Preventing Methane Emissions by Sealing Wells

Dr. Eric van Oort
The University of Texas at Austin
ARPA-E REMEDY Workshop

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Introduction/Background

- O&G Industry Background (20 yr Shell), UT Austin (8 yr)
- Director of CODA joint industry program at UT dedicated to well integrity, decommissioning & abandonment

New Cementitious Materials	Novel Sensors & Measurement	Advanced Modeling & Software	New & Efficient Abandonment Techniques	Undergraduate Programs

Geopolymers & Hybrids
- Formulation optimization

Geopolymers & Hybrids
- Experimental testing

Geopolymers & Hybrids
- Shrinkage, mitigation

Geopolymers & Hybrids
- Self-Healing

Magneto-Rheological Cement
- Controllable behavior

Magnetic Sensors
- Cement quality, measured

Fiber-Optic Sensors
- RT Displacement tracking
- Cement evaluation
- ZI monitoring
- Loads on casing tracking

Mud Displacement Modeling
- Independent assessment

Geomechanical Load & Casing / Cement Deformation Modeling
- Assessing long-term risks

Wellbore Strengthening Optimization
- Better narrow-margin construction

Wellset JIP
- Path to MR implementation

Shale as a Barrier
- Abandonment, simplified

CODA Well Construction Decom & Abandon

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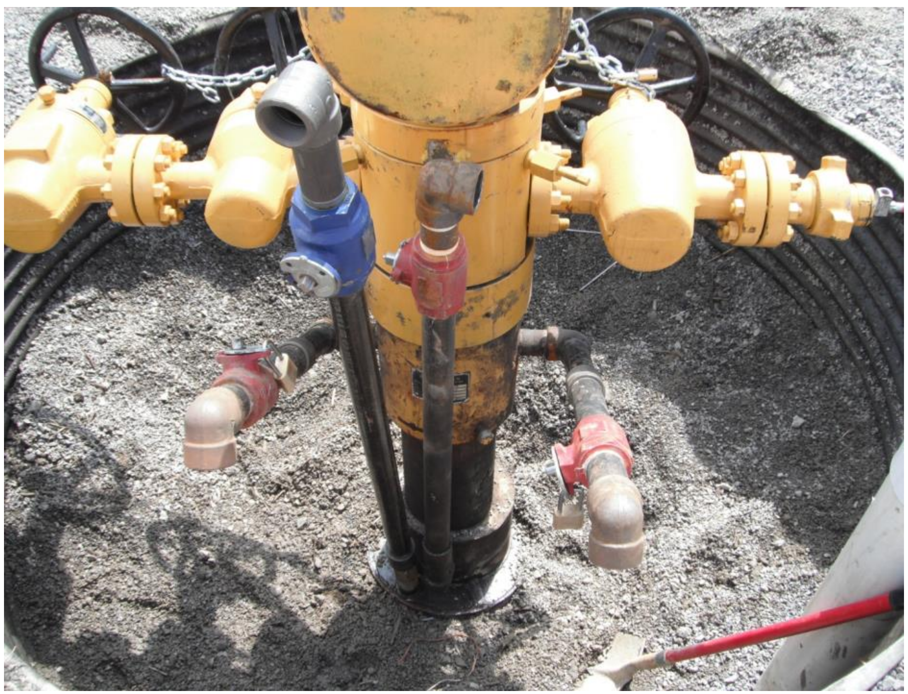
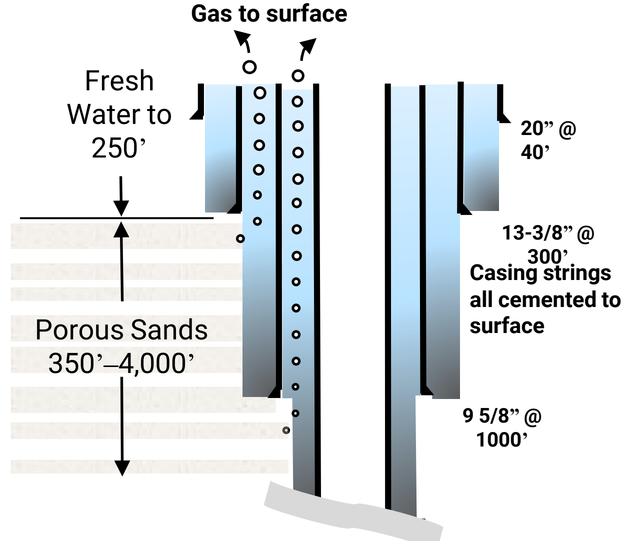
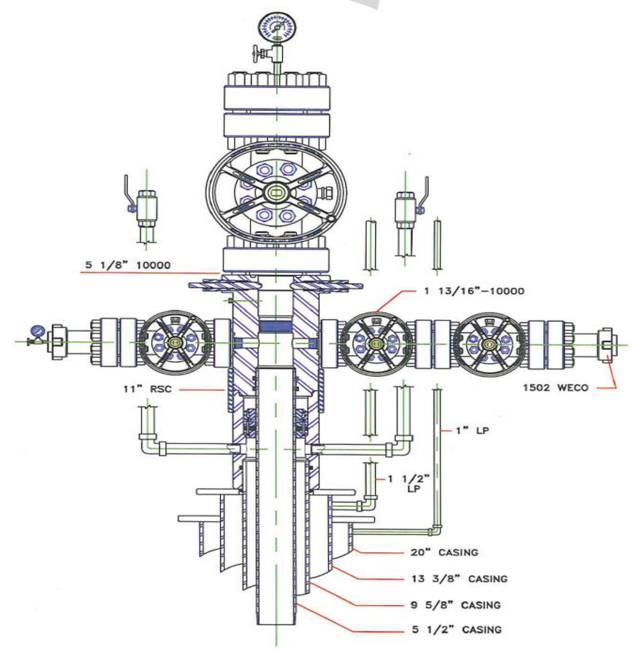
Overview

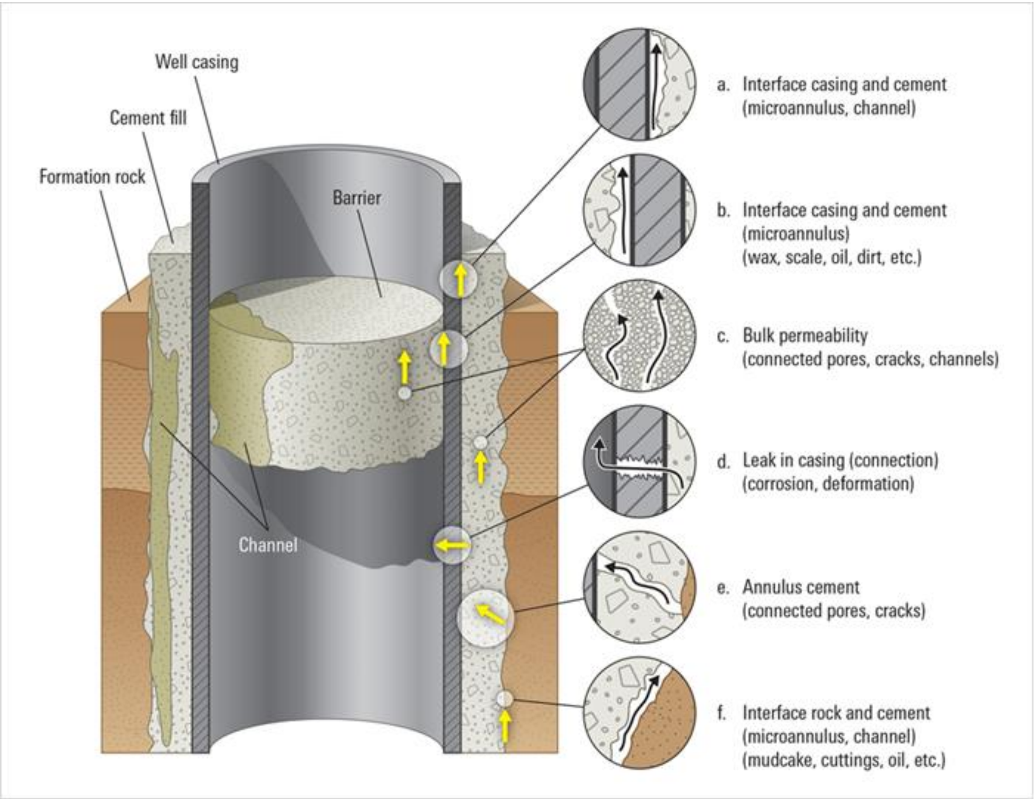
- Problem statement
- 2 Technologies by UT CODA
  - Geopolymers
  - Shale-as-a-Barrier

