Long Term Integrity of CO_2 Storage - Well Abandonment

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The IEA Greenhouse Gas R&D Programme (IEA GHG) is a major international collaboration, investigating technologies that could reduce greenhouse gas emissions. This poster provides an overview of a recently completed study report completed on IEA GHG's behalf by TNO in the Netherlands.

Background to the Study

IEA GHG recently commissioned TNO in The Netherlands to conduct a review of abandonment procedures and methodologies from around the world in order to determine whether the predominant factor influencing the methods used is regional location and regulatory led, or if it is purely down to operator preference. The study also included an assessment of best practice for long term well abandonment.

CO_2 geological storage projects will likely incorporate a range of well types, from injection and production wells, to abandoned and previously completed wells. While newly drilled and completed wells are likely to be governed by and subject to regulations designed to uphold the integrity of storage sites, wells completed and abandoned in the past may have been subject to less strict governance, and it is these wells that are, therefore, considered to be the greater threat to long-term storage integrity.

Storage in deep saline aquifers may minimise risks, as the number of wellbores expected to be encountered during a storage project should often be minimal. However, the greater developed and understood option for geological storage of injection into depleted oil and gas reservoirs is likely to incorporate a greater number of wells perforating the caprock of the reservoir due to the historical exploitation of these fields.

While the historical exploration of oil and gas fields creates the very potential for geological storage of CO_2 to take place in these reservoirs, it may have given rise to the greatest threat to the storage operation by providing multiple pathways for injected CO_2 to migrate through wellbores to overlying, unbounded geological areas, or the atmosphere. This study aims to address this issue, assessing the state of knowledge and identifying methodologies and best practices designed to minimise risks associated with injection into previously drilled and explored areas both on and off-shore.

Leakage can occur through faults and fractures in the caprock above the storage reservoir, and through poorly completed or abandoned wellbores from previous exploitation or exploration. While site selection criteria should work to minimise the risks posed by faults and fractures, a good understanding of well abandonment and remedial measures necessary to ensure secure storage is necessary to provide assurance to regulators and the general public that CCS is a safe option for greenhouse gas mitigation.

The study was undertaken by TNO in The Netherlands, with the project team being led by Tjirk Benedictus.

Review of Plugging Techniques

The report includes a high-level review or the variety of techniques that are employed around the world to facilitate well abandonment. The report describes the preliminary work necessary, such as removal of equipment from the well and cleanout of the wellbore before plugging can take place. The report outlines the basic principles involved in each plugging method and highlights the drawbacks and limitations of the methods. These are summarised in the table below.

Abandonment Method	Description	Benefits / Limitations
Balanced Plug	The more common method of abandonment, whereby the tubing is placed at the target plug depth, and the cement slurry is then injected onto a bridge plug device which forms the plug base. Cement is then pumped into the annulus until it is equal to the level inside the casing.	One of the simplest techniques, incurring lower costs than some, the main limitation is caused by the potential for cement contamination. This can be minimised by use of best practice and best suited plug base materials.
Cement Squeeze	Squeeze cementing involves pressurised forcing of cement at a pre-determined depth coinciding with perforations in the casing. The pressure forces the liquid of the slurry into the formation, leaving the cement to form a seal.	Often used as a remedial measure for flawed or damaged primary cement, the exact quantity of cement required cannot always be calculated, leading to possible excess cement which can enter the casing above the packer. This would effectively stick the tubing into the hole, preventing future removal.
Dump Bailer	A known quantity of cement is lowered into the wellbore on a wireline, and the bailer is activated when it reaches the correct position, just over the bridge plug and raising the bailer releases the cement.	The stationary nature of the slurry during the descent can lead to premature setting, so this is more suited to setting plugs at shallower depths.
Two-plug	A complex process whereby a top and bottom plug are set at calculated depths, the lower plug cleans the well as it is lowered, and the cement can then be placed with minimal contamination from other fluids.	Allows maximum accuracy of placement with minimum cement contamination. The isolation of the cement slurry from other fluids ensures predictable cement performance.

Case Studies

The study covered case studies of abandonment practices at three locations around the world:

- Proposed storage of CO_2 in the depleted De Lier field, The Netherlands,
- Well evaluation at Gulf Coast and SACROC, Texas, USA,
- The Alberta Basin, Alberta, Canada.

