Well Abandonment Practices

IEA GHG Wellbore Integrity Network Meeting
Calgary, May 13, 2009

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Introduction

• In 2008 TNO was contracted by IEA GHG to conduct a review study into well abandonment practices based on available literature.

• Results are to be published as IEA GHG report.

• Draft results presented here: any feedback is appreciated!
Scope of the study

- Previously abandoned deep oil and gas wells
- Well abandonment techniques
- High order evaluation of abandonment practices, through:
  - Expert opinions (questionnaire)
  - Governing regulatory frameworks
- Suitability for CO₂ storage
  - Overview of state of knowledge on well material degradation
- Risk assessment
- Recommended best practice
Types of wells

- Regarding CO₂ storage, different types of wells need to be distinguished (after Watson & Bachu, 2007):

  - **Future wells**
    - Wells directly related to the storage operations (i.e. CO₂ injection or monitoring wells)
    - Wells penetrating or transecting CO₂ storage reservoirs aiming at reservoirs at deeper levels
    - To be designed and abandoned taking into account CO₂ storage

  - **Existing wells**
    - To be abandoned taking into account CO₂ storage
    - Accessible wells (e.g. operating, shut-in)

  - **Previously abandoned wells**
    - Main risk for well integrity (leakage)
Case study: De Lier (the Netherlands)

*Previously presented at the 3rd Wellbore Integrity Network meeting*

- Feasibility study to store CO\textsubscript{2} in the depleted gas reservoir of the onshore, stacked De Lier field
- Penetrated by 51 abandoned wells
- Wells are abandoned according to regulations; abandonment did NOT take into account CO\textsubscript{2} storage
- Some wells would need reabandonment
- Consequently, the proposed storage project was discontinued
Case study: Gulf Coast, Texas (USA)

- Suitable geology for CO$_2$ storage, but...

- Extremely high well density (although decreasing with depth): high probability of encountering (abandoned) wells

- No comprehensive database on oil and gas wells ever drilled (especially older wells, i.e. pre-1930s, are lacking): high uncertainty regarding abandoned wells (e.g. location, abandonment status)

- After: Nicot et al., 2006; Nicot, 2008
Plugging techniques

Balanced plug method

Dump Bailer method

Cement squeeze method

Two-plug method

After: Nelson and Guillot, 2006
Historical developments in plugging

- 1922: Patent on Two-plug method by Halliburton, limiting potential mud contamination
- 1928: Multiple cement types became available for plugging
- ~1930: Introduction of centralizers, enabling more uniform cement distribution in wells
- 1940: Introduction of two types of Portland cement and three types of additives
- 1940s: Invention and widespread use of caliper, enabling calculation of the exact quantity of cement
- 1953: Publication of API standards on well cements

- Wells that were abandoned prior to 1953 are often not considered to have effective cement plugs
Abandonment practices

• Results based on a survey/questionnaire presented to approximately 200 experts (at operators, service companies, research institutes, regulatory bodies).

• Only 9 responses from different regions (North America, Europe, Australia)

• Questionnaire subjects comprise:
  • Drilling & completion operations
  • Abandonment regulations
  • Abandonment practices
  • Data availability
Questionnaire: Drilling and completion

• Various steel grades used for casing (e.g., J55, K55, L80, N80, C95, P110, Q125), generally following (API) guidelines on H₂S content, temperature and pressure.

• Common practice to use Cr-13 type steel in corrosive environments

• Primary cement sheath typically present along 30-70% to 70-90% of the wellbore

• 0-10% to 10-30% of wells show initial leakage (i.e. SCP, gas migration), due to casing corrosion/wear, poor cement coverage, improper slurry design, or overpressurization

Well Abandonment Practices

Well Abandonment Questionnaire

Name:
Company:
Region:
Field:
Depth range:
Pressure (MPa) range:

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Questionnaire: Abandonment regulations

- Regional or national regulations, or (in absence of these) international guidelines (OSPAR, London Convention)

- Balanced plug method is most commonly prescribed

- Minimum number of plugs ranges from 1 to 3

- Minimum plug length ranges from 8 to 100 m

- Plug testing generally involves either weight or pressure test

- Requirements for corrosive environments are rarely in place
Questionnaire: Abandonment practice

- Majority of operators has not been taking into account potential second life applications when abandoning.