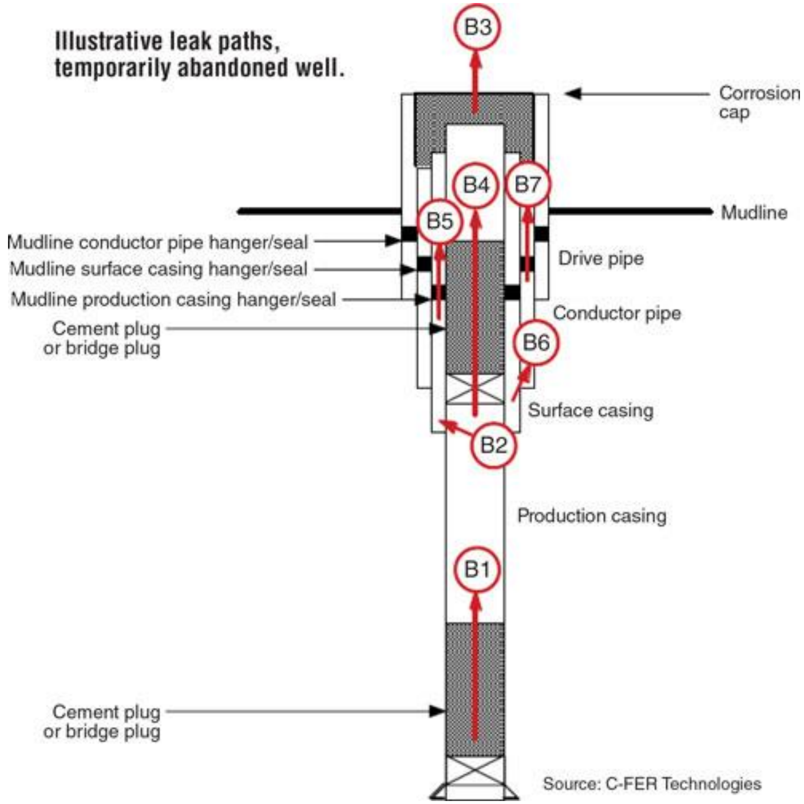






Problem Statement





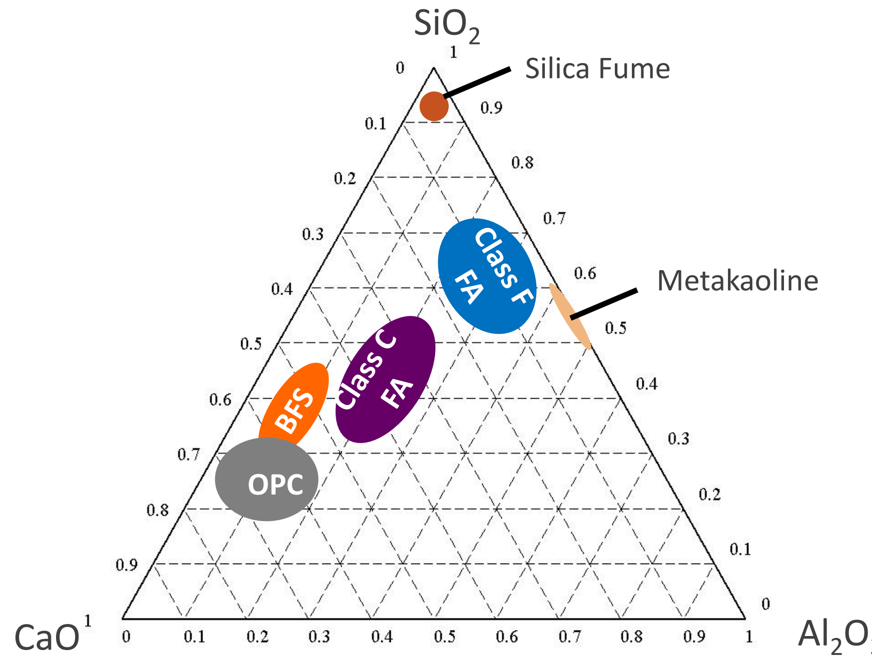
Loss of zonal isolation for P&A'd well/ leak paths due to poor cementing operations and/or casing failure. (Images courtesy Schlumberger & C-Fer)

OPC Alternative: Geopolymer Formulation

Aluminosilicate
eg. Fly Ash

Alkaline Activator
eg. NaOH, Sodium Silicate

Geopolymer



OPC – Ordinary Portland Cement
BFS – Blast Furnace Slag
FA – Fly Ash

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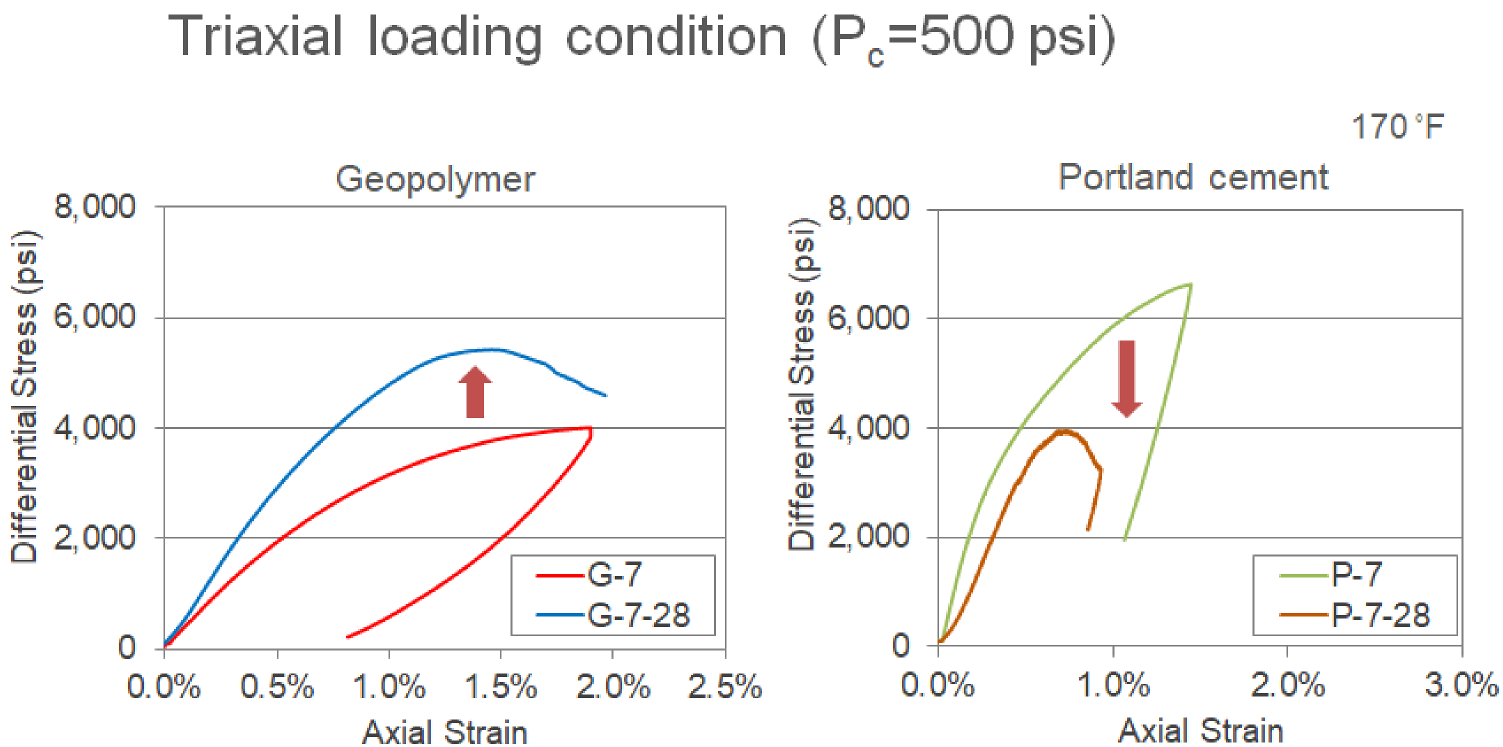
Self-Healing Capabilities of Geopolymers



Geopolymers have been shown to self-heal after damage / cracking, which is not observed in Portland cement: once a crack / leak path is formed in Portland, it is unlikely to close, whereas this is a possibility in geopolymers

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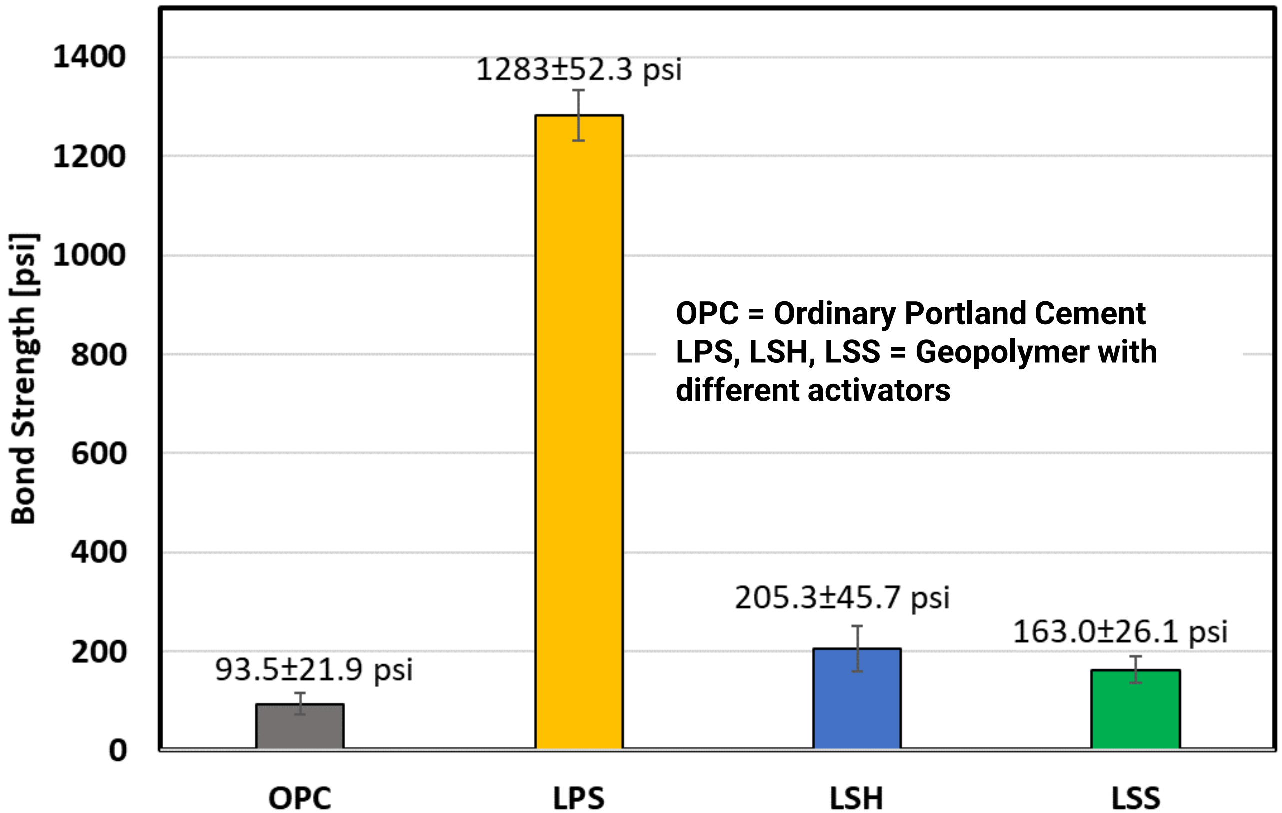
Increased Casing Bonding



Geopolymers demonstrate much better bonding to casing, thereby helping to prevent the formation of a micro-annulus that can be a prime conduit for methane migration to surface

