Life Cycle Well Integrity of CO_2 Storage Wells: Engineering Imperatives for Success

GWPC UIC Conference, San Antonio, TX, February 16 – 19, 2020

Talib Syed, P.E.
www.talibsyed-assoc.com
Email: talibs@ecentral.com
Phone: +1 720.877.1272 (m)

TSA
TALIB SYED and ASSOCIATES, Inc.
CONSULTING PETROLEUM ENGINEERS

Outline of Presentation – CO_2 Storage (Class VI) Injectors

- Well Integrity
  - Definition and Importance
  - Life Cycle Well Integrity
- Life Cycle Well Integrity – Key Engineering Imperatives for Success
  - Well Design and Construction Phase
    - **Casing design**
    - **Cement design/ primary cementing**
    - **Material selection/tubulars/completion**
  - Operations/Production Phase (including well interventions/workovers)
    - **Maintaining Well Integrity**
  - Plugging & Abandonment
- Summary

Well Integrity - Definition

- "Application of technical, operational, and organizational solutions to reduce the risk of an uncontrolled release and/or unintended movement of well fluids throughout the life-cycle of a well" (NORSOK Standard D-010 and API RP 90)
- "Containment and the prevention of the escape of fluids to subterranean formations or surface" (ISO 16530-1)

Note: *Well integrity differs from wellbore integrity (borehole instability)* – open hole interval that does not retain its gauge and/or structural integrity

Why is Well Integrity Important?

(Skinner – http://www.worldoil.com/January 2003)

Blowout during workover to clean out fill in miscible CO2 injector

Blowout showing effects of expansion cooling when pressure containment is lost –dry ice

Well integrity – Life cycle governance (ISO 16530-1)

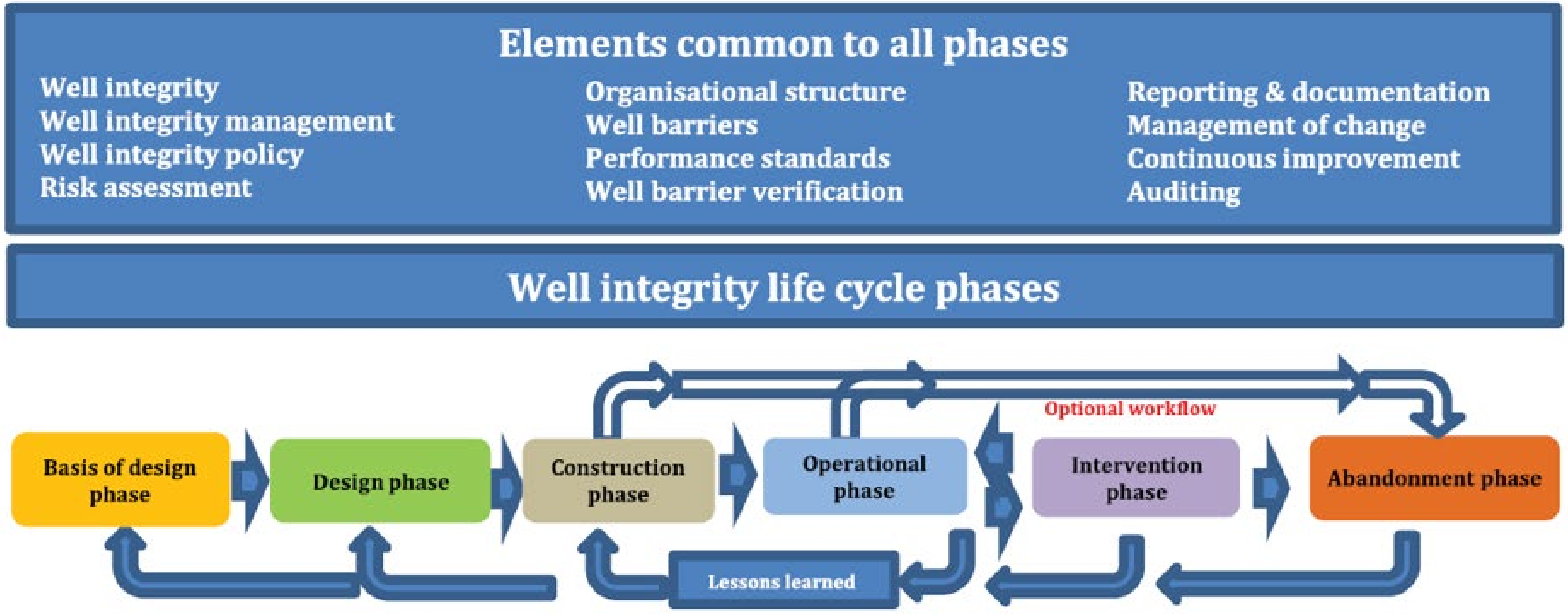
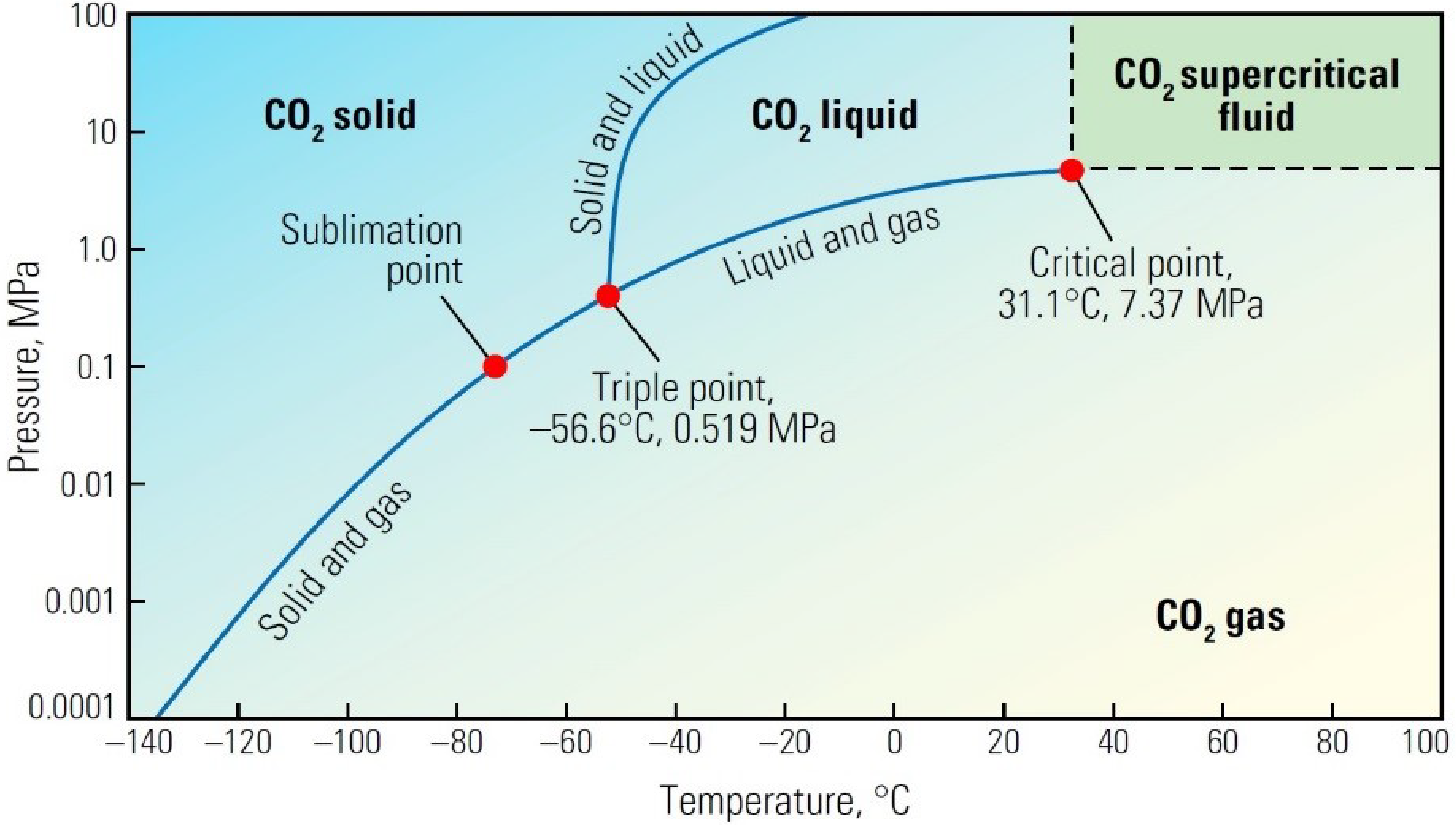