These case studies were chosen as they represent a range of aspects of wellbore integrity, and the potential impact these have on storage operations.

Of these case studies, the De Lier field was deemed to be not feasible for further development due to geological constraints, and urban and industrial development above numerous abandoned wells. Additionally, many wells were abandoned several metres below ground, making identification and re-entry more difficult.

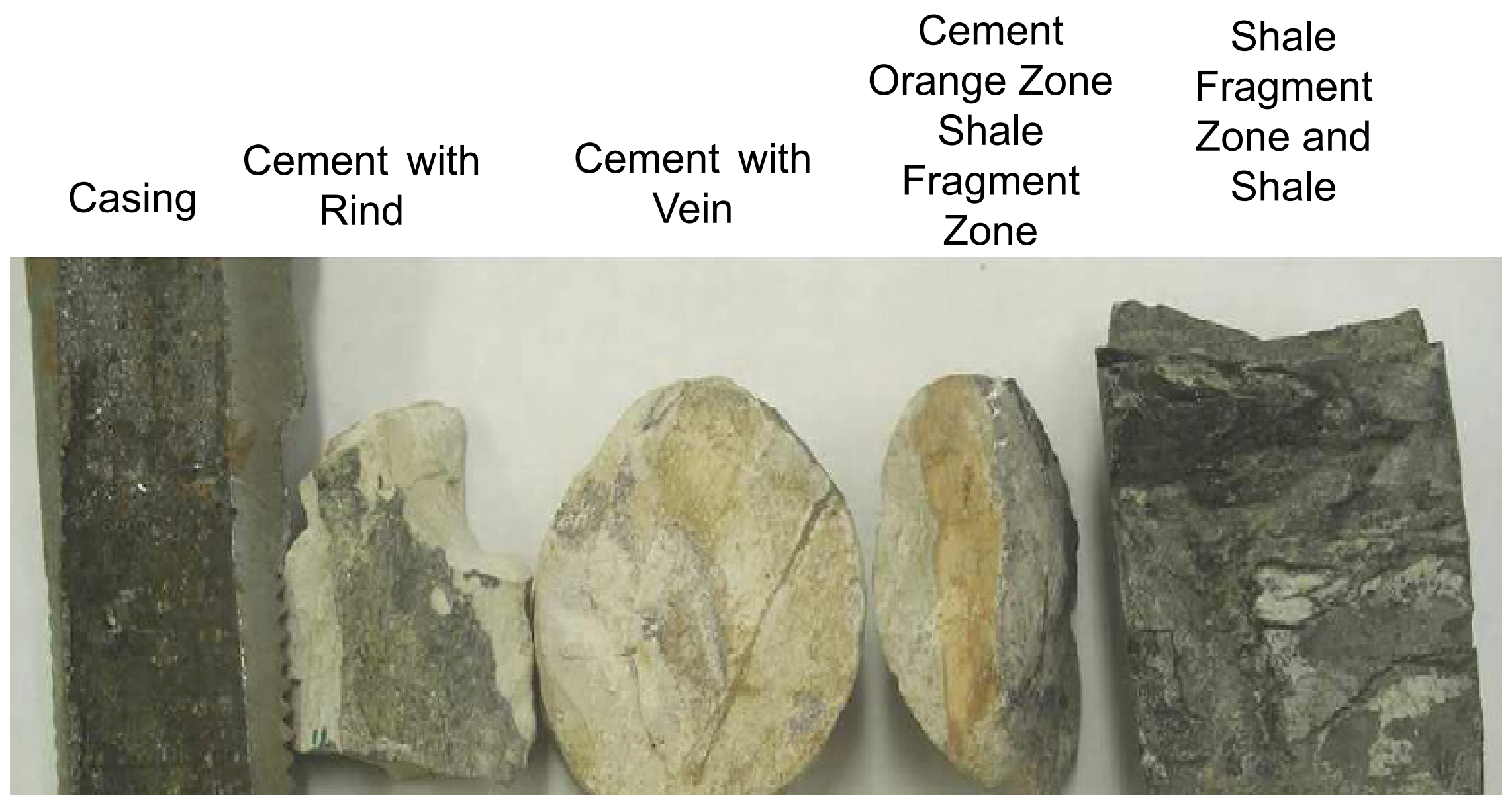

Figure 1: Photograph of samples retrieved from well 49-6, showing (from left to right) casing, cement with alteration zones at both interfaces, a zone of fragmented shale and shale caprock (Carey et al., 2007).