OPC vs. Geopolymer - Conclusions

OPC

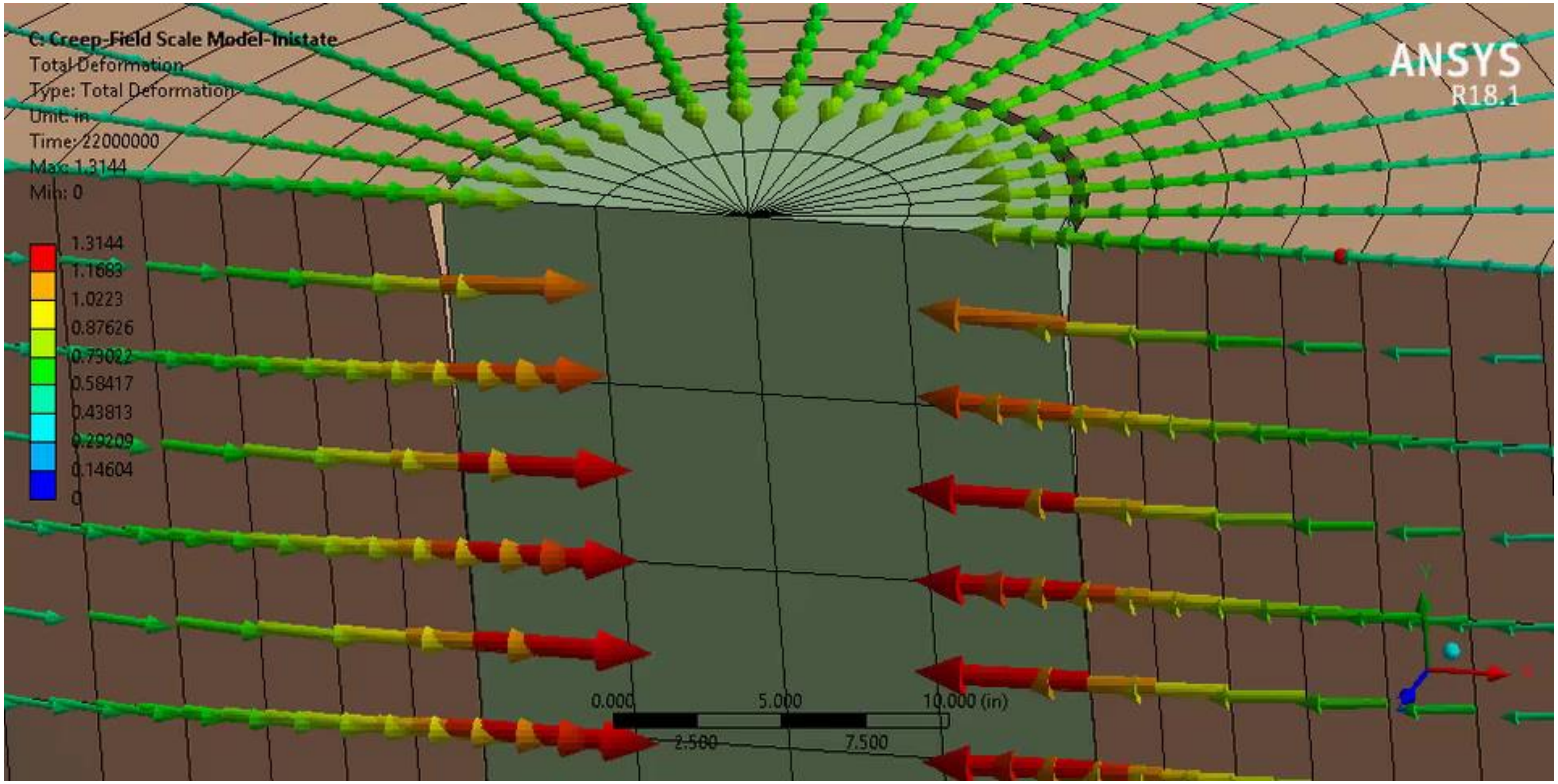
- Low mud contamination resistance (highly sensitive to oil-based fluids)
- Higher compressive strength
- Lower rel. tensile strength
- Lower bond strength
- Fails in brittle mode
- Re-healing not observed
- High CO_2 in manufacturing

Geopolymer

- High mud contamination resistance (will actually solidify oil-based fluids)
- Lower compressive strength*
- Higher rel. tensile strength
- Very high bond strength
- Fails in ductile mode
- Re-healing observed
- No additional CO_2 in manufacturing

* Strength more than sufficient for all cementing applications

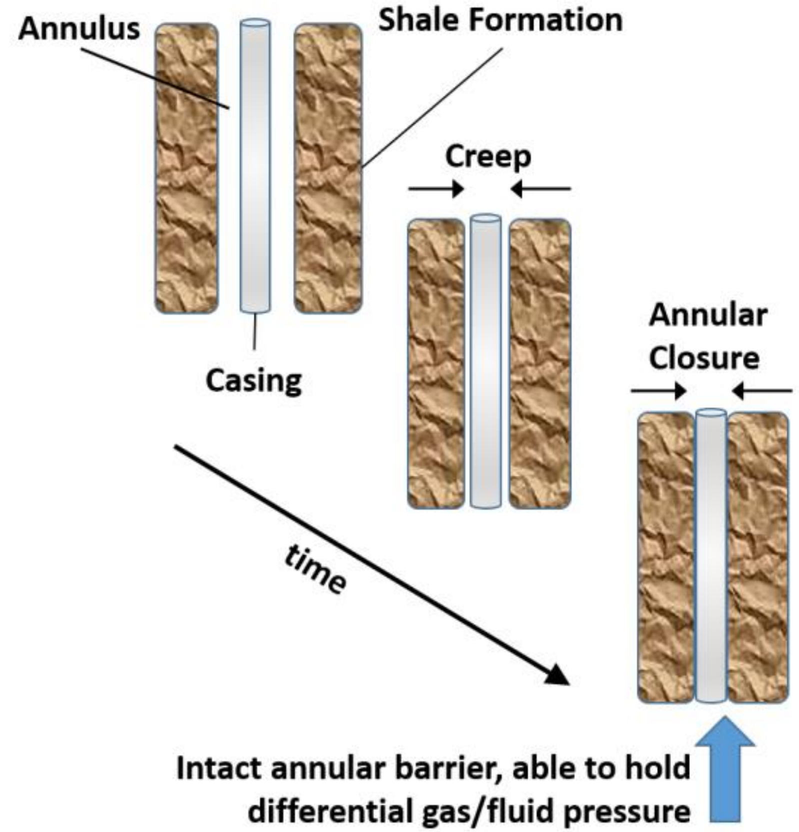
Using Shale (or Salt) as a Barrier - SAAB



Simulation of creep behavior in shale, leading to the closure of an open casing-formation annulus

UT-CODA SAAB Study Objectives

1. Study the sensitivity of the shale to factors such as **temperature**, **pressure** and **annular fluid chemistry** that may influence creep / swelling behavior;
2. Model the experimental results numerically, such that **extrapolation to the larger field scale** becomes possible;
3. From experimental and modeling work, generate **an estimate of minimum shale barrier length and permeability** behind pipe needed to control a certain amount of differential pressure and form a seal.
4. How, once creep/swelling has occurred, this can be definitively **detected by CBL logs** in terms of CBL mV, dB/ft, Impedance, VDL.



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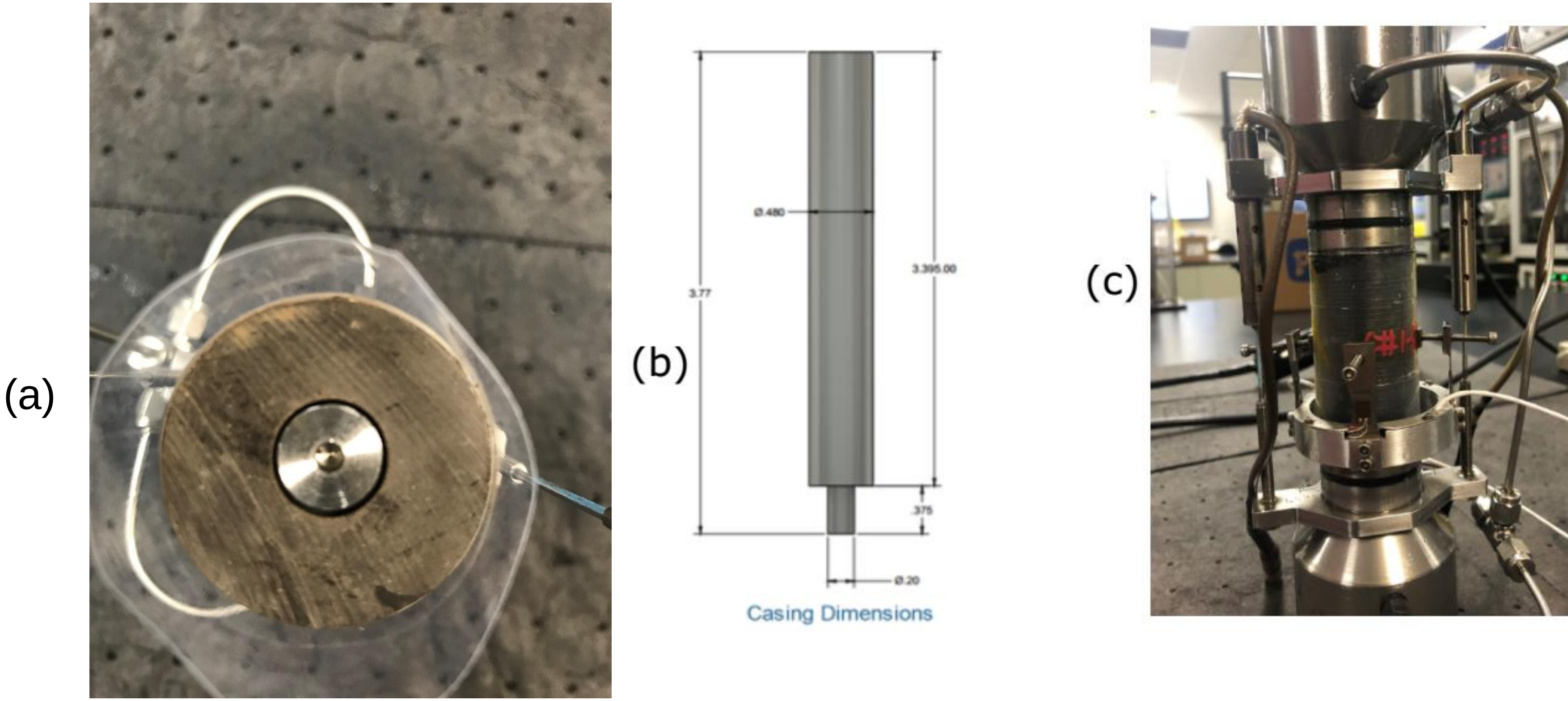
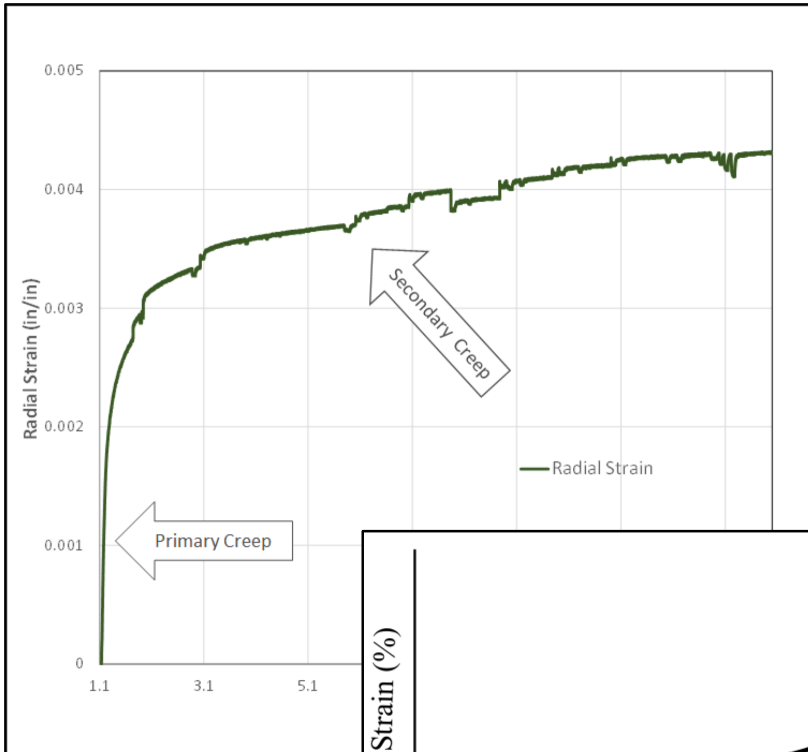
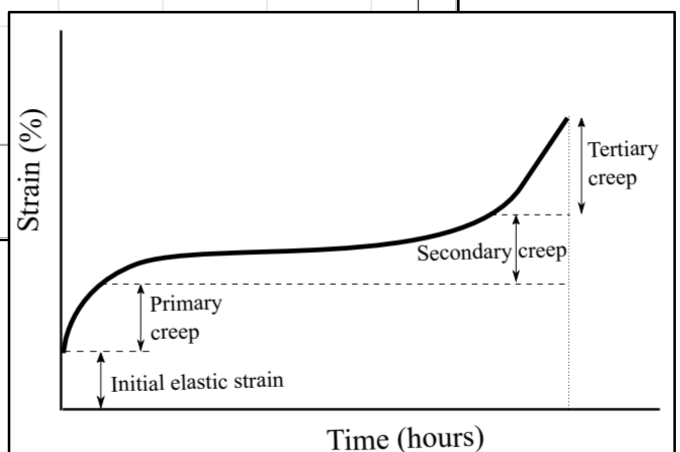
Experimental: Set-Up Details