- However, some operators recently started to evaluate field’s value for future purposes prior to abandonment.

- Company practices closely reflect governing regulations; more stringent measures (e.g. longer plug lengths, advanced materials) may be applied, especially in corrosive environments.
Questionnaire: Data availability

- Majority of respondents (a single exception) indicated that for 90-100% of the wells data is available on:
  - Well location (coordinates)
  - Present well status
  - Well configuration (i.e. cased depths, top of cement, plug lengths, materials applied)
Well Abandonment Regulations

• Literature research of well abandonment requirements in international regulations and a selected number of countries/states with petroleum history, including:
  • Australia
  • Canada
  • China
  • Europe (e.g. Denmark, Netherlands, Norway, UK)
  • Japan
  • USA (Alaska, California, Texas)

• Data obtained of plug lengths and position requirements used in:
  • the transition zone from uncased to cased sections
  • reservoir (uncased) section
  • perforated cased sections
Selection of minimum plug requirements

• Transition zone from uncased to cased sections;
  • Europe; 50-100 m, except UK; 30 m
  • International; 30-60 m, except Canada; 15 m depending on formation

• Reservoir (uncased) section
  • Europe and International; 50-100 m, except UK and Canada; 30 m

• Perforated cased sections
  • Europe; 50-100 m, except UK; 30 m
  • International; 30-60 m, except Canada; 80 m

Note: plug lengths in feet have been converted into meters and rounded off
Minimum plug lengths per country/state
Transition zone from uncased to cased sections

USA & Canada: 100 m
Europe: 100 m
Australia: 100 m
Asia: 100 m

Legend:
- Length above casing shoe (m)
- Length below casing shoe (m)
Remarks on review of abandonment regulations

- Assessment of the regulatory framework provides a first order proxy for initial identification of abandonment practices only

- Cement plug is compulsory in all evaluated regulatory documents

- Main differences involve plug requirements (lengths) at the level of the deepest casing shoe

- The application of mechanical plugs often require additional cementing (exact requirements differ significantly among regulations)

*Note that reviewed documents often involve unofficial translations of the original documents from the native languages to English*
Impact of CO$_2$ on wellbore integrity: an overview

• Cement degradation is considered to be diffusion-controlled

• Function of e.g. pH, T, P and salinity, but also on curing conditions, experimental setup (static vs. flowing, supercritical vs. dissolved CO$_2$)

• Extrapolating published experimental data according to Fick’s Law of diffusion ($d = C \cdot t^{1/2}$), shows divergent results: Time ($t$) required to degrade $d = 25$ mm of cement, ranges from 15 days to over 724,000 year (under different conditions)
Impact of CO₂ on wellbore integrity: an overview

• Limiting factors apply translating experimental results to field cases, e.g.:
  
  • Limited reaction surface in the field (taken into account by some authors)
  
  • Limited availability of free water (especially for some depleted gas fields)
  
  • High salinity (especially abundance of Ca²⁺) may reduce degradation or even lead to self-healing through calcite precipitation
Impact of CO$_2$ on wellbore integrity: an overview

- **Steel corrosion** is a linear process

- Function of pH, temperature, salinity and partial CO$_2$ pressure

- Published experimental results show corrosion rates in the order of mm’s per year

- Under favorable conditions (T>60-100°C; pH>5) siderite (FeCO$_3$) precipitation can retard corrosion, forming a (partially) protective layer

- In general, higher grade steel is more susceptible to corrosion
Impact of CO₂ on wellbore integrity: an overview

