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TNO report

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Final Report – TKI Encapsulation of bentonite pellets for controlled downhole placement and sealing

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1 Project information

Subsidy reference: TKI2018-06-GE

Topsector Energy, TKI Nieuw Gas:

Program line Geo Energy – Decommissioning and Abandonment

Project duration:

May 1st, 2018 – November 1st, 2019

Project partners:

TNO (coordinator), EBN, Total, Shell, Oranje Nassau Energie, Neptune, Nouryon

2 Technical reporting

2.1 Management Summary

The total inheritance costs for P&A of existing and future wellbores will be tens of billions worldwide and a few billion Euros for the Netherlands alone. Future P&A costs will impact the current economic feasibility of small field development which is a threat for the success of small field policy in the Netherlands. Durable and more economic P&A solutions would have a beneficial impact on the feasibility and economic competitiveness of O&G but also promising sustainable geo-energy options, such as geothermal energy or gas storage. |

Lately, research focusing on safe and durable P&A options identified bentonite as a promising seal for O&G wellbores.

Although bentonite well plugging is a common practice in other domains, like water wells and nuclear waste disposal and its application for O&G has been demonstrated in the field, innovations with respect to placement, i.e. delaying the swelling by coatings or tailored wellbore fluids which could retard the swelling are required for an implementation of this technology.

The project goal was to demonstrate the feasibility to control the start and progress of bentonite swelling by encapsulation of bentonite pellets with a polymer coating. It aimed at developing a coating for bentonite pellets, a coating method and defined placement options to create a natural wellbore plug for depths of at least 2000 meters.

The operational framework was defined, and relevant patent and scientific papers were reviewed. Based on this an experimental plan was established to develop an approach for coating bentonites and to choose a proper coating material.

The required delay for the swelling of bentonite pellets while using placement by gravitation is about 2-3 hours for a target depth of 2500m based on gravitation tests with different pellet shapes and at different temperatures. This delay can be achieved by the application of the investigated coatings materials and coating methods. An effective bentonite plug can be created at depth by gravitation method and use of polymer coated bentonite pellets to control the placement and hydration process. A placement using a bio-degradable oil to provide hydrophobic protection during placement was successful and is a placement option to consider, especially for highly deviated wells where gravitation is not an option. Different bentonite types and coating types combined with reactive additives may offer solutions for specific placement conditions, controlling hydration rates and plug density.

““Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.”

2.2 Introduction, motivation and scope

The total inheritance costs for P&A of existing and future wellbores will be tens of billions worldwide and a few billion Euros for the Netherlands alone¹. Future P&A costs will impact the current economic feasibility of small field development which is a threat for the success of small field policy in the Netherlands. Durable and more economic P&A solutions would have a beneficial impact on the feasibility and economic competitiveness of O&G but also promising sustainable geo-energy options, such as geothermal energy or gas storage. It is of utmost importance to lower the costs related to P&A operations without compromising on safety to ensure the long-term sealing performance of well barriers.

Lately, research focusing on safe and durable P&A options identified bentonite as a promising seal for O&G wellbores^{2,3,4}. The advantages of using natural downhole materials over cement are their long-term sealing capacities and their stability under downhole conditions.

Bentonites are natural, swellable clays (mostly smectites) which are chemically stable, ductile and highly impermeable under downhole conditions. They have been used for sealing water wells for decades. Their ability to seal (deep) oil and gas wellbores is currently being investigated and provides a promising opportunity for low-costs but durable long-term wellbore sealing⁵. More than a decade ago the first promising field tests in Australia for sealing coal-bed methane wells were already performed up to 1500m⁶, but to date, bentonites have never been broadly applied in deeper O&G well plugging operations.

The downhole placement of bentonite is generally expected to require less expensive placement equipment, lower material costs and monitoring⁵. However, when placing swelling clays downhole the immediate swelling of this material as soon as it gets in contacts with water must be prevented to avoid bridging and to ensure a proper placement and functionality of the plug.

Although bentonite plugging is a common practice in other domains, like water wells and nuclear waste disposal and its application for O&G has been demonstrated in the field, innovations with respect to placement, i.e. delaying the swelling by coatings or tailored wellbore fluids which could retard the swelling are required for an implementation of this technology.

