm the sealing properties of the placed, hydrated bentonite plug;
- Confirmation of the plug height from the tagging operation in the well through stacking experiment
- To validate numerical models for bentonite plug performance prediction supported by testing and specifying petrophysical model input parameters, such as swelling pressure and elastic moduli
- Communication to other national and international research groups, companies, policy makers and stakeholders to facilitate a near-future application of the technology.
- Establish a working window of ion components' concentrations & combinations within the curing fluid to generate a good quality bentonite plug

4 Main results and key messages

Overall, it can be concluded that the project created successfully a proper bentonite plug at the intended depth of ~1500 m which was verified in accordance to the Dutch Mining Law requirements. The design and operational program could serve as blue-prints for future projects. As a result of this project there are two manufacturers that, together, can deliver sufficient quantities of STARNITE with the required quality. They have indicated that they are also open for further development of the manufacturing process. Lastly, the placement method that was used to place the bentonite into the well in a controlled way proofed viable under operational conditions. By nature of the field trial design the full plug quality cannot be completely validated. However, by means of tagging and sampling a detailed impression of the plug quality could be derived, which provides positive indications on the plugging and sealing capacity of the created plug (Figure 3).

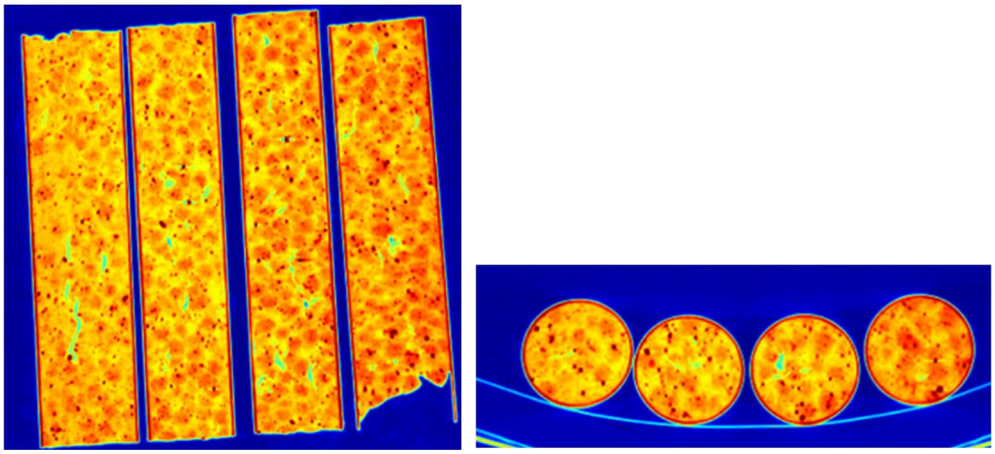

Figure 3. CT scan sections of the 2m plug sample retrieved by the developed tagging/sampling tool indicating good sealing capacity without interconnected pore space or conduits. Left shows longitudinal sections increasing in depth. Right shows cross sections increasing in depth from left to right. Blue represents low density and red represents high density.

By experimental work the potential working window for bentonite plugs could be further constrained and indicates that proper plugs can be placed in a wide range of fluid compositions and salinities (up to sea water level). The results give a good indication of favourable or rather unsuitable fluid conditions to ensure a proper sealing performance of a STARNITE plug. Case-specific safety margins should be elaborated and applied until these findings could be validated in future field trial and pilot projects.

The numerical model together with empirical evaluations based on tests performed in the program provide an additional approach for the estimation of the potential sealing capacity of bentonite and STARNITE plugs under certain downhole conditions.

For future field trials and bentonite plug implementation, TNO recommends the following points:

- The density analysis from both manual measurement and CT-scan and mechanical analysis from UCS tests are suggested to be included as accompanying plug evaluation methods in the bentonite abandonment program. These analyses are highly reliable and generate valuable information regarding the quality of the plug.
- The new insights on the working window for bentonite plugs and the predictive methods should support the decision making in plug design and selection of hydration fluid properties by the operators to ensure the required plug sealing capacity (such as length of plug, type of fluids and quantity and type of bentonite pellets needed).