Figure 1 — Elements common to the phases of well integrity management

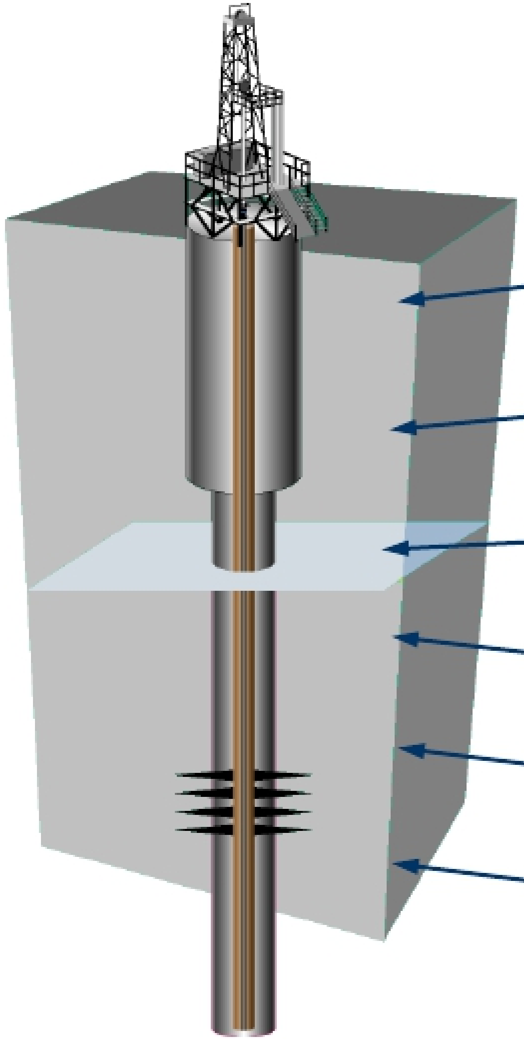
References: (1) ISO 16530-1-2017 – Well Integrity Part 1: Life cycle governance – www.iso.org; (2) https://oilandgasuk.co.uk/product/well-life-cycle-integrity-guidelines; (3) www.hse.gov.uk/offshore/ed-well-integrity.pdf; (4) http://www.hse.gov.uk/offshore/wells.htm

- Include unique CO_2 phase behavior in well and piping design, operations and in well intervention
- Low corrosion risk when injected stream is dry (CO_2 purity > 95%) and in supercritical stage
- Long-term stability of wellbore materials is complex. Incorporate material and reservoir properties into well design/completion programs

CO_2 Phase Behavior (Oilfield Review September 2015)



Why Mechanical Analysis?