¹<https://www.nexstep.nl/wp-content/uploads/2018/07/Re-use-decommissioning-report-2018-English-Version.pdf>

² Towler, B. F., Firouzi, M., Mortezaipoor, A., Hywel-Evans, P.D. (2015): Plugging CSG Wells with Bentonite, Review and Preliminary lab Results, SPE 176987 (2015)

³ H. Fischer, B. Orlic, S. Osinga, P. Hopmans, J. Wollenweber, K. Geel, "Options to initiate and enhance ductile properties of shale for well bore sealing," TNO, "TKI Plugging wells by enhanced formation ductility" - Deliverable report D5.1, TNO report R10970, 2016

⁴ 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

⁵ Hopmans, P. and Wollenweber, J. (2018). TKI Project "Using bentonites for zonal isolation and well abandonment" – Deliverable D3.1 Business case for using bentonite for O&G wellbore sealing, TNO 2018 R11235

⁶ Clark, J. & B. Salisbury, 2003. Well Abandonment using highly compressed Sodium Bentonite – An Australian case study. SPE Paper 80592

The project goal was to demonstrate the feasibility to control the start and progress of bentonite swelling by encapsulation of bentonite pellets with a polymer coating. It aimed at developing a coating for bentonite pellets, a coating method and defined placement options to create a natural wellbore plug for depths of at least 2000 meters

Therefore, this study focussed on the following research questions:

- What are the chemical and operational requirements for a bentonite coating?
- Which candidate bio-organic polymers and synthetic polymers are available and affordable?
- What dissolvment properties do the polymer materials have in the well bore fluids at wellbore temperatures?
- Is the resistance to flow induced wear sufficient to facilitate downhole pumping through tubing?
- Is encapsulation sufficient or are other additives required to control the swelling timing?
- How can wellbore fluid properties support the prevention of instantaneous swelling of bentonites?
- How can the coating be placed on the pellets in a simple but effective manner?

2.3 Project structure and execution

To answer the research questions mentioned above four key activities have been conducted:

1. Define the chemical, environmental and operational constrains of the coating
2. Definition of the test plan for coating dissolvment and resistance to flow induced deterioration
3. Build and prepare test equipment to test retardation behavior and resistance of the coating
4. Experimental testing

The project had a duration of 18 months and was conducted from May 1st 2018 to November 1st 2019 together with the industry partners EBN, Shell, Total, Nouryon, Neptune and Oranje Nassau Energie.

During the project no major problems occur, However the original project duration had to be extended due to organizational reasons for six months in agreement with the partners and TKI. Nouryon replaced their in-kind research contribution by cash payment. The overall project budget or scope was not affected. Deliverables have been submitted on time at the agreed dates.

2.4 Results and conclusions

A brief summary on the key-messages of the project is given in the following. Within the project 3 separated technical deliverable reports have been compiled which provide further technical details on each topic.

2.4.1 Operational requirements and coating options

The operational framework is defined by downhole conditions of a typical Dutch gas well. They do not differ from general boundary conditions for O&G wellbore plugging and depend on:

- Geological field conditions and downhole fluids
- Plugging depth, and with that pressure and temperature
- Travel/gravitation time, i.e. duration of resistivity 2-3 hours based on gravity tests performed for ~2500m depth

We defined relevant test conditions. See also Hopmans et al. (2019)⁴:

- Representative for 2000-2500 m depths (~200 bars)
- Temperatures up to 80°C
- Typical downhole fluids such as API brine, but also composition representative for NL
- Density of the plug need to be larger than 1.5 g/cm³ to perform according to the requirements for a seal for abandonment of oil and gas wells⁷

Various potential placement methods have been identified for placing bentonites with gravitation and squeezing through perforations being the most preferable ones.

A literature survey did not reveal any studies investigating the coating options for bentonite pellets for deep wellbore plugging at around 2000-2500m. Several relevant patents could be identified^{8, 9, 10, 11}. For details and more information please refer to Hopmans et al. (2019)¹². Especially the US 5476543 describes a coated pellet as envisaged in this study. Since the patent was already filed in 1994, there is no restriction in using this technology.

A survey of patents for potential bentonite coating procedures and technologies revealed several options that could be applied with Basu et al. (2013)¹³ being of most importance describing various technologies for the application of the coating on a tablet or pellet surface.

Based on the surveys the following coating techniques have been reviewed for suitability and coating selection process was developed (Figure 1):

⁷ Castelein, K., Hopmans, P., Van der Valk, K., Fischer, H. and Wollenweber, J. "Results of large-scale bentonite well sealing experiments," TKI Project Using bentonites for zonal isolation and well abandonment, project report D1.2, TNO 2019 R10813

⁸ Burts, B.D. et al. (2008). Downhole mixing of encapsulated plug components for abandoning a well, US7409990B1, <https://patents.google.com/patent/US7409990B1/en>.