a) Cylindrical shale sample with casing insert, (b) casing insert, (c) mounted sample, strain gauges and pressure lines.

Experimental: Strain Observation





Creep behavior and barrier formation observed during/after testing

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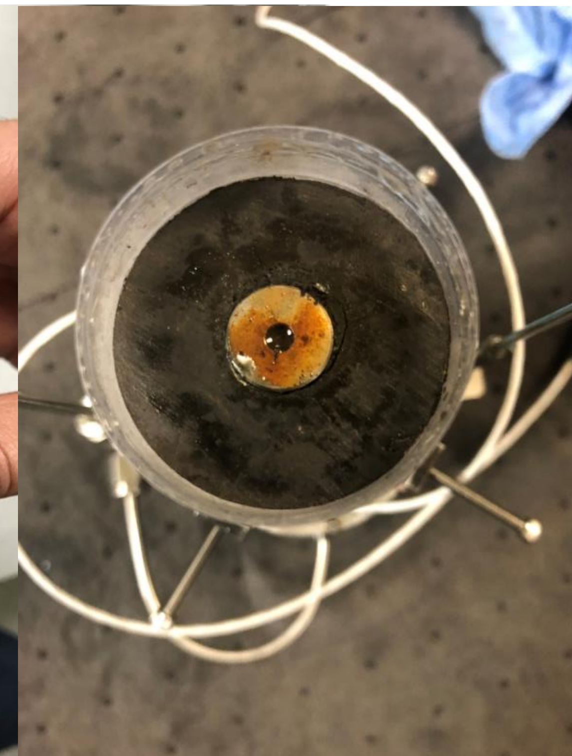
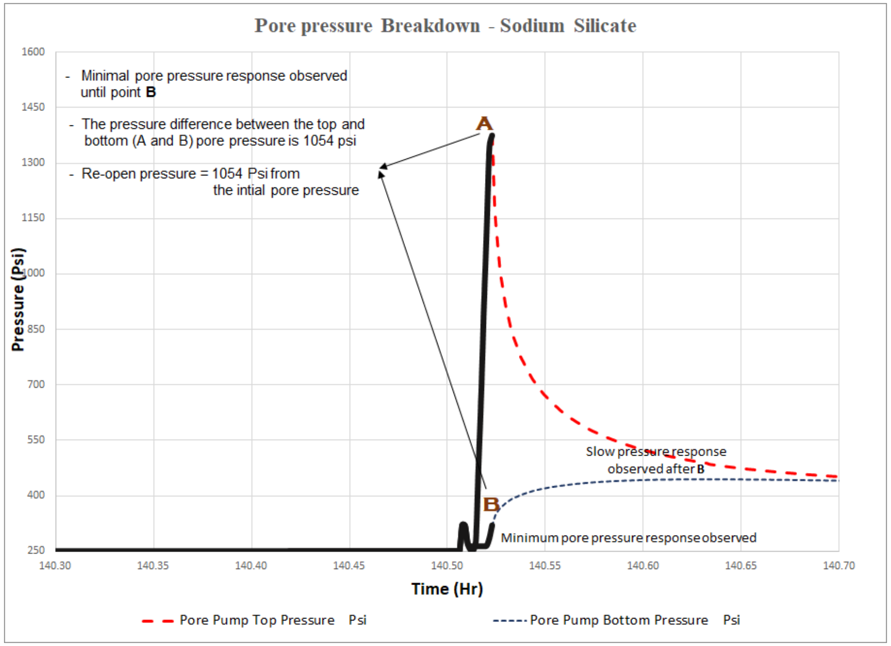
SAAB Test Result Before and After Testing

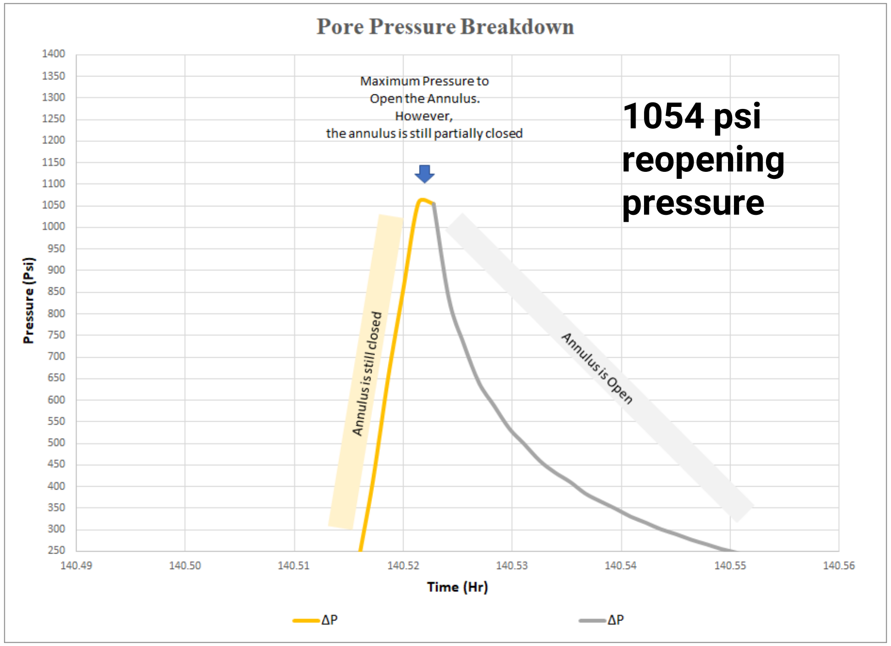
Pre-Test

Post-Test



How good is a SAAB Barrier?





1054 psi reopening pressure

Re-opening pressures (=maximum pressure held by the newly formed barrier without rupturing) approaches theoretical maximum of minimum effective horizontal stress

SAAB Main Conclusions

Shales (and probably salts too) form superior & preferred "Geo-barriers" to prevent leakages to surface

- **Annular pressure reduction** and **temperature elevation** increased the shale creep rate and accelerated the time for barrier formation.
- **Annular fluid chemistry has a large effect on the rate of barrier formation**. Offers the opportunity for <u>accelerated barrier activation</u>.
- **Breakthrough pressure was found to be approaching the theoretical value of the minimum horizontal effective stress**.
- **Shale barrier permeability was found to be in the range of 1.0 - 12.5 μD after only a few days**, which is three order of magnitude larger than the natural shale permeability of 3.5 nD. However, comparable to Portland cement permeability with a lower bound of 10 μD.
- New testing (Phase II) will focus on **barrier characterization using CBL logging techniques**
- **Work to date has only been performed for North Sea shale; it would be prudent to test and verify SAAB behavior for US / Canadian shales also!**

Questions & Contact

WHAT STARTS HERE CHANGES THE WORLD

Dr. Eric van Oort
vanoort@austin.utexas.edu
https://coda.drilling.utexas.edu/

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The University of Texas at Austin

Additional Slides

Why Decommissioning & Abandonment R&D?

Canada is expected to abandon a record number of oil and gas wells in the coming years, with 93,000 wells currently abandoned temporarily. (Source: Globe and Mail, November 21, 2016).