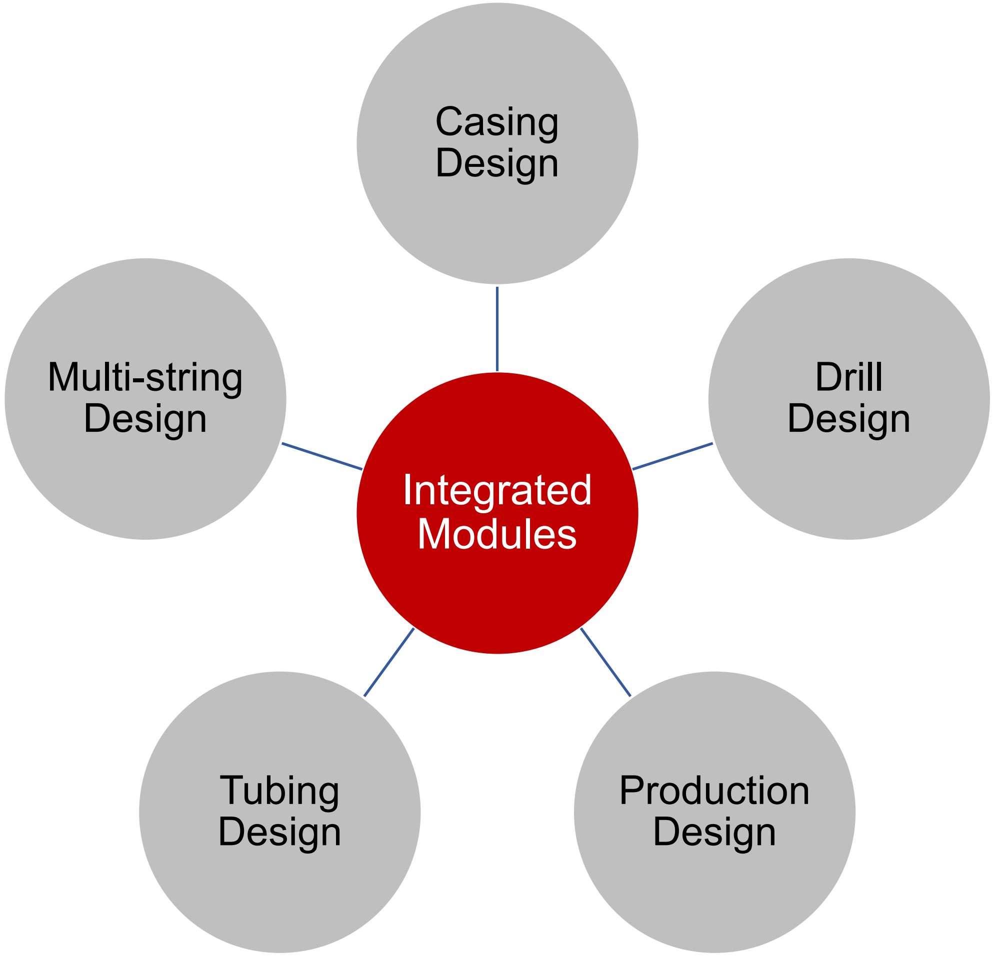


A well is a stressful environment

- Production/Injection
- Temperature changes in upper casings during production/injection
- Pressure changes: drilling, production injection
- Permanent well abandonment
- Formation changes/tectonic activity
- Well completion/perforation/stimulation

(Kirksey, 2013)