- Mechanical deformation
  - Reservoir decompaction due to CO₂ injection: strain incompatibility at cement-steel interface may cause debonding, and tensile cracks in the cement sheath
  - Shear deformation at the interface between reservoir and cap rock may damage the wellbore
  - Micro-fractures and micro-annuli may arise from:
    - Poor cement job (incl. cement shrinkage)
    - Temperature and/or pressure changes or cycles
Impact of CO$_2$ on wellbore integrity: an overview

- Interaction of casing corrosion and cement degradation along micro annuli

- Experimental work on a cement-steel sample in CO$_2$-brine (incl. Ca$^{2+}$) by Carey et al. (2008) shows:
  - No significant loss of mass of both steel and cement
  - Precipitation of siderite (FeCO$_3$) on the steel surface
  - Limited penetration of CO$_2$ in cement consistent with 1-D diffusion
Impact of CO$_2$ on wellbore integrity: an overview

- Interaction of chemical, mechanical and physical processes
  - Huerta et al. (2008) and Lécolier et al. (2008) report self-healing at cement-casing interface in lab experiments
  - At increasing confining stress, mechanical weakening results in rapid closure of fractures
  - Lécolier et al. (2008) report decreasing permeability and flow rates
Recommended best practice

• Future wells can be designed, drilled completed and abandoned taking into account any CO₂ storage reservoirs

• Suitability of existing wells for CO₂ storage needs to be evaluated
  - Accessible wells may require workover operations to be able to adequately isolate CO₂ storage reservoirs; techno-economical considerations determine the feasibility
  - Abandoned wells generally are not accessible. Especially older wells may pose threats to CO₂ storage. Furthermore, timing and stringency of global abandonment regulations varies considerably
Managing previously abandoned wells

• Lab experiments show cement degradation rates extrapolating to a maximum of 12.4 m in 10,000 years under severe T conditions, i.e. 204°C, 69 bar (in practice penetration is likely to be less)

• Prescribed cement plug lengths range from 15 to 100 m

• Quality and mechanical integrity of cement plug and sheath seems to be of more significance than chemical degradation:
  • Fractures or annular pathways in or along the cement will likely govern the permeability of the wellbore system

• Supported by investigations of downhole cement samples by Carey et al. (2007) and Crow et al. (2008):
  • Diffusion-based degradation of cement is limited
  • CO₂ migration was observed along cement-steel and cement-formation interfaces
Risk Management: assessment

- When considering long-term CO₂ storage, the current state of wells involved needs to be confidently assessed, including previously abandoned wells
  - Evaluation of abandonment configuration with respect to second life application
  - Evaluation of current state of materials and placement, extrapolating from data gathered prior to abandonment
Risk assessment methodologies

- Qualitative RA → FEP (Feature, Event, Process) analysis to identify site-specific CO₂ storage related hazards (e.g. TNO CASSIF, Quintessa)

- Quantitative RA
  - Deterministic (applicable to small numbers of wells)
  - Probabilistic (applicable to large sets of wells; e.g. OXAND methodology)

- Semi-quantitative: e.g. data mining
Risk Management: monitoring

• Monitoring well integrity as part of the entire suite of monitoring techniques employed on a storage site

• Monitoring abandoned (inaccessible) wells will be limited

• Potential techniques involve:
  • (near-)surface measurements (soil gas/fluxes, groundwater chemistry)
  • remote sensing
  • geophysical methods (e.g. seismic)

• In order to enhance discrimination between natural and injected CO₂, tracers could be added to the injected CO₂
Risk Management: remediation

- Remediation of abandoned wells requires re-entering and re-abandonment and is extremely costly and generally unfeasible.

- The ultimate measure to mitigate leaking storage reservoirs would be releasing pressure by venting CO₂ into the atmosphere.

- Obviously costly remediation or venting CO₂ should be prevented, initially by performing a comprehensive assessment of the wells involved prior to CO₂ injection.
Thank you!

Any suggestions, comments or input regarding the Well Abandonment report would be appreciated.

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