⁹ James M.C. and James M.L. (1998). Drill hole plugging method utilizing sodium bentonite nodules. US5810085A, <https://patents.google.com/patent/US5810085A/en>

¹⁰ Robert G. Ryan (1994). Environmental Safe Well Plugging Composition, US 5476543 (1994)

¹¹ Schoenmakers, J.M.M. (2017) Plugging to-be-abandoned wellbores in the earth. EP3196402A1 <https://patents.google.com/patent/EP3196402A1/it>

¹² P. Hopmans, H. Fischer, J. Wollenweber, 2019. D2.1 An inventory of the current knowledge on coating options and operational requirements. TKI Geoenergy - Encapsulation of bentonite pellets for controlled downhole placement and sealing, TNO report TNO2019 R10719

¹³ Basu, A., De, A., Dey, S. (2013). Techniques of Tablet Coating: Concepts and Advancements: A Comprehensive Review. RRJPPS, Volume 2, Issue 4, October-December, 2013 <http://www.rroj.com/open-access/techniques-of-tablet-coating-concepts-and-advancements-a-comprehensive-review-1-6.pdf>

The developed selection process which was followed for the testing is illustrated in Figure 1, defining the potential coating material, the coating process, test condition, effectiveness, and coating cost. In discussion with manufacturers and confectioners of chemicals, organic film coating has been found to be the best starting process. Consequently, the two most promising organic film coating technologies have been identified: fluid bed coating and drum coating, both were tested.

It became evident, that the material of the coating should allow the unlimited swelling of the pellets and the undisturbed formation of a dense and structural integer bentonite plug. Hence one option is to use water-soluble polymers which result in a slow dissolution up to a complete disintegration of the applied protective and swelling-retardant coating leaving no residue which could block or prevent swelling of the bentonite.

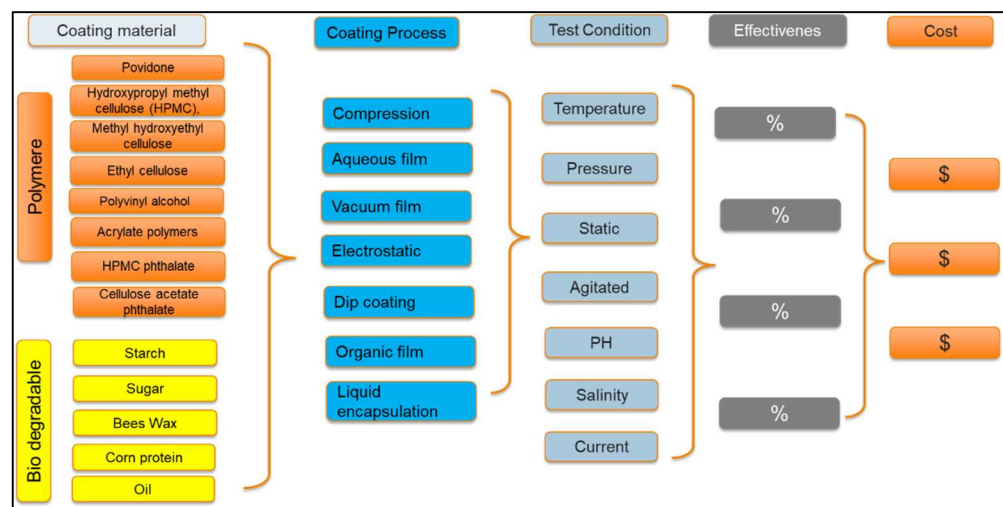


Figure 1. Bentonite pellets coating selection process

One promising class of materials to investigate (see also Figure 1) are natural polymers which are modified to become water soluble or synthetic water-soluble polymers. Another option is the use of material which allow a diffusion of water through the material (semi-permeable membrane) and which are deformable to ensure a proper swelling and settling of a plug like cellophane like materials.

2.4.2 Experimental results

The test program conducted has provided confidence that:

- A placement procedure using a bio-degradable oil to provide a hydrophobic protection fluid during placement can be an option to consider in a field test and in the field, specific for highly deviated wells where gravitation is not an option. A small-scale test using this placement option was successful.
- Bentonite pellet types and coating types combined with reactive additives may offer solutions for specific placement conditions and can be varied to control especially hydration rates and achievable plug densities.
- The application of a coating to bentonite pellets in an industrial scale appears to be feasible. A trial with ProCept resulted in a good overall coating quality.

The required delay for the swelling of bentonite pellets while using placement by gravitation is about 2-3 hours for target depth of 2500m based on gravitation tests with different pellet shapes and at different temperatures (Figure 2). This delay can be achieved by the application of suitable coatings. An effective bentonite plug can be created at depth by gravitation method and use of polymer coated bentonite pellets to control the placement and hydration process. A placement using a bio-degradable oil to provide hydrophobic protection during placement was successful and is a placement option to consider, especially for highly deviated wells where gravitation is not an option. Different bentonite types and coating types combined with reactive additives may offer solutions for specific placement conditions, controlling hydration rates and plug density.