Overview of State-of-Art Casing Design Software



Casing Design

Multi-string Design

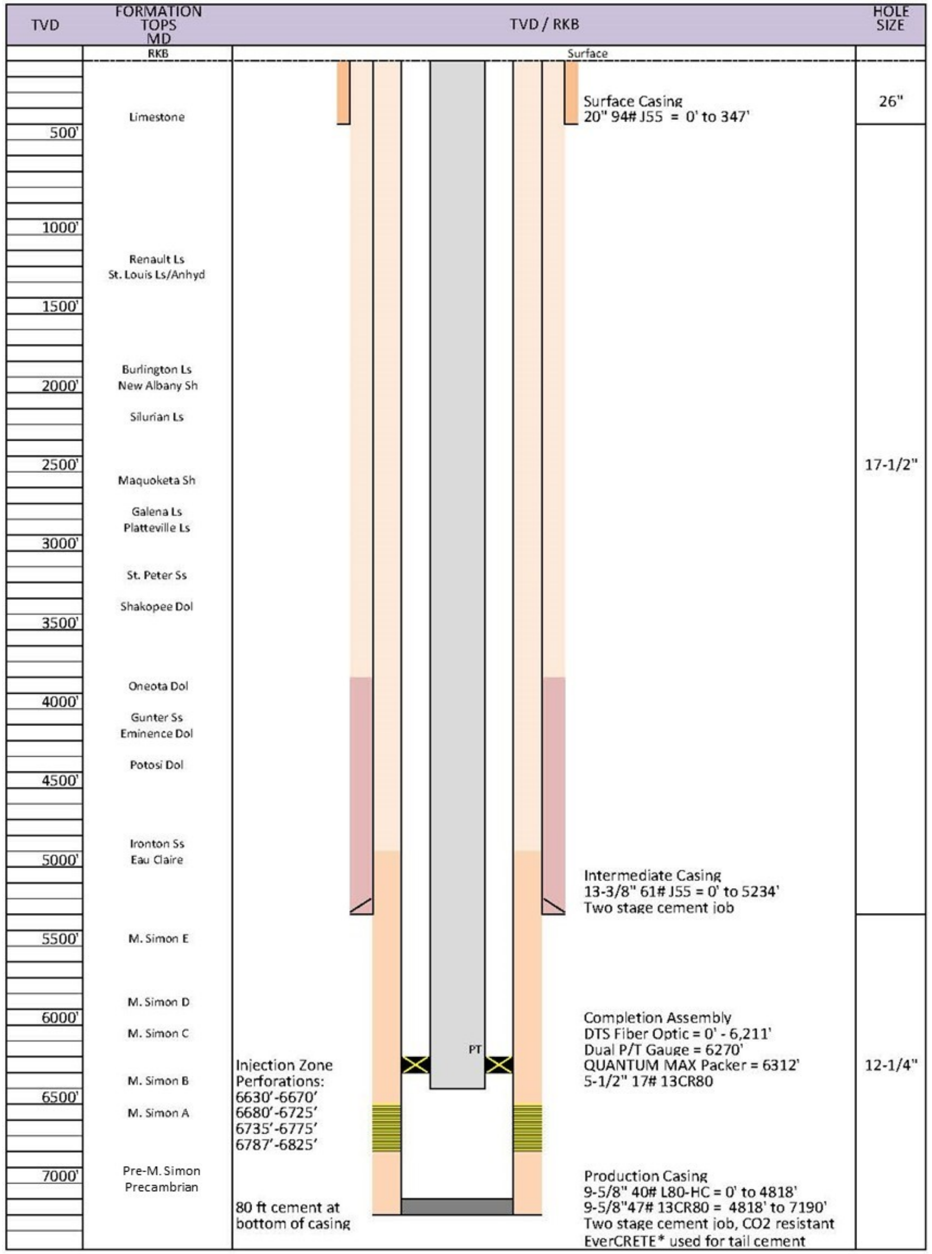
Integrated Modules

Drill Design

Tubing Design

Production Design

ADM CCS # 2 Class VI-GS Well, Decatur, Illinois, U.S.A.



Surface Casing
20" 94# J55 = 0' to 347'

Intermediate Casing
13-3/8" 61# J55 = 0' to 5234'
Two stage cement job

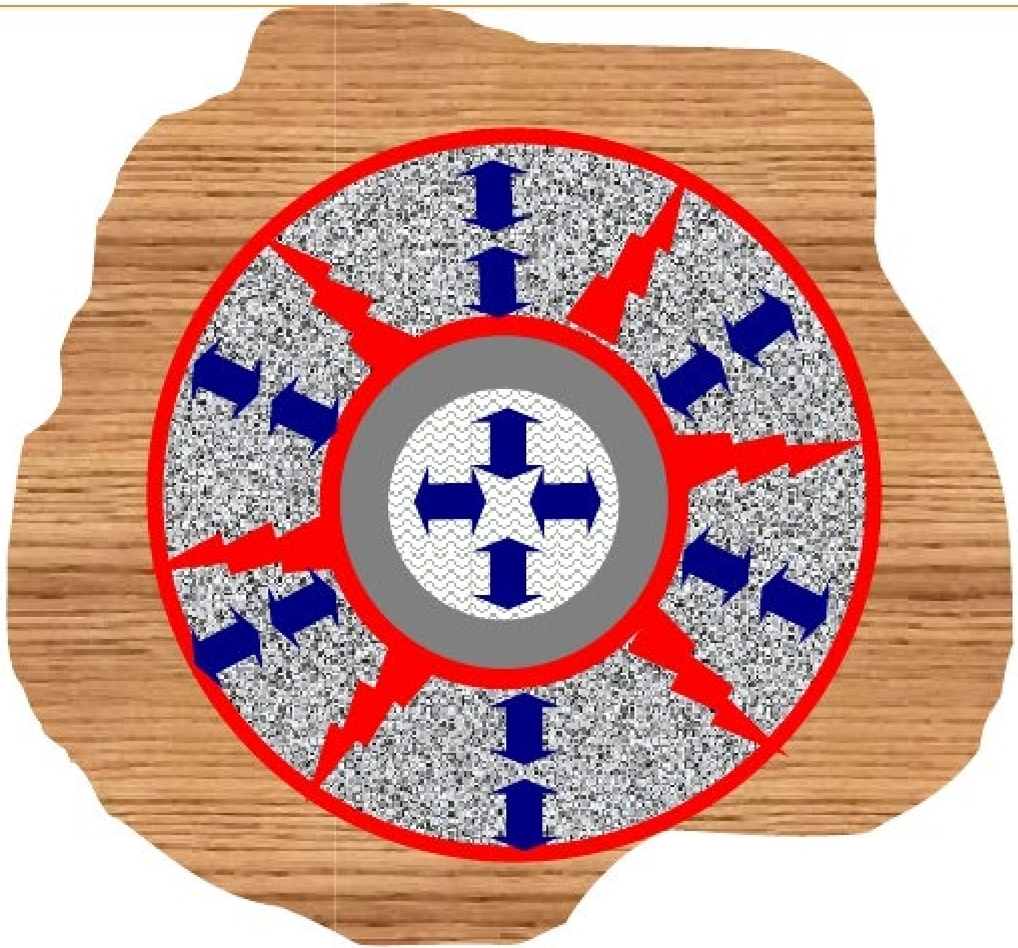
Completion Assembly
DTS Fiber Optic = 0' - 6,211'
Dual P/T Gauge = 6270'
QUANTUM MAX Packer = 6312'
5-1/2" 17# 13CR80

