Storage 2 - Containment

Wellbore Integrity

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Wellbore Integrity

- A well: how it’s made, what it does
- The challenge of well integrity
- Key components and interfaces
- What could possibly go wrong?
- How could you tell?
- How can you fix it?
- Solutions for well integrity
VIDEO: Drilling, Casing, and Completing a Well
Wellbore Integrity – the challenge

Not just a ‘hole in the ground’
— a complex hydro-mechanical system designed to fulfil many requirements:

Shape: *really* strange (2km long, 20cm wide → 10,000 : 1 aspect ratio)
- Connects the surface to storage formation
- Holds the borehole open
- Long-lasting
- Unaffected by CO₂
- Materials – steel, cement, elastomers, fluids
- Barriers for fluid flow
- Economical – cost effective
- Repairable
- Geologically compatible
- Environmentally acceptable
- Retirement strategy – ‘plug and abandon’
Regulation – a well also has to be legal

US Environmental Protection Agency, Class VI well guidelines

Geologic Sequestration of Carbon Dioxide

Draft Underground Injection Control (UIC) Program
Class VI Well Construction Guidance for Owners and Operators

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Major goal is to protect underground sources of drinking water (USDWs)
CO$_2$ well integrity – it’s not just the injection well
Interfaces – some critical points

1. wellhead
2. USDW boundary
3. borehole – cement
4. cement – casing
5. casing – annulus
6. annulus – tubing
7. tubing – CO₂
8. packer – casing & tubing
9. caprock – storage formation
10. well – storage (perforations)

From US Environmental Protection Agency, Class VI well guidelines
Possible leakage paths across a single cemented annulus

What can go wrong?

- no isolating material where required
  - (wrong volumes)
  - losses during placement
- incomplete isolating material coverage
  - “mud channel”
- improper bond with formation
  - “mud removal”
- improper bond with tubular
  - “micro-annulus”
- isolating material not performing
  - contamination during placement
  - mechanical failure during well life
Careful consideration of possible paths

- Overall ‘system approach’ required for evaluating well integrity and risk management

- Risks inducing CO₂ leaks:
  - Debonding between cement and casing
  - Diffusivity, open porosity
  - Casing corrosion
  - Cracking, mechanical failure of cement

- Studies of the alteration of structural and transport properties
  - Near wellbore
  - Cement
  - Casing

Source: Gasda et al.
Effects of drilling on initial borehole status

- Breakouts and fractures
  - Controlled by state of stress, mud weight, etc.
- Strong electro-osmotic effects (clay swelling/contraction)
  - Dependent on mud activity
- Breakout and washouts
  - Poor centralization → Channeling
- Near wellbore degradation

Source: GMI training material
Laboratory-scale geochemical experiments: reaction fronts

CO$_2$ reactor at SRPC (France)
Field experience

Fig. 1 – Photograph of samples recovered from well 49-6 showing the casing (left), gray cement with a dark rind adjacent to the casing, 5-cm core of gray cement, gray cement with an orange alteration zone in contact with a zone of fragmented shale, and the shale country rock.

J.W. Carey et al., “Cement with 30 years of CO₂ exposure”  
Int. J. GHG Control I (2007) 75-85
Steel corrosion – key factors

- Steel quality
- Pressure
- Temperature
- Impurities
- Moisture
- Dissolved elements
- Protective surface layers
- Flow conditions
- Pipe geometry

→ Overall design and selection of appropriate grade of materials is critical
Steel Corrosion experiments

Interface Experiments

Carey et al 2010; IJGGC
Mitigation of leakage through wells

A full well design based on risk assessment
- Position of well components
- Definition of overlaps
- Where to use each cement system / completion materials

- Providing secondary barriers as much as possible

- Robust construction practices required
Monitoring techniques

- Detection
  - Is something happening?

- Quantification
  - How much? How fast?
  - Requires measuring CO\(_2\) flowrate to estimate risk and impact

- Techniques:
  - Mechanical Integrity Testing → pressure at wellhead
  - Casing annulus pressure monitoring and sampling at surface
  - Downhole pressure and temperature monitoring along the well
  - Continuous temperature profile, e.g. Distributed temperature sensing
  - Noise logs to determine turbulent flow behind casing
  - Cement and corrosion monitoring tools
  - Soil gas surveys especially around abandoned wells
Opportunities for intervention and remediation vary...

...however

- casing holes can be repaired
- cement channels filled

Mississippi
CO₂ injection wellhead

Sleipner
Norwegian
North Sea
Offshore platform

Snøhvit
160 km offshore
330m subsea wellhead

Photos courtesy of Statoil and US DOE
Risk mitigation: Repair and Abandonment

Repair:
- “Squeeze job” → force liquid cement under pressure to seal long, thin pathways
- Casing patches or new sections

'Plugging and abandonment':
- Closure of access to storage formation
- Multiple steel / elastomer / cement plugs
- Material selection and optimal placement
Process is important

- As for all aspects of CCS, a formal process approach integrating risk assessment and management is critical to the construction of successful wells.
Wellbore Integrity – the solutions

- Safety – the priority at all stages
- CO₂ pathways – wanted & unwanted
- Hole quality – drilling matters
- Lifecycle – design, construction, operation, decommissioning
- USDW – protecting underground sources of drinking water
- Management of risk – process methodology
- Barriers – the key to integrity
- Existing wells – not just new ones
- Remediation – casing and cement repair
- Geometry & design – to match the geology
- Evaluation – measurements & monitoring
- Regulation & permitting, and ‘best practice’
Final thoughts …

- Remember, it’s this shape (10,000 : 1 aspect ratio)
  - that makes it a *long* way between surface and storage

- A well is not just a ‘hole in the ground’.

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