Texas is an area often used as a case study due to the high number of abandoned wells, and the history of hydrocarbon exploitation and production. Here the issues are with well densities, and completion methods. Many wells were completed before 1930, and were not plugged with cement and were not subject to governing by the site operators.

Alberta is another region that has seen extensive drilling and oil and gas production, but unlike Texas, the Alberta Basin shows a very high quality and complete database on oil and gas wells. Similar to many regions of the world, monitoring is required by regulations during a sites active lifetime, but following adequate abandonment, no further monitoring is required.

Regulatory Review

The report also looks at several examples of regulatory regimes in place around the world aimed at controlling CCS operations and making operators accountable for leakage and problems over the longer site lifetime. Assessment of current regulatory frameworks can help to determine and evaluate initial abandonment practices only, and subsequent changes to legislation mean that during the lifetime of a commercial scale CCS project it is conceivable that well abandonment practices would change. It is also unlikely that regulatory regimes will stipulate the exact abandonment methods for all wells encountered in a field, rather that it would allow operators to assess and make informed judgements as to which methods are necessary to fulfil requirements and ensure safety, while not entailing excessive or prohibitive costs. It is accepted that a site specific survey would be required for each potential storage site, and site selection criteria would likely remove some potential sites from the reckoning due to excessive remedial costs for abandoned wells.

The report looks at 11 different regulatory regimes from European, Australasian and American countries, and also assesses the London Convention and Protocol and the OSPAR Convention, with the role they play as International Conventions.

From this review, it is clear that there is a large repository of regulatory information and tools available to regulators of CCS activities, and much of this has evolved from the legislation governing petroleum well abandonment.

Generally, the regulations in place provide guidance on abandonment methods for existing wells, and although the review shows that there is always a need for a cement plug, the length of cement plug varies greatly, from a minimum of 15m in Canada, to up to 100m in some European scenarios. Other areas where variation is apparent include verification of abandoned wells, provisions made for CO_2 storage, and data availability.

The single most difficult hurdle encountered by TNO when assessing international regulatory positions, was the language barrier that exists. Many countries do not offer their regulations in anything but their native language, and any translation is deemed unofficial. TNO recommend in the report that to facilitate international cooperation, all regulations should be provided with an official English language translation, and indeed further discussion should be entered into as to whether such regulations should be freely available for those who wish to read them.

Best Practice Recommendation

Carlsen and Abdollahi (2007; In: Randhol et al., 2007) describe a methodology for abandonment that is shown in figure 2 below. The process involves removing the tuber and packer before placing a cement plug at the bottom of the well, and then injecting a specialised fluid into the reservoir to clog the near-well area and displace the CO_2 to minimise contact between CO_2 and wellbore materials. The casing is then milled at the level of the caprock and cement injected into this open section to prevent leakage along micro-annuli between casing and cement elements. The well is then filled with non corrosive completion fluid. If secondary seals are present, then an additional cement barrier should be placed at this point.