Injection Zone
Perforations:
6630'-6670'
6680'-6725'
6735'-6775'
6787'-6825'

80 ft cement at
bottom of casing

Production Casing
9-5/8" 40# L80-HC = 0' to 4818'
9-5/8"47# 13CR80 = 4818' to 7190'
Two stage cement job, CO2 resistant
EverCRETE* used for tail cement

Stresses on the Cement Sheath



Tensile cracks
- Wellbore pressure increase
- Wellbore temperature increase
- Cement shrinkage

De-bonding cement/ rock interface
- Formation stress decrease
- Wellbore pressure decrease
- Hydraulic fracturing
- Cement shrinkage

De-bonding steel/ cement interface
- Wellbore pressure decrease
- Temperature decrease
- Casing movement
- Cement expansion

Potential Results
- Loss of Well Integrity
- Sustained Casing Pressures
- Collapsed Casing

(Kirksey, 2013)

Cement job evaluation – Indirect Methods

Since proper primary cementing is critical to well integrity, cement job evaluation is “indispensable”. Since only volumes of mud and cement pumped and the pumping rates are known, we look for three general indicators of success: **full returns, lift pressure, and on-time plug landing**

Full returns* –** volume of mud returning from well during cement job equals volume of fluids (spacer, cement and mud) pumped down into the well – by monitoring mud tank volumes (if not results in ***lost returns *or* ***lost circulation****)*

***Lift pressure* –** steady increase in pump pressure when cement flows out the bottom of well and “turns the corner” to flow upward against gravity. A steady pressure increase observed at the appropriate time after cement is pumped, means that the increase is lift pressure and cement has “turned the corner” and is filling up the annulus (and not being lost into the formation)

***Plug landed or bumped* –** knowing inside well volumes and pumping rates of fluids can determine time for bottom and top plugs to land. When pressure spikes on rig gauges show up when expected, can infer that plugs landed properly and cement flowed out of shoe track into annulus and was not contaminated with large volumes of mud.
Pressure and volume indicators, however, will not show channeling or TOC (run CBL/USIT)

Cement job evaluation techniques – Hydraulic Testing

Pressure testing - most common technique to confirm zonal isolation

- **Casing Integrity Test –** performed first to verify mechanical integrity of casing. Test csg to 2500-3000 psi for 30 minutes. Typical pump rates of ¼ to 1 bpm. Straight line – good test, otherwise indicates poor cement job at shoe – requires remedial cementing

- **Leak Off Test (LOT) and Formation/Pressure Integrity Test (FIT/PIT)** – also referred to Limit Test – test formation below casing seat prior to drilling ahead. Objectives: (1) investigate cement seal around shoe and (2) determine wellbore capability to withstand pressures below the casing shoe in order to allow setting depth of next casing.

- **Inflow testing** (also known as dry testing) is a drill stem test (DST) to assess the isolation. Essentially opposite of a pressure test – the pressure inside casing is reduced and the well monitored to detect ingress of formation fluids. A successful dry test shows no downhole pressure change during the opening of the downhole valve or during the following shut-in period

