Development Of A UK Approach To Sealing Deep Site Investigation Boreholes: Knowledge Transfer From Other Industries

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This paper presents some results from a three year project to develop generic approaches to seal deep boreholes drilled as part of site investigations at a potential Geological Disposal Facility (GDF) site in the UK. The project (Sealing of deep site investigation boreholes: Phase 2) is being funded by Radioactive Waste Management Limited (RWM) and undertaken by a team comprising of Amec Foster Wheeler, Bedrock Geosciences, Clay Technology, Galson Science, Nagra, Quintessa and Schlumberger. We describe how techniques used in the oil and gas industry to place materials in boreholes could be used or modified to seal deep boreholes at a site being investigated to host a potential GDF. The project has previously concluded that post-closure seals in site investigation boreholes associated with a GDF site should be formed from natural materials such as bentonite; therefore, this paper specifically considers the application of oil and gas techniques to place bentonite in deep boreholes.

1 Introduction

At the present time, the UK siting process for a Geological Disposal Facility (GDF) is at the generic stage; no sites are being investigated and there is no preferred geology. In this generic stage, RWM considers three illustrative geological settings in its development of generic disposal concepts [i,ii]. The three illustrative geological settings considered in the 2010 generic Disposal System Safety Case (gDSSC)[1] are higher strength rocks (HSR), lower strength sedimentary rocks (LSSR) and evaporites. In the case of lower strength sedimentary host rocks and evaporite host rocks, the host rock will be overlain by sedimentary cover rocks. In the case of a higher strength host rock, the host rock may either extend to surface or be overlain by sedimentary cover rocks.

2 Scope and objectives

RWM is undertaking R&D into borehole sealing because it expects it will be necessary to demonstrate how site investigation boreholes might be sealed before drilling begins at a potential site. An R&D programme into sealing deep site investigation boreholes commenced in 2013. Phase 1 of the project [iii] comprised of a review of borehole sealing approaches in a range of industries and concluded with a recommended programme of work for a Phase 2 Project. Phase 2 commenced in June 2014 and is scheduled to complete in March 2017. The overall objective of the Phase 2 project is to develop an approach or approaches for sealing deep (up to 2,000m) site

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1 We recognise that the gDSSC will be updated in 2016 and that the detailed descriptions of the geological environments are currently evolving. For the purposes of this report, we refer to the 2010 gDSSC and supporting documents as published

investigation boreholes against groundwater flow and gas migration in a range of geological settings potentially relevant for a UK GDF. It was the view of the Phase 1 report that generic R&D should be focused on developing and demonstrating sealing concepts for HSR and LSSR environments. The composition of seals in evaporites (using either natural evaporite minerals or salt-saturated cements) would depend on the site evaporite mineralogy, and would be addressed once a site is under consideration.

3 Conclusions from the Phase 1 project

The Phase 1 borehole sealing report [iii] presented the approaches to borehole sealing taken by a number of organisations and industries: overseas Radioactive Waste Management Organisations; oil and gas; CO_2 storage; and, water resources. Borehole diameters and depths of potential relevance to RWM are fairly typical of onshore and shallower offshore oil and gas wells. Likewise, oil and gas drilling encounters many rock types worldwide, from weak overburden, through competent sedimentary formations, to hard basement reservoirs. As such, there is considerable technology and knowledge in the oil and gas industry on borehole sealing that may be appropriate to deep site investigation boreholes for a GDF.

The approach to abandoning/decommissioning boreholes is broadly consistent across the industries considered, although this is sometimes obscured by the different nomenclatures used. The main common themes are:

- sections of boreholes are sealed to prevent or reduce to an acceptable degree the movement of fluids through the borehole for as long as is required. These seals must have sufficiently low permeability and sufficient longevity to meet these requirements. In the Phase 2 'Sealing Boreholes' project, we refer to such seals as 'post-closure seals';
- intervals between the seals are filled with materials that provide mechanical stability for the surrounding rock and overlying and underlying seals. Additionally, these materials greatly reduce the permeability of the section relative to that of the open borehole, although this is not their primary function. In the non-nuclear applications that we have reviewed, lengths of cemented casing often remain in-situ between the seals; in this case, the cemented annulus rather than the material filling the casing provides the resistance to flow through the section. We describe the component used to fill the intervals between seals as the 'support element';
- seals are placed across lower permeability sections of rock in uncased sections of hole. Their lengths depend on the rock properties and sealing concept; 30m or more is typical. Working in conjunction with the surrounding rock, they restrict fluid movement along the borehole. Seals are not placed directly across high permeability horizons.

4 Conclusions and achievements from the first year of the Phase 2 project

The main conclusions and achievements from the first year of the Phase 2 'Sealing Boreholes' project are listed below.

- The performance required of the borehole sealing system should be informed by the requirements of post-closure performance, rather than by a requirement to return the rock to its pre-drilled condition.
- Post-closure seals in HSR and LSSR should be formed from natural materials; it will not be practicable to demonstrate the required longevity using engineered materials. Bentonite, in a number of physical forms, is a candidate material and has been examined in detail in the laboratory programme undertaken as part of the Phase 2 'Sealing boreholes' project.