5 structures in the Gulf of Mexico and their associated wells are expected to be decommissioned between 2019-2023 (source: Oil and Gas Journal, May 5, 2014)

Decommissioning activities on the UK Continental Shelf will ramp up over the next 5 years. (Source: Wood MacKenzie, Oil and Gas Journal June 6, 2016)

Decommissioning activities in the North Sea are estimated to require an $80 billion investment between now and 2040. (Source: Wood Mackenzie, Oil and Gas Journal, May 2, 2016)

IHS: Decommissioning of aging offshore oil and gas facilities Increasing, annual spending rising to $13B by 2040

November 29, 2016

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CODA Vision & Mission

Vision & Mission

- To research and develop new materials, systems, methods and computational models for successful, cost-effective well construction and long-term well abandonment

R&D Areas

1. New materials, alternatives to Portland cement
2. New sensors and measurement techniques
3. Advanced models and software
4. New abandonment methods and techniques

- CODA will access relevant **multi-disciplinary expertise** from Civil, Mechanical, Rock-/Geo-Mechanics, Computational and Petroleum Engineering inside and outside of UT Austin
- CODA's focus will be on **applied basic research**, i.e. high-quality research that can be published in leading journals, but with a highly applied character – field application of knowledge, systems and tools is a main goal

CODA Focus Areas

CODA R&D Focus Areas

- **Novel (Cementitious) P&A Materials**
- **Novel Sensors & Measurement Techniques**
- **Advanced Modeling & Software**
- **New & Efficient Abandonment Techniques**
- **Undergraduate Research Programs**

CODA

Well Construction
Decom, Abandon

Fiber Optics for Cement & Casing Monitoring

The University of Texas at Austin

Goal/Scope of DFOS Project

Goals:

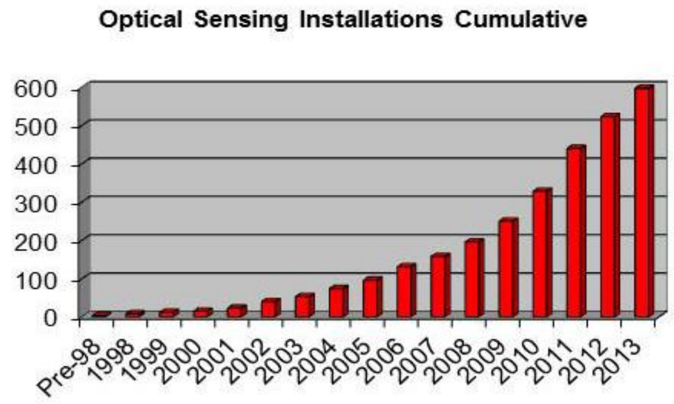
- Investigate both cement and casing health monitoring using Distributed Temperature and Strain Sensing (DTSS) system
- Demonstrate capability to serve as early warning system to prevent/limit casing damage and cement failure, and associated hydrocarbon leakage to surface
- Life-time / real-time / automated monitoring (during well construction, completion / stimulation, production, abandonment phases) without the need for wellbore re-entry

Scope:

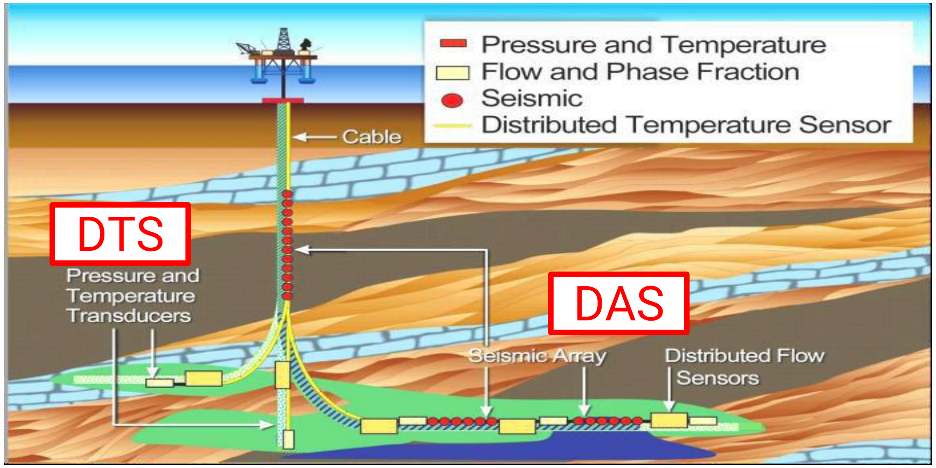
- Casing deformation monitoring (through strain measurements)
- Hydrocarbon leakage detection (through strain measurements)
- General fluid invasion detection (through temperature measurement)
- General 360^{o} cement hydration monitoring (through temperature measurement)

Distributed Fiber Optic Sensing (DFOS) Technology

- FOS in the Oil and Gas Industry
  - Distributed Temperature Sensing (DTS), Distributed Acoustic Sensing (DAS)
- Types of FOS
  - (Fully-)distributed: Raman/Brillouin/Rayleigh backscattering
  - Quasi-distributed: Fiber Bragg Grating (FBG)



Fiber Optic Sensing Installation Cumulative (Weatherford, 2014.)



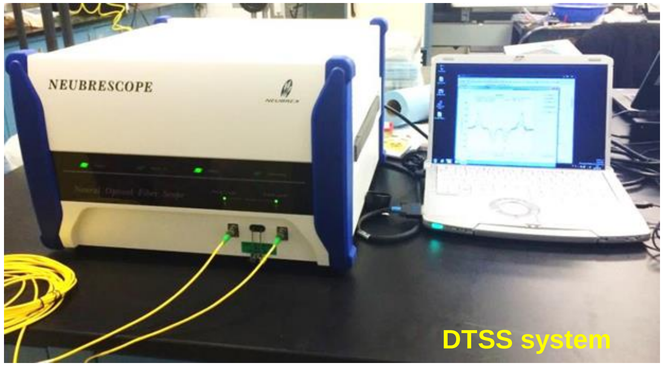
Fiber Optic Sensing Application in the oil and gas well (Baldwin, C.S., 2014.)

Advantages of DFOS System Developed by UT

- Novel technology to monitor the state of zonal isolation using fibers that are sensitive to hydrocarbons
- Real time & in-situ monitoring
- Continuous monitoring capability instead of a “snapshot”
- No need for active wellbore entry
- Life-time monitoring (well construction, production, abandonment)

NEUBREX

- Distributed Temperature & Strain System (DTSS)
  - Neubrescope system by Neubrex
  - high spatial resolution (up to 2 cm) across km’s of cable
  - any standard single-mode optical fiber
  - separated temperature and strain measurement

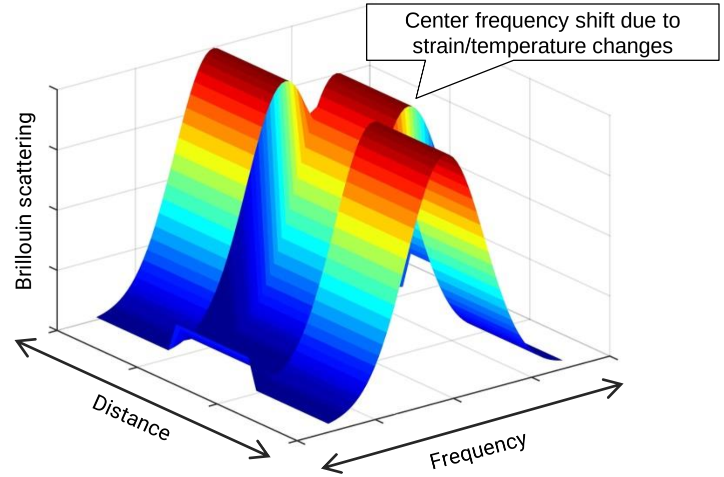


Hybrid Brillouin-Rayleigh DFOS

- For Brillouin (B) backscattering,

$$\Delta v_B = C_{11}\Delta\varepsilon + C_{12}\Delta T$$

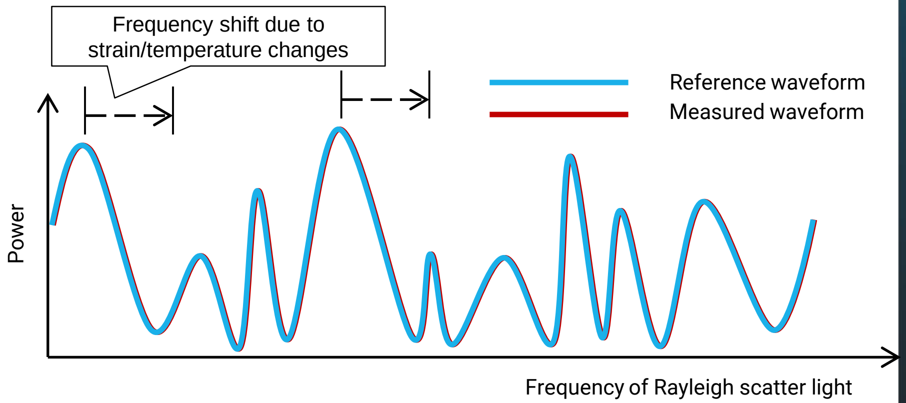
C_{11} =strain coefficient
C_{12} = temperature coefficient