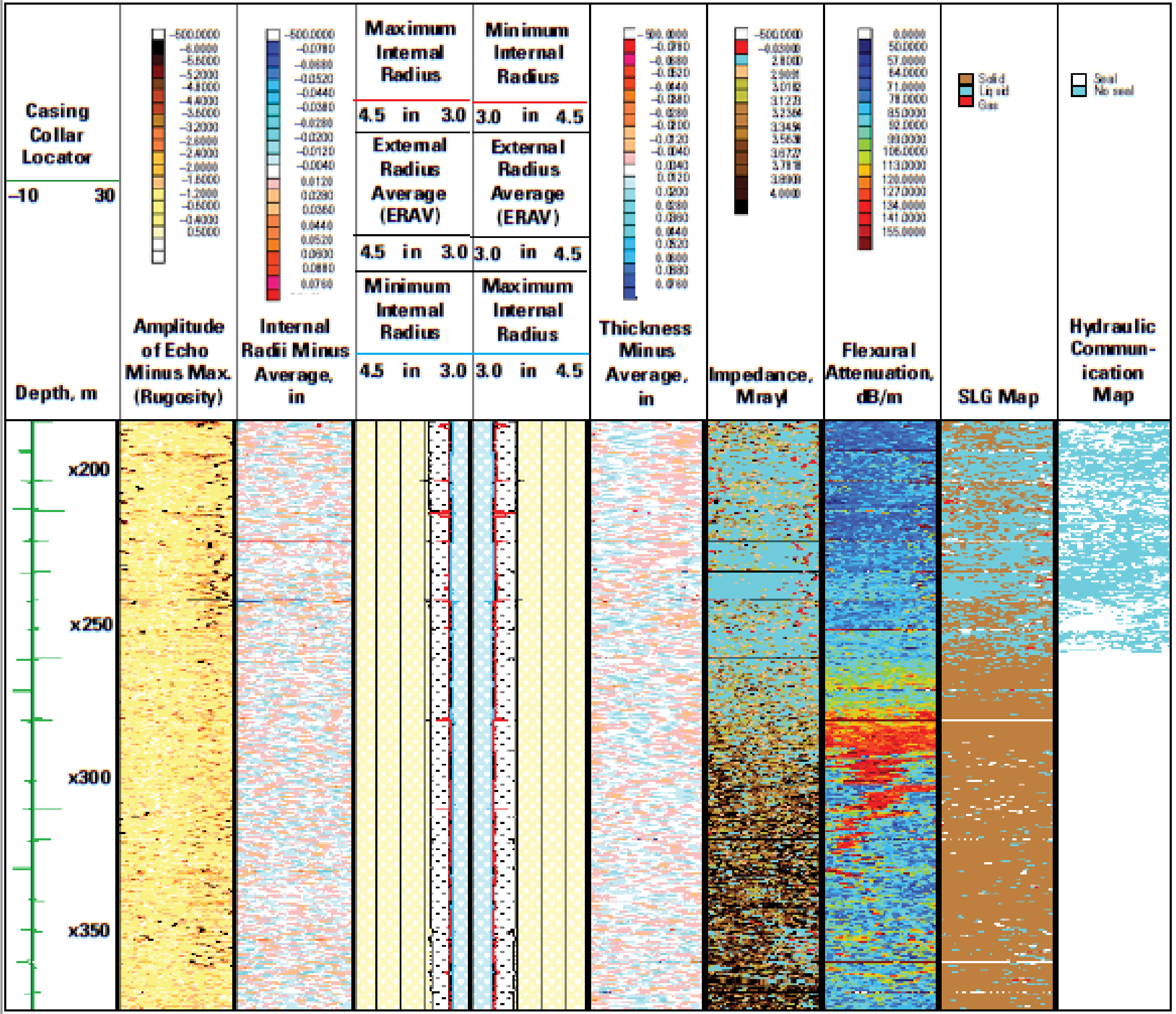
Cement Job Evaluation with Acoustic Logs – Current Techniques

- The **Ultrasonic Imaging Tool (USIT), CAST-V (Circumferential Acoustic Scanning Tool – Visualization) and UltraView** is a continuously rotating pulse-echo type tool with nearly 100% coverage of the casing wall (acoustic impedance – Z).

- The **Segmented Bond Tool (SBT**) measures the quality of cement effectiveness, vertically and laterally around the circumference of the casing in 6 segments around the pipe. SBT is usually run with VDL (variable density log)

- The **Isolation Scanner** combines pulse-echo technology with new ultrasonic technique of flexural wave imaging to evaluate cement job and casing condition for a wide range of cements – heavy, traditional to light weight cements.

- Other logs used to determine top of cement and channeling/flow behind casing due to bad primary cement job include: **Temperature, Radioactive tracer (RTS), Boron – Pulsed Neutron, Oxygen activation (OA) logs**



In additional to pulse-echo information on the rugosity, radius, cross section, and thickness of the 7-in [17.8-cm] casing, Isolation Scanner service processed the acoustic impedance and flexural attenuation data to produce an SLG map. Although the cement is heavy Class G, the flexural attenuation map clearly displays low-density material from X,320 to X,270 m, revealing that the cement is contaminated in that interval. Regardless of the density difference, the material is correctly indicated as solid on the SLG map.

Isolation Scanner log

Cements for CO_2 - Rich Environments

Cements for CO_2 EOR and CO_2 GS

- It has been shown that CO_2 -laden waters can degrade the structural integrity of set Portland cements. Downhole this may lead to a loss of casing protection and zonal isolation. Addition of pozzolans and latex can reduce the set cement permeability and lower the corrosion rate by as much as 50%.
- Specialty CO_2 -resistant cements are in increasing use for CO_2 GS wells (to demonstrate long-term well integrity). EverCRETE^{TM} has proven highly resistant to CO_2 attack during lab tests, including wet supercritical CO_2 and water saturated with CO_2 environments under downhole conditions. It can be used for both primary cementing as well as for P&A purposes
- Self-healing cements for CO_2 service showing promise – engineered particle size distribution (EPSD) blend containing a reactive material that swells upon contact with $CO_{2.}$ Swelling allows closures of micro-fissures, heals the cement sheath and reestablishes well integrity