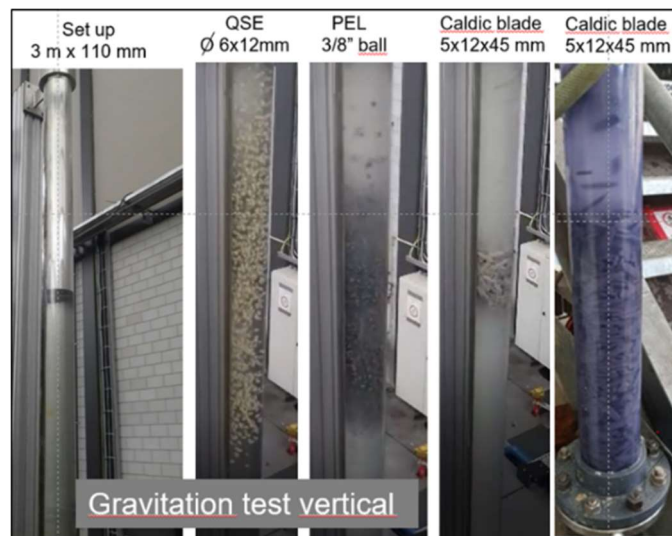


Figure 2. Vertical gravitation test of different bentonite pellets in fresh water in a 6 m x 110 mm transparent tube

Tests of the most suitable coating processes, in a scale of 0.5 and 2 kg of material, resulted in good homogenous coatings with the envisaged performance, upscaling on industrial size equipment is easily possible.

All defined research questions (as mentioned in Section 2.2) could be answered and the findings are outlined in the restricted technical deliverable reports of this project.

2.5 Contribution to the TKI Nieuw Gas, program line Geenergy Roadmap objectives, the TKI subsidy regulation and knowledge development

The project contributes in providing technology to use the natural sealing capacity to seal and abandon wellbores, which is an essential part of the TKI Nieuw Gas, Programme Line Geo Energy and relevant for both, hydrocarbon and sustainable geenergy operations such as geothermal or gas storage. It tackles an operational hurdle for the development of these technologies which controlled placement of bentonite pellets for well sealing. The project helps to achieve specific objectives of the research theme Decommissioning and Abandonment, which are in particular:

- Minimize negative effects of small-scale gas extraction on the environment and economics
- Re-use of existing infrastructure and integration with other energy activities in the North Sea.

- Development of sustainable and cost-efficient methods and techniques relating to integrity and state monitoring (pipelines, wells, installations); closure of wells, platforms and finding useful use (decommissioning);
- Safety, reliability and integrity (offshore installations and pipelines).

Natural sealing of abandoned wells (using coated bentonite pellets) is cheaper requiring substantial less energy and is in principle much more sustainable than engineered solutions and will reduce both the cost of decommissioning and associated CO₂ emissions. Leakage of methane has a large greenhouse effect (>20x CO₂ effect) and CH₄ emissions from abandoned boreholes have been proven to present a significant but underestimated source of greenhouse gas emissions¹⁴. Effective borehole sealing significantly contributes to reducing greenhouse gas emissions, energy consumption of P&A operations and protecting the environment, major goals of the TKI subsidy regulation.

The approach is unique in the world and when successful demonstrated, it will create an alternative to the current methods of abandonment and has the potential to become a game-changer technology enabling cost-efficient and reliable well plugging and abandonment methods.

2.6 Follow-up activities, spin-offs and exploitation

Based on the results of this project and related work in the program Line on natural sealing for wellbores, the following spin-offs could be initiated to tackle remaining challenges and research questions with respect to the feasibility to use bentonites as wellbore seals. Both follow-up projects aim at demonstration of the sealing technology at large- and full-scale tests including using a rig and test well at the Rijswijk Centre for Sustainable Geoenergy (RCSG).

TKI 2019: Natural seals research and test well

TKI 2020: Natural Sealing Large-scale implementation

The good progress in developing this alternative sealing technology led to an extension of the consortium of the TKI Reuse and Decommissioning program line with Wintershall joining the program line.

As the project rather aimed at technology and patent development the work has not yet been published in journals or conferences.

For further information on this project please contact the secretary of TNO's Applied Geoscience Group at secretariaat-aarde@tno.nl.

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¹⁴ Kang et al. (2014). Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania (doi:10.1073/pnas.1408315111)