- For Rayleigh (R) backscattering,

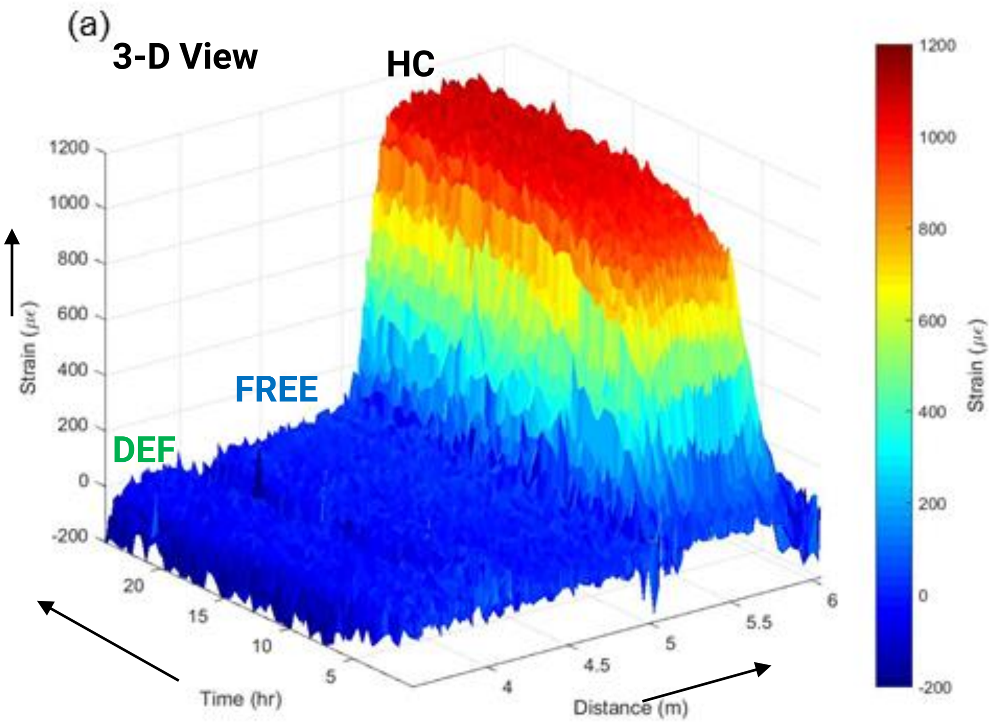
$$\Delta v_R = C_{21}\Delta\varepsilon + C_{22}\Delta T$$

C_{21} = strain coefficient
C_{22} = temperature coefficient



Detect frequency shift by cross-correlation spectrums between reference and current states

DFOS Hydrocarbon Leakage Monitoring



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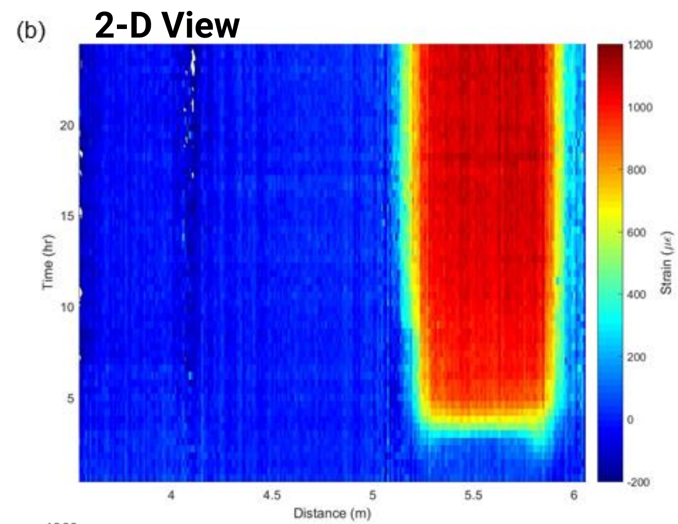

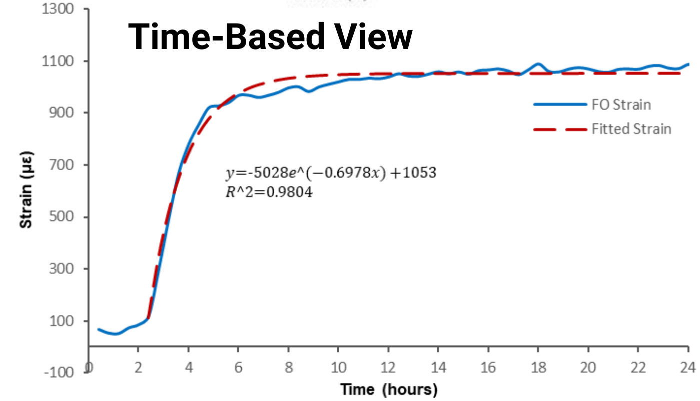

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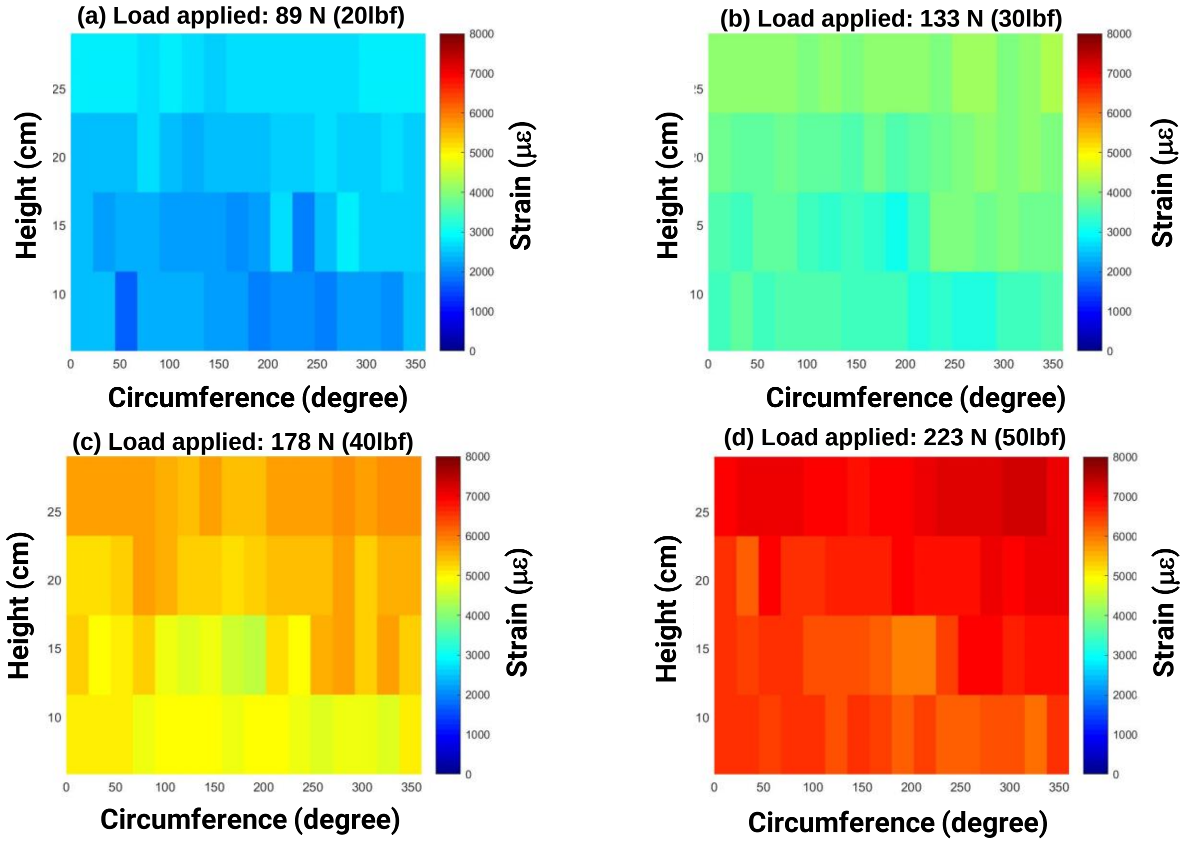
DFOS Strain Response under Different Casing Loads



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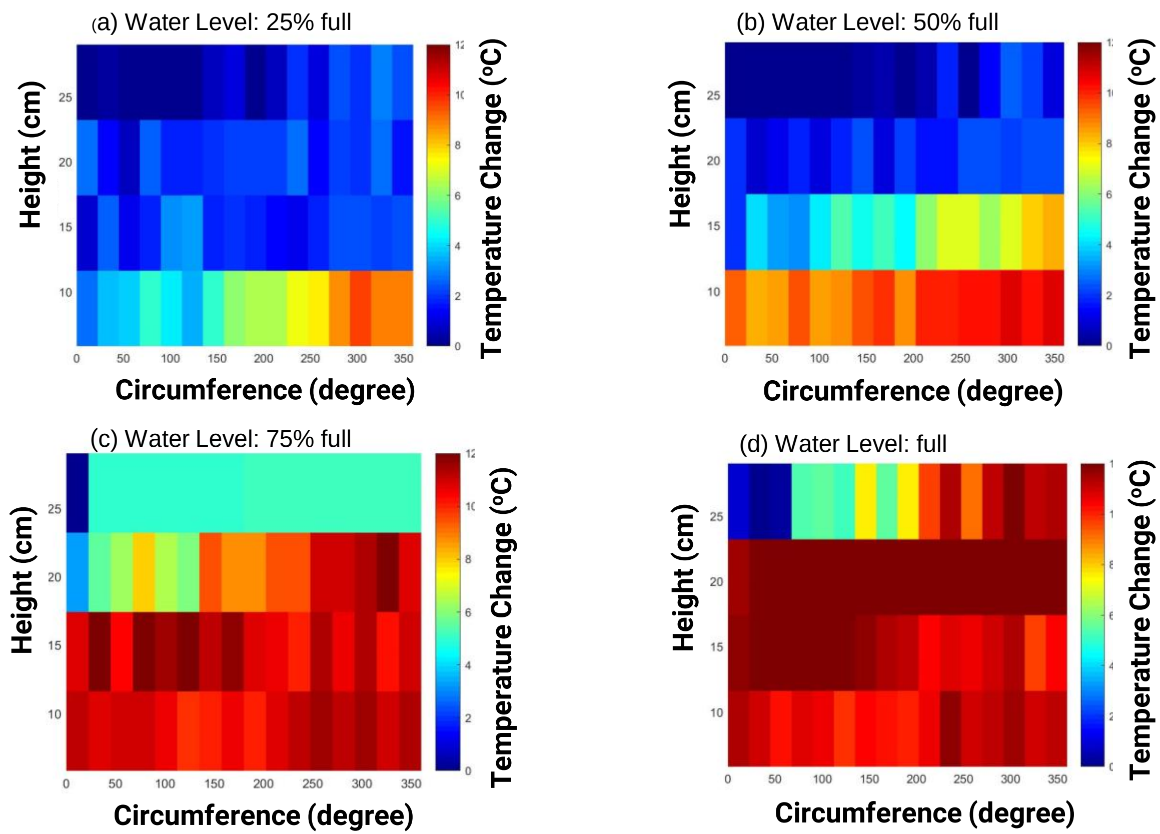
DFOS Elevated Temperature Fluid Level Tracking