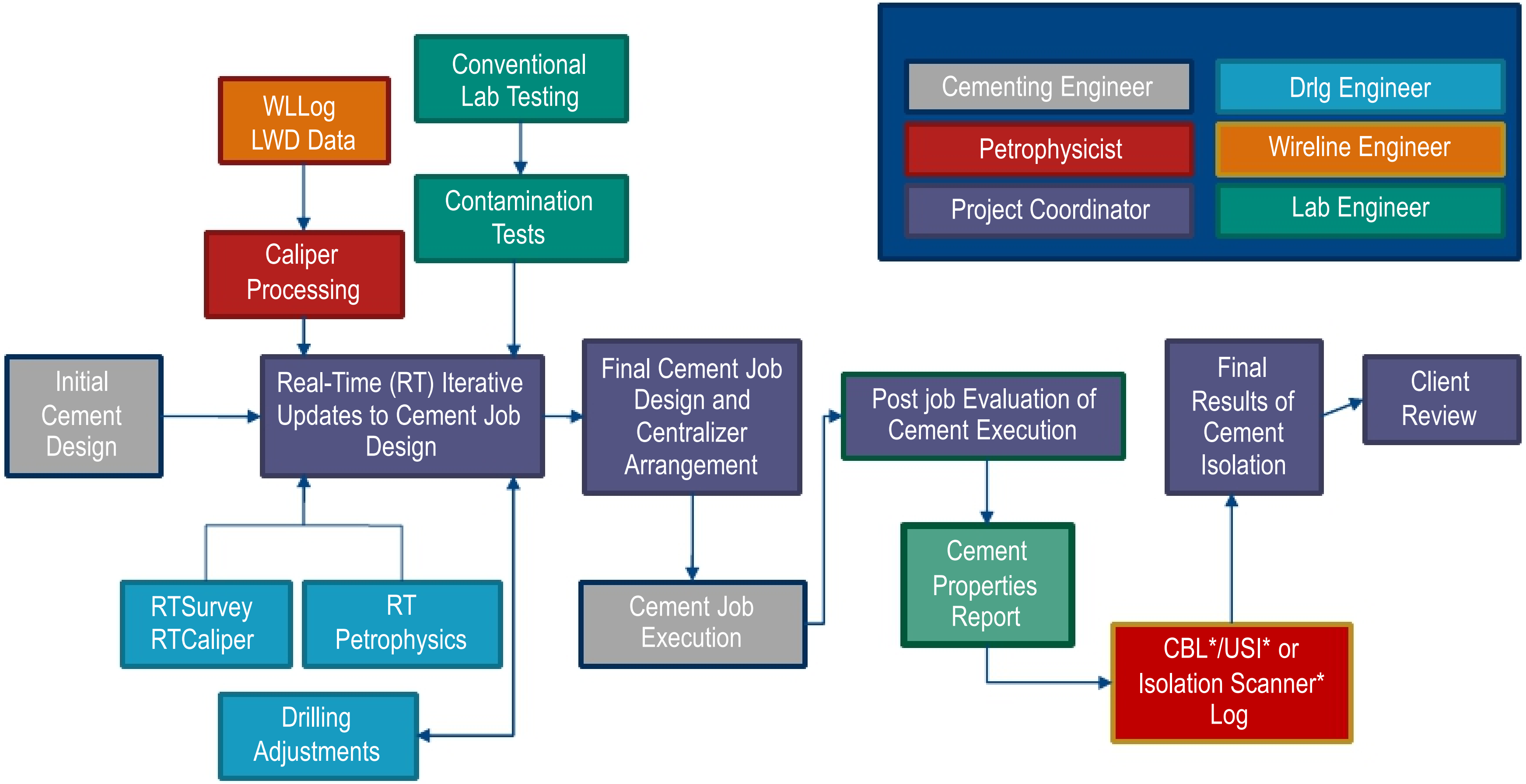
Good Cementing Practices

- Wellbore geometry
- Centralization
- Mud conditioning
- Displacement
- Casing movement
- Accurate BHCT and downhole pressure

- Cover all potential flow zones. Uncemented zones may not flow in short-term but may lead to SCP (sustained casing pressure) over long term

- Pressure tests to confirm isolation at shoe (FIT/LOT)

Cement Design Flow Path (Kirksey, 2013)



Well Design & Construction (Drilling/Workovers)

- Also, CO_2 EOR and CO_2 storage well designs are similar, with latter more stringent in some cases (CO_2 -resistant tubular and cement)
- Due to unique CO_2 phase behavior, be aware of potential for loss of well control (especially during well intervention/workovers)
- CO_2 stored for a long period (decades). Specific requirements for well design and monitoring and abandonment (MMV – monitoring measurement and verification) depending on jurisdiction
- Drilling in CO_2 injection environments results in complex loading conditions on casing/tubular/cements etc. Use casing design software such as WELLCAT^{TM} , DrillPlan^{TM} and also appropriate materials of construction for CO_2 service (tubulars and cements)

Material Selection & Specifications

- Material selection for CO_2 injection wells depends on high strength combined with high corrosion resistance
- Run chemical analysis of reservoir fluids; also temperature and pressure profiles and stresses on tubulars
- Consider contact with wet CO_2 especially in deeper sections of well
- Consider performance at low temperatures (brittle materials may not stop CO_2 leakage), and O_2 – related impacts
- Use appropriate corrosion resistant metallurgy
- Cementing is critical for mechanical performance and life cycle well integrity.
- Use appropriate cements/specialty cements for zonal isolation and well integrity.
- Use current industry best practices for successful cement design, execution and evaluation

Well Integrity

- Complex loads/stresses on casing/tubing and cements from CO_2 injection handled with appropriate software
- Impacts of CO_2 corrosion on well tubular and cements handled with appropriate selection of materials of construction (MOC)
- Minimize thermal cycling (on-off injection and CO_2 supply disruption) to avoid potential cement debonding and injectivity effects
- Annular pressure monitoring – primary concern is loss of well control (SCP etc.) (API RP-90, NORSOK D-010, ISO 16530-1)
- Proper maintenance of CO_2 injection wells necessary – well integrity surveys, improved BOPE maintenance, crew training and awareness, contingency/emergency response
- *User-friendly, complete and up-to-date* well data (including handovers)
- Analyze data, audit losses due to well integrity
- Monitoring – flowing and annular pressures; gas and fluid rates/composition