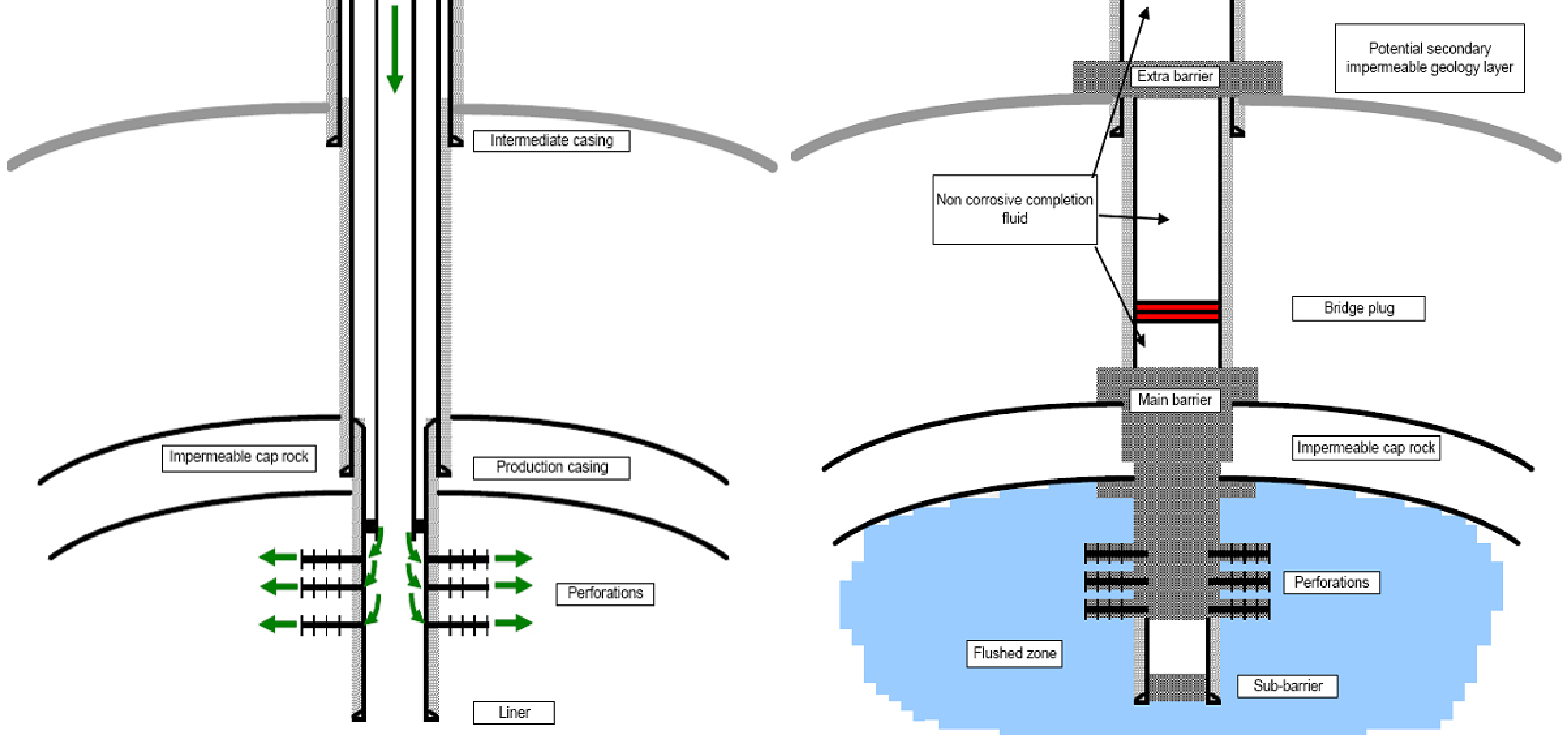

Figure 2: CO_2 Storage well before (left) and after abandonment (right) according to the methodology described by Carlsen and Abdollahi (2007; In Randhol et al., 2007)

Conclusions

The study references work carried out by Watson & Bachu, 2007, that states that wells can be classified as either existing or future wells. Existing wells are further sub-categorised as abandoned or operational, effectively giving 3 well categories: abandoned, operational and future wells.

Future wells can be designed, drilled and abandoned taking into account the CO_2 storage operation, hence using state-of-the-art technologies can remove many of the risks associated with the leakage of CO_2. These technologies are in existence now, and are widely used in the oil and gas industry.

Operational wells are often suitable to adaptation as injection or monitoring wells, and although this can be expensive, methods and technologies exist for these purposes. The cost involved means that the main considerations for these wells are techno-economic, and this assessment would likely have a direct impact on storage operations. Additionally, operational wells tend to be accessible for adaptation purposes, whereas often abandoned wells are abandoned below the surface.

The recommended best practice for well abandonment with specific focus on long term well storage integrity involves 4 aspects:

- Advanced materials: improvements in the capacity of wellbore sealants to isolate stored CO_2 can be applied during drilling, completion, workover and abandonment operations,
- Reduced cement permeability and reactivity: either by reducing the water to cement ratio or the addition of specialist materials which also allows the slurry density to be adjusted over a range of values.
- Use of non-Portland cements: these are less reactive with wet CO_2, however they are not compatible with Portland cements, and cross-contamination must be avoided. They also entail higher costs than Portland based cements.
- Self healing cements and swelling packers: these contain specific additives that react with the fluids present to effectively block cracks and annuli to prevent flow. Swelling packers are used in case of cement failure – they are designed to swell upon contact with hydrocarbons, water or both.

References:

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