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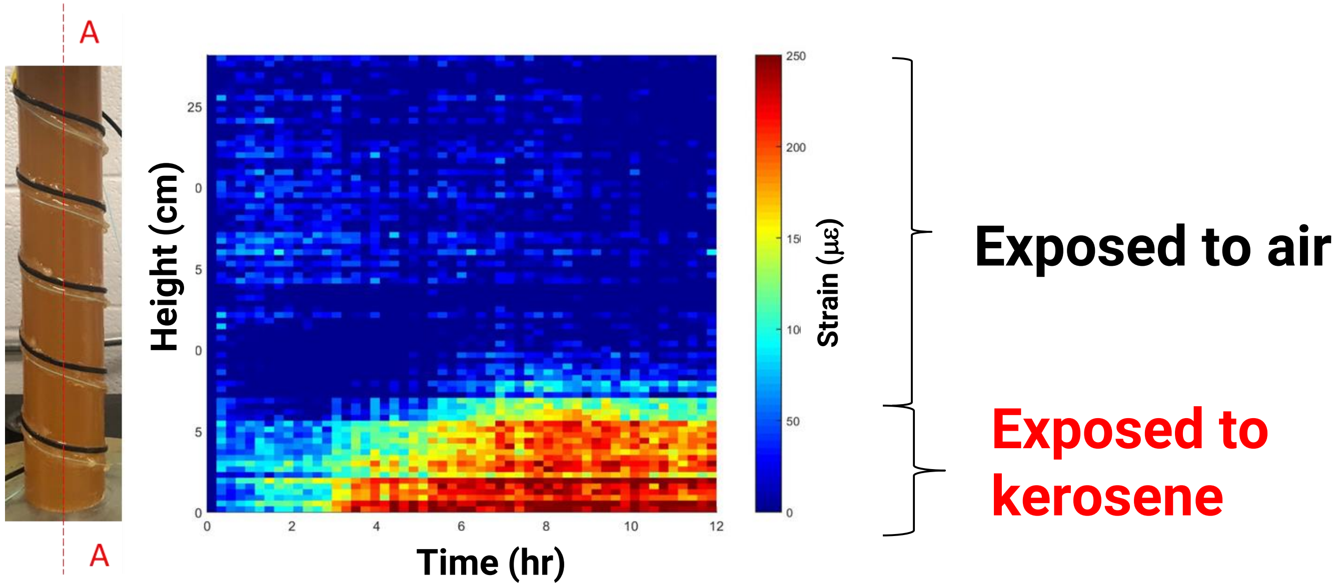
DFOS Hydrocarbon Leakage Detection with Helical Wrapping



- The HC cable strain measurement at section A-A, demonstrates the capability of using the helical wrapping installation to detect hydrocarbons when the cement integrity becomes compromised.

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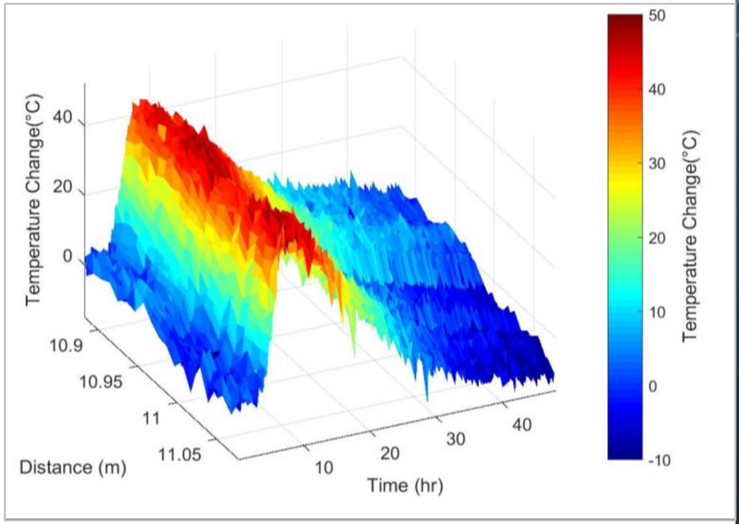
DFOS Cement Hydration Monitoring using Helical Wrapping

- Cement hydration monitoring
  - Exothermic chemical reaction
  - Heat evolution follows a specific time-dependent pattern
- Evaluation of cement job by DTSS (SPE-181429)
  - Actual required wait-on-cement (WOC)
  - Location of top of cement (TOC) and lack of cement in certain sections (e.g. voids, cracks, and channels)
    - Contamination of drilling mud / non-optimal displacement efficiency
- What if the channels are not intersected by the fiber optic cable?
  - Helical wrapping better than axial installation
  - Helical wrapping installation at a lower wrapping angle



Temperature changes due to exothermic cement hydration process with fiber optic cable embedded in the cement sample (SPE-181429)

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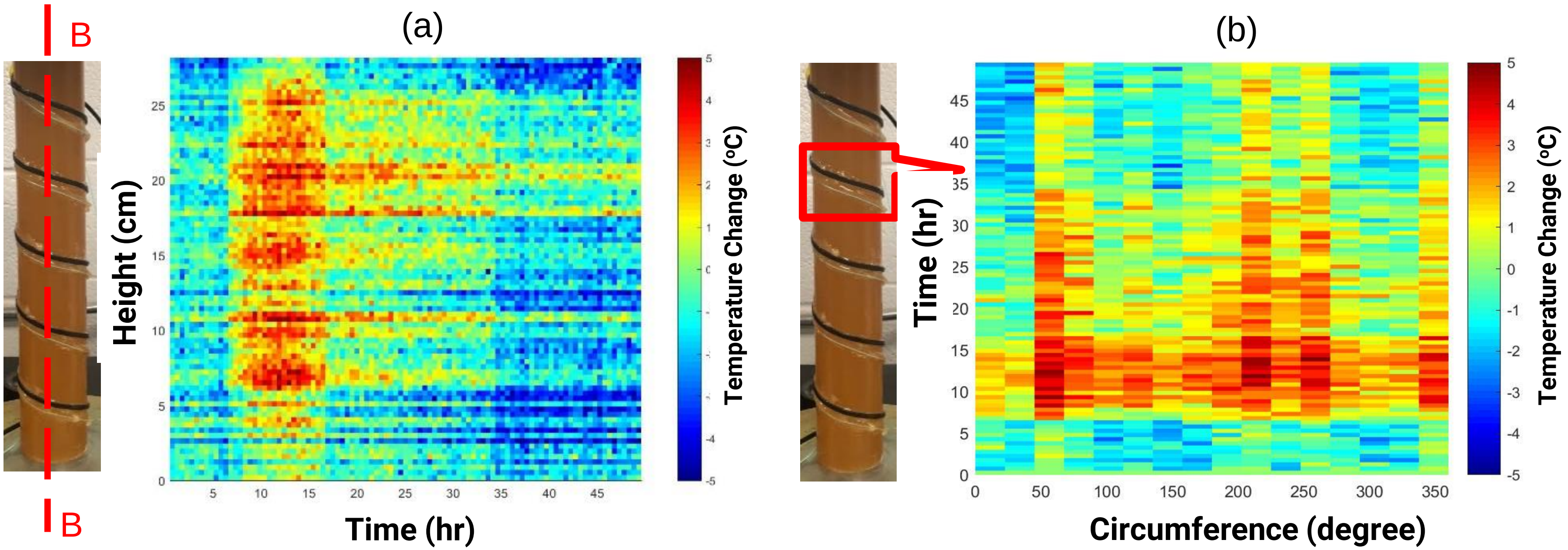
DFOS Cement Hydration Monitoring using Helical Wrapping



- Temperature measurement characterizes the exothermic cement hydration (a) at section B-B, and (b) at one turn of fiber optic cable around the rod (circumferential image).

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DFOS Monitoring Conclusions

Demonstrated fiber optic sensor capabilities include:

- Capability to carry out distributed temperature sensing (DTS), distributed strain sensing (DSS), and also distributed chemical sensing (DCS) → **DCTSS**
- ‘360 degree image’ around the casing provided by helical fiber wrapping installation

Laboratory experiments demonstrate that the system can:

- monitor casing deformation independently using strain measurements
- identify hydrocarbon leakage independently through strain measurements
- detect any fluid migration from another zone with a different temperature
- evaluate the degree of mud displacement and the quality of the cementing job itself

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Cement Displacement Modeling

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What is Important in Cementing?

Cementing is 80-90% a (dis)placement problem and 10-20% a chemistry problem

~85% Displacement!

Placement

- Wellbore integrity - no flows /no losses / no instability
- Wellbore deviation
- Wellbore quality / uniformity
- Annular clearances
- Casing centralization
- Flow rate
- Mud-spacer rheological relationship
- Cement-spacer rheological relationship
- Cement volume - contact time
- Pipe movement (rotation/reciprocation)

~15% Chemistry

Chemistry

- Cement-formation-pipe material property (bonding) relationship
- Cement material properties

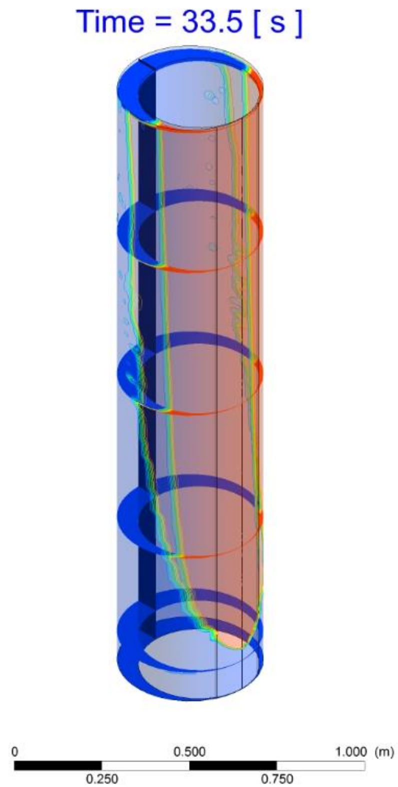
Cement Displacement Modeling

1. **Few displacement models readily available for job design / evaluation**
   - Usually proprietary / black box
   - Usually company exclusive
2. **Cement displacement is a very complex problem**
   - Must account for drilling fluid, spacer(s), cement (lead, tail)
   - Must account for contrast in density, viscosity, polarity, etc. between fluids
   - Must properly reflect non-Newtonian viscosity (3-parameter model such as YPL)
   - Must account for pumping schedule, rates, laminar vs. turbulence, contact time
   - Must account for well trajectory (depth, deviation, azimuth, tortuosity)
   - Must account for casing characteristics (connections, floats, shoe track, etc.)
   - Must be able to simulate pipe eccentricity
   - Must be able to simulate casing movement, i.e. rotation / reciprocation
   - Etc.
3. **Modeling requires sophisticated software**
4. **Modeling requires relevant expertise**