5 Contribution to the objectives of the TKI New Gas Program Line

The project contributes to providing unique data and technology to use natural sealing materials to plug and abandon wells, which is an essential topic of the TKI New Gas program line for Geoenergy. In addition, it is relevant for both hydrocarbon and sustainable geoenergy operations (such as geothermal or energy storage). Materials that are comparable to the composition of the cap rocks in the subsurface, for example based on salt and/or clay, could be an alternative to cement. These materials have some properties that are very favorable for a permanent seal, such as very low permeability and plastic behavior. In addition, they are natural materials that already occur in the subsurface. This project focuses on the application of bentonite and thus helps to achieve specific objectives of the research theme Decommissioning and Abandonment of the program line, in particular:

Minimize the negative effects of gas extraction on the environment and economy
Reuse of existing infrastructure and integration with other energy activities in the North Sea.
Development of sustainable and cost-efficient methods and techniques with regard to integrity and condition monitoring (pipelines, wells, installations); closing wells, platforms and finding useful uses (decommissioning);
Safety, reliability and integrity (offshore installations and pipelines).

Sealing deep wells with natural materials is cheaper and requires significantly less efforts and energy. In addition, the principle is much more sustainable than using artificial materials, reducing both the costs of dismantling and the associated CO_2 emissions. Methane is a significant greenhouse gas (more than 20 times the effect of CO_2), making any methane emissions from abandoned boreholes a point of concern. Effective sealing of boreholes therefore makes a direct contribution to reducing greenhouse gas emissions and protecting the environment. The use of natural materials as an alternative to or in addition to cement could contribute to this.

Restoring the initial seal layer and using natural sealing materials, such as salt and clay, offers a unique combination of benefits: minimizing the industry's environmental footprint while at the same time increasing long-term safety through the use of proven natural sustainable materials and this at lower costs. The project findings therefore contribute to the roadmap of the TKI New Gas Geo-energy program line and to the overarching objectives of the subsidy scheme of the Ministry of Economic Affairs and Climate.

The innovative approach developed in this project, and in other linked research as part of the research theme “Decommissioning and Abandonment”, delivers a unique competitive advantage for national operators and service companies. In addition, it reduces the likelihood of unforeseen and expensive future intervention operations, including possible negative environmental consequences due to leakage.

6 Follow-up, spin off within and outside the sector

The project demonstrated the operational feasibility to place a bentonite plug in a deep wellbore, rig-less by gravitation without any heavy machinery, and can form an impermeable, durable long-term barrier according to regulatory requirements. The applied STARNITE product presents a first-viable-product which can be further tested and demonstrated in future field trials and pilot projects by the operators.

The next step towards wide implementation is to perform a technology qualification process to enable the acceptance of bentonite/STARNITE as plug and abandonment material by the national regulator, State Supervision of Mines (SoDM) which have been informed regularly about the progress and results of the program. A Joint-Industry Project is currently being prepared by the consortium partners.

Parts of the results of this project have been presented at the SPE Transatlantic Virtual Workshop " Onshore Plugging and Abandonment" (24-26 January 2023) and outcomes from full-scale testing of previous projects have been published in the journal " Rock Mechanics and Rock Engineering" (Corina et al., 2022)[20].

For more information on the program and its achievements please contact the secretary of TNO's Applied Geosciences Group at secretary-ags@tno.nl.

[20] Corina, A.N., Wollenweber, J., Fischer, H., van der Valk, K., Castelein, K., Moghadam, A., Heerens, G-J. - *Evaluation of Bentonite Application for the Abandonment of Deep Geo-energy Wells*, Rock Mech Rock Eng (2022)

7 Acknowledgements

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Signature

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