- Seals with permeabilities significantly higher than that of the surrounding rock are likely to be acceptable in many cases from a post-closure safety perspective. This means that a range of borehole sealing concepts is potentially acceptable and should be considered.
- Deep boreholes drilled in many geological environments of potential interest to RWM are expected to show significant variability in borehole diameter. This variability will influence the suitability of potential sealing approaches.
- Principles and requirements for selecting post-closure seals have been developed (see Figure 4-1~~Figure 4-1~~). Candidate materials for post-closure seals in HSR and LSSR have been identified, and a preliminary assessment of their applicability in different settings has been undertaken.
- Potential sealing materials for boreholes in HSR and LSSR have been grouped into the following categories:
    - high density sealing elements, such as high density bentonite blocks;
    - granular materials, such as bentonite pellets;
    - pumpable materials such as bentonite slurries

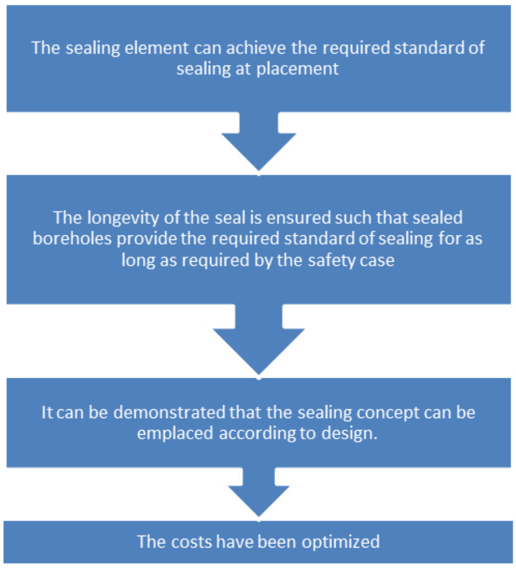

Figure 4-1. Principles and requirements for selecting sealing elements. The top requirement must be met before assessing the requirement at the lower level

5 Placement of bentonite seals in boreholes: knowledge transfer from the oil and gas industry

5.1 Placement techniques used in the oil and gas industry

Brief descriptions of the main techniques used by the oil and gas industry to place materials in boreholes are given below, together with the types of materials that are currently typically placed using each technique.

- **Conventional pumping**: the use of a combination of drilling rig or workover rig, tubing string and high horse power, high rate pump for placing materials in wells. This is the default technique for plugging and abandoning oil or gas wells internationally, used for most wells with few exceptions. The technique is typically used in the oil and gas industry for placing cement-based slurries.

- **Coiled tubing pumping**: the approach is more precise in depth control and has better rate control than conventional pumping. Consequently, the technique has developed significantly over the last decades to place small volumes of materials at specific depths. The technique is typically used in the oil and gas industry for placing cement-based slurries and granular materials (sand plugs).
- **Gravity placement**: the dropping of the material that will form the seal or support element from surface so that it free-falls inside the wellbore intending to land at the bottom of the well. Note that the oil and gas industry still views this approach as being more of an 'art' than a 'science'. The technique is typically used in the oil and gas industry for placement of bentonite pellets for sealing purposes.
- **Dump bailing**: the use of a metallic cylindrical vessel run on wireline or similar containing a small volume of material that can be released at a desired depth either by gravity alone or by positive displacement. The technique is typically used in the oil and gas industry for placing small volumes of cement-based slurries and granular materials (sand plugs).
- **High velocity and high pressure pumping of particulates**: the placement of particulate materials in the wellbore or formation by high velocity or high pressure pumping. The techniques are typically used in the oil and gas industry for placing gravel packs, for hydraulic fracturing and for 'frac-and-pack', which is essentially, a combination of the first two techniques.

Borehole sealing in the oil and gas industry is usually achieved through the use of cementitious materials, although bentonite pellets have been successfully used in recent years to seal near-vertical boreholes up to 1,000m deep [iii,iv]. Consequently, with the exception of gravity placement of bentonite pellets, the oil and gas industry has no direct experience of placing bentonite for sealing purposes in boreholes, though there is extensive experience of pumping bentonite-based drilling muds for viscosity and filtration control [v]. We have therefore considered whether the techniques described above could be used directly or modified to place bentonite, in the form of slurries, pellets and blocks, for sealing boreholes. Potentially suitable techniques are discussed below.

5.2 Potential application of conventional pumping and coiled tube pumping

Both conventional pumping and coiled tube pumping are standard techniques used in the oil and gas industry to place slurries in boreholes. Conventional pumping is the most commonly-used technique for placing cement-based slurries. Coiled tube pumping offers advantages in terms of precision of placement, and is used for placing slurries, as well as for placing granular materials. Although neither technique has been used to place bentonite seals, both could be used to pump bentonite slurries. Bentonite slurries will have lower placed densities, and hence (other things being equal) higher permeabilities, than either bentonite pellets or blocks. It is not clear whether, or under what circumstances, they would be suitable for forming borehole seals. The required permeabilities of borehole seals are considered further in [vi]; in the current paper, we are only concerned with the practicality of approaches to place bentonite in deep (up to 2,000m) site investigation boreholes at a potential GDF site.