Previous Work on Fluid Displacement

A number of studies have been carried out on fluid displacement in pipes. The main issues observed in most of these studies are as follows:

- Many simplifying assumptions are made which get the numerical results that do not reflect field conditions
- Combined physics of the model complexity such as pipe geometry, eccentricity, etc. with non-Newtonian rheology are barely used in the context of a finite element tool
- Computational requirements are intensive (excessive)
- Model/software is proprietary / not readily accessible



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Contribution by UT Austin

- **CFD modeling work**
  - Numerical model with analytical solutions and simple cases
- **Concentric and eccentric pipe scenarios**
- **Two-phase immiscible flow**
  - Mud / spacer, spacer / cement, or mud / cement displacement
- **Newtonian and YPL fluid models**
  - Most drilling / cementing fluids follow YPL model
- **Effect of pipe rotation**
- **Instability study and gravity effect**
- **No simplifying assumptions in solving the N-S equations!**

2017 SPE / IADC Drilling Conference 2017

Society of Petroleum Engineers

SPE-184702-MS

Advanced Modeling of Cement Displacement Complexities

Saeid Enayatpour and Eric van Oort, The University of Texas at Austin

Abstract

Cement job success is largely determined by fluid displacement efficiency. Optimum displacement requires understanding of flow patterns, frictional pressure losses and mutual interactions of mud, spacers and cement in annular spaces. Modeling this complex behavior is very difficult, but understanding it is essential to guarantee displacement success. A state-of-the-art cement displacement study was carried out using the very latest in computational fluid dynamics (CFD) modeling techniques, to identify practical guidelines and solutions to cement displacement challenges.

A state-of-the-art 3D "3-phase" (i.e. mud-spacer-cement phases) CFD model was created and simulations were carried out, featuring tracking of fluid interfaces during displacement, calculation of frictional pressure drops, and characterization of complex flow profiles. These simulations accounted for the effects of such complexities as non-Newtonian rheological behavior of all fluids involved, eccentric / narrow annuli, and pipe movement / rotation. The integrated study clearly identifies the root cause(s) of cement displacement failures and highlights comprehensive practical solutions, which are proposed for implementation in field operations.

There are many causes for cement displacement problems and failures, including poor borehole conditioning, inappropriate displacement flow rates, insufficient casing centralization, viscosity contrast mismatches between mud-spacer-cement leading to interface instabilities, etc. Our high-resolution finite element study quantifies the effects of many of these causes and highlights parameters that can improve displacement, such as avoiding high shear strength in non-Newtonian mud and cement rheology, reducing pipe eccentricity and applying pipe rotation during displacement. The modeling approach is used to identify optimum parameters values, and studies interdependencies between factors, for instance determining optimum rheology, flow rate and pipe rotation speeds when pipe is placed eccentrically in the hole, in order to maximize the probability of displacement success in the field. Particularly revealing are the non-intuitive results obtained while modeling mud, spacer and cement as non-Newtonian yield power law (YPL) fluids, which has never been done before.

This paper presents: (1) a new, state-of-the-art 3D CFD model; (2) advanced numerical analysis of cement displacement, taking into account complexities such as non-Newtonian rheology, borehole enlargement, pipe eccentricity, and pipe movement during displacement; (3) practical guidelines derived from the modeling results that can be used for improved cement job pre-planning and field application.

SPE-184702-MS
Advanced Modeling of Cement Displacement Complexities
Saeid Enayatpour and Eric van Oort, The University of Texas at Austin

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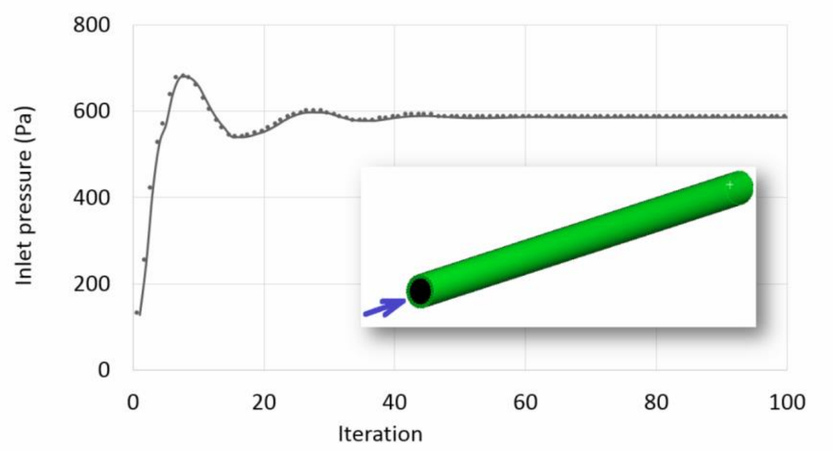
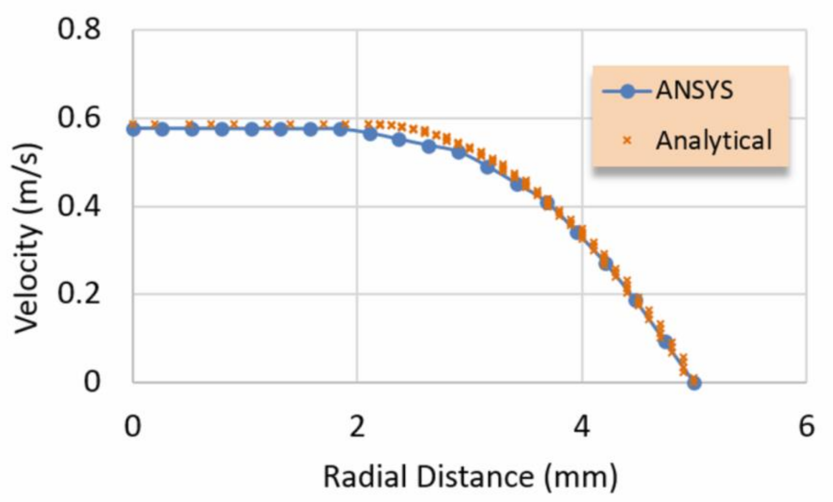
Modeling Approach

- ANSYS Fluent 17.0 CFD software Finite Volume Method (FVM)
- Multi-"Phase" Modeling
  - Mud, spacer, cement
- VOF Method
  - Free surface modeling to track fluid interfaces
- Validation with analytical solutions & simple cases
- Application to new, complex cases

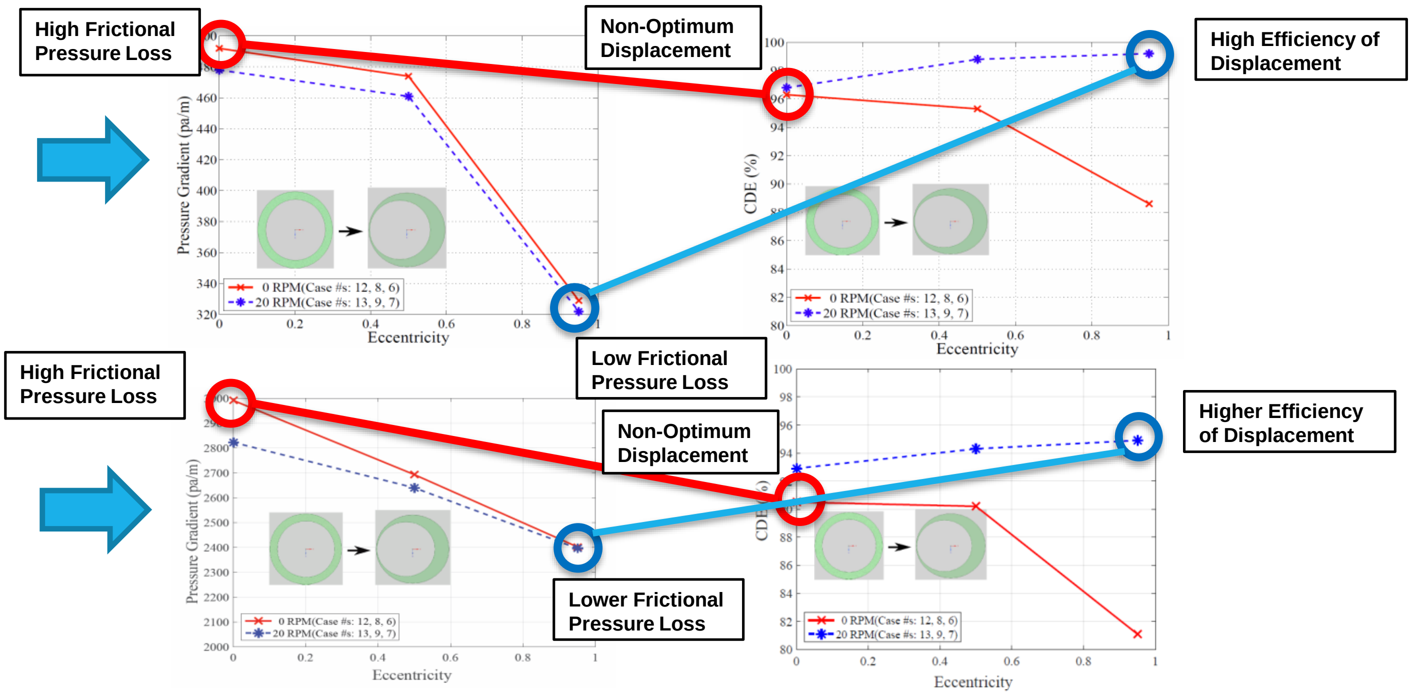




Effect on Frictional Pressure / CDE

Intermediate Casing

Production Casing



Instead of centralization, focus on rotation (rotatable casing/liner hangers, connections, etc.) instead!

Conclusions

- Advanced CFD Model for cement placement job design and optimization
  - No simplifying assumptions to solving NS equations
  - Non-Newtonian rheologies (mud, spacer, cement)
  - Pipe Eccentricity
  - Pipe Movement (primarily rotation)
  - Laminar & Turbulent Flow
  - Borehole Enlargement
  - Two phase flow instability and gravity effect
- Intent to make advanced modeling more readily available for cement job planning and execution
- Work will continue as part of new Consortium for Well Decommissioning and Abandonment (CoDA)