Common Well Integrity Challenges

Common well integrity problems

Casing trajectory issues

Casing wear

Cement channeling

Pipe deformations

Formation movement

Holes

Internal and external corrosion

Metal loss

Pitting

Split collars

Weatherford, 2014

Injectivity and Regularity

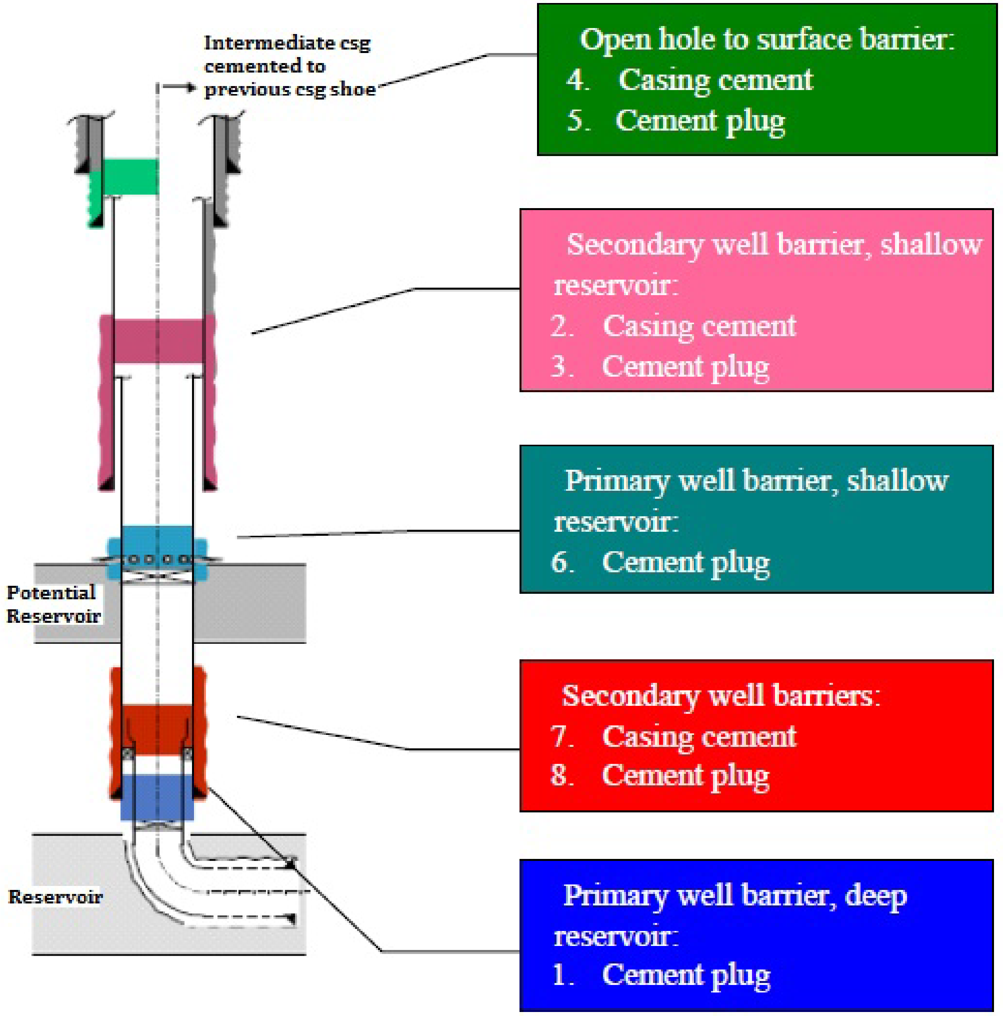
- Injectivity and injection regularity critical for success of a CCS storage project (storage of millions of tons of CO_2 in a 50-year time frame)

- Large scale CO_2 storage requires good/sufficient capacity reservoirs with good petrophysical properties (dissipate pressure buildup and avoid interference with adjacent O&G operations, if present). Primary objective for CCS storage is to maximize injection volumes/storage capacity with minimum number of wells

- Injectivity loss factors: wettability, trapping, increased scaling, paraffin and asphaltene precipitation. Additional factors: fines migration, borehole deformation, fault intersection, facies variation and shale swelling

Typical Well Plugging & Abandonment

- Quality of a P&A evaluated by type of plugging material and plug placement technique
- Plugging materials: cements, formation, grouts, thermosetting, gels, metals (bismuth/thermite)
- Placement techniques: Balanced plug, Dump-bailer, Two-plug and Jet grouting
- Successful P&A protects environment, with downhole integrity, regulatory compliance



Open hole to surface barrier:
4. Casing cement
5. Cement plug

Secondary well barrier, shallow reservoir:
2. Casing cement
3. Cement plug

Primary well barrier, shallow reservoir:
6. Cement plug

Secondary well barriers:
7. Casing cement
8. Cement plug

Primary well barrier, deep reservoir:
1. Cement plug

Source: Randhol and Carlsen/SINTEF, 2001

Summary

- Imperatives for Success in CO_2 Injection Operations: Industry has the technology, knowledge, experience:
  - To safely handle and manage CO_2 operations; to avoid potential catastrophic impacts to safety, human health, environment, economic loss; and maintain Social License to operate
  - Original well design and conversions must meet critical casing and cementing requirements with appropriate materials of construction (tubular and cements)
  - Implement best practices/sound engineering for well design/construction/injection
  - Implement appropriate well integrity testing and monitoring procedures and compliance with stringent regulatory requirements (will also reduce risks from legacy wellbores)