5.3 Potential application of gravity placement and dump bailing

Gravity placement is a proven technique for placing bentonite pellets in boreholes up to 1,000m deep. The requirement is that hydration (swelling) of the bentonite pellet is delayed for sufficiently long to allow it to sink to the required position in the borehole; up to one hour sinking time for pellets in a 1,000m deep borehole. Premature swelling can result in bridging of the pellet at shallower depth or spalling, which can further reduce the settling speed and prevent the bentonite from reaching the required depth. The conventional approach to delaying hydration of pellets is through coating them, typically with a water-soluble coating. Commercially-available pellets claim to provide up to 90 minutes protection against swelling. The technique of gravity placement is potentially applicable for use with bentonite pellets in boreholes up to 2,000m deep, although we have been unable to find any examples. The longer sinking time (up to two hours) and greater sinking distance mean there is greater potential for bridging and premature hydration. Gravity placement is also potentially applicable to placing bentonite blocks in boreholes, as illustrated by patents envisaging placement of tapered' bullets' of bentonite.

An aspect of the Phase 2 'Sealing Boreholes' project has been a major laboratory programme to investigate the performance of bentonite (as slurries, pellets and blocks) in a wide range of water compositions. One component of this programme is investigating the early swelling behaviour of coated and uncoated bentonite pellets, to build an understanding of their likely behaviour during placement in a deep borehole. Results indicate that bentonite pellets, even if commercially coated, are physically unstable in highly saline water and their surfaces spall quickly. In such circumstances, gravity placement would not be a suitable placement technique. The outcome of these laboratory studies will confirm the circumstances under which the various placement techniques might be suitable for placing bentonite.

Dump bailers are routinely used to place cement slurries and sand to depths greater than 2,000m in boreholes. The approach may be applicable for accurately placing known volumes of bentonite slurries, pellets or blocks for sealing purposes. One advantage of this approach is that we may be confident that all bentonite has been placed at the required depth, and that no 'bridging' of bentonite at shallower depth is possible. Further, some dump bailers are designed to isolate the contents of the bailer from groundwater as the bailer is lowed in the borehole; the bailer is only opened, and the contents displaced from it, when the bailer has reached the required position. This design feature could be useful as it removes the possibility of premature hydration or spalling of the bentonite pellet or block before the bailer is opened.

There are two potential downsides of using dump bailers, which are being considered as part of the project's forward programme:

- firstly, that only relatively small volumes of material can be placed in currently available dump bailers, though the potential exists for linking two our more dump bailers together to increase the volumes placed on each occasion. Cost is a major consideration in the oil and gas industry, and is the major reason why dump bailers (through the use of multiple trips) are not used to place larger volumes of material in a borehole. This constraint may be less important for sealing boreholes at a GDF site, both because of the relatively small number of boreholes that will require sealing and because of benefits that dump bailers could provide in terms of accurate placement and simplicity of approach, thus enabling correct placement of the seal to be demonstrated;
- second, that some development would be needed to demonstrate that the positive displacement system on a dump bailer would be suitable for pushing bentonite from the bailer into the borehole.

These issues will be considered further in the ongoing programme.

6 Summary and conclusions

Phase 2 of the 'Sealing boreholes' project has identified bentonite as a potential material that could be suitable for use in sealing site investigation boreholes associated with a UK GDF. Bentonite is a natural material, and its behaviour over long timescales is understood to the necessary level. Use of cementitious materials for the construction of post-closure borehole seals in the context of a GDF is not recommended. Another aspect of Phase 2 of the 'Sealing boreholes' project is to identify suitable materials for constructing the 'support elements' of the borehole sealing system (see Section 3). This work, which is in progress, is still considering the potential use of cementitious materials for this role.

Bentonite pellets have been successfully used in recent years by the oil and gas industry to seal near-vertical boreholes up to 1,000m deep; other than this, the oil and gas industry has no direct experience of placing bentonite for sealing purposes in boreholes. As part of the ongoing Phase 2 'Sealing boreholes' project, we have considered the various techniques used by the oil and gas industry for placing other materials (typically cement, sand and ceramic particles) in boreholes and have considered whether these techniques could be used directly or modified to place bentonite, in the form of slurries, pellets and blocks, for sealing purposes.

We have identified conventional pumping and coiled tube pumping as being suitable for placing bentonite slurries but, as noted in Section 5.2, it is not clear whether, or under what circumstances, bentonite slurries would be suitable for forming borehole seals. We have also identified dump bailers as having the potential to place bentonite at higher initial densities, as pellets and blocks. The final phase of the project, to be undertaken by March 2017, will involve recommending a preferred approach or approaches for sealing deep site investigation boreholes in the various geological environments of potential relevance to RWM.

7 References

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