CODA Industry Affiliate Program (IAP)
Introduction

April 2017
Aramco Services Company, Houston
Introducing CODA

**co·da**

/ˈkôdə/  

*noun*  
MUSIC

the concluding passage of a piece or movement, typically forming an addition to the basic structure.

- the concluding section of a dance, especially of a pas de deux, or the finale of a ballet in which the dancers parade before the audience.
- a concluding event, remark, or section.  
"his new novel is a kind of coda to his previous books"
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
Guaranteeing Permanent Abandonment

• Having to fix old, leaking wells after abandonment is a costly, time-consuming proposition (e.g. Porter Ranch gas well in CA)

A relief well being drilled last month to stem the gas leak in Porter Ranch. (Brian Khan / Los Angeles Times)
Vision & Mission

• To research and develop new materials, systems, methods and computational models for successful, cost-effective, 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 Focus Areas

CODA R&D Focus Areas

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

- Self-Healing Geopolymers, MR Cement Barriers
- Fiber Optic Sensors
- Displacement & Geomechanics Modeling Software
- “Shale Formations as a Natural Barrier”

CODA
Well Construction
Decom, Abandon
CODA’s Multidisciplinary Leadership Team

- CODA will access relevant **multidisciplinary 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.
UT CODA Capability: Laboratories

API HPHT Cementing Lab

- 2 HPHT (40,000 psi, 600°F) consistometers
- Various pressurized viscometers, including a HPHT (30,000 psi, 500 °F) viscometer
- 3 Atmospheric viscometers
- Stirred fluid loss cell (2,000 psi, 400 °F)
- Static gel strength (SGSM) tester (5,000 psi, 400 °F)
- 2 Twin low pressure UCAs (5,000 psi, 400 °F)
- 1 HPHT UCA (20,000 psi, 400 °F)
- Dual curing chamber (5,000 psi, 700 °F)
- Various load frames for (bond) strength investigation

Rock Mechanics Lab

- Triaxial load frame
- Pressure transmission test equipment
- Hydraulic fracturing
Fluids Laboratory
• Fully equipped HPHT (30,000 psi, 500°F) fluids laboratory

External Lab Capability (MRL Houston)
• Various load frames and state-of-the-art equipment for a large variety of rock-mechanical tests, including for “shale as a barrier” investigation
UT CODA Capability: Previous Publications

UT CODA Capability: Software & Programming

• FEA Programming
  o ANSYS
  o COMSOL
  o ABAQUS
  o DIANA

• Other programming
  o Matlab / Simulink
  o C / C# / C++
  o Python
  o Java
  o As required by members
New Materials: Geopolymers & Hybrids

**Abstract**

Targeting the incompatibility issues between traditional Portland cements and non-aqueous drilling muds, a solidification technique based on geopolymers was recently introduced to the industry. This technique was achieved by incorporating non-aqueous fluids (NAF) such as synthetic-based or oil-based drilling mud in a geopolymer cement that is formed by blending an aluminosilicate powder with an alkaline activating solution. In a previously completed study, the consolidated mud, or “geopolymer hybrid”, was evaluated for its compressive strength, thickening time and stability for applications including primary cementing as well as lost circulation control. In an effort to further develop the geopolymer hybrid system as a new generation well cementing material, the present work comprehensively studies its mechanical properties, self-healing capabilities and cement-to-pipe bond strength.

One of the concerns currently preventing the use of geopolymers for well cementing is its low early compressive strength. This study shows that although the early age uniaxial compressive strength of geopolymer is lower than that of Portland cement, with an applied confining stress, geopolymers have more than sufficient strength for primary cementing applications. Furthermore, the abilities of cement to properly bond with steel casing and rock formations, as well as to withstand subsurface stress changes over time are of paramount importance for long-term cement integrity. The triaxial tests performed in this study show that geopolymers are less brittle than Portland cement, and can therefore accumulate stress changes without localized failure. The geopolymer bond strength measurements showed that geopolymer could bond to steel even in presence of non-aqueous drilling muds. In addition, the triaxial tests revealed that geopolymers exhibit true self-healing capabilities, characterized by samples fully regaining their mechanical competence with 28 day post-failure strength exceeding the native 7-day strength. Portland cement, in comparison, retained lower ultimate strength than its 7-day strength. The self-healing capability of geopolymers is ideally suited to adapt to subsurface stress changes, making such materials ideally suited for use as permanent barriers in plug and abandonment operations.

**SPE 184675 – SPE/IADC Drilling Conference 2017**
New Materials: Geopolymers & Hybrids - 2

![Geopolymers diagram]

Aluminosilicate eg. Fly Ash + Alkaline Activator eg. NaOH → Geopolymer

- New Materials: Geopolymers & Hybrids

CODA
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SiO₂
Silica Fume

CaO

Al₂O₃

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

Class C
Class F

SLIDE 13
New Materials: Geopolymers & Hybrids - 2

**SPE 180325 HIGHLIGHTS**

### Rheology

- **Geopolymer**
  - 0% SBM
  - 10% SBM
  - 20% SBM
  - 30% SBM
  - 40% SBM

### Strength

- **170 °F, 3000 psi**
  - 0% SBM
  - 20% SBM
  - 30% SBM
  - 40% SBM
New Materials: Geopolymers & Hybrids - 3

Pre-loading on day-7, load again on day-28
– Self-Healing Effects
New Materials: Geopolymers & Hybrids - 4

ANALOGY: REHEALING BROKEN BONE
New Materials: Geopolymers & Hybrids - 5

Cement-to-pipe bond with clean steel pipe

- Steel Bar
- Cement
- Steel Base Plate

Apply vertical load at constant rate

7-day cement-to-pipe shear bond strength (psi)

- Portland (1)
- Portland (2)
- Geopolymer (1)
- Geopolymer (2)

170° F

Time (s)

0 50 100 150 200

0 50 100 150 200

CODA Well Construction
Decom & Abandon
Introduction
SLIDE 17
• Magneto-rheological cements are sensitive to magnetic fields:
  • Control viscosity / rheology
  • Control flow direction & pattern
  • Use to generate top-, bottom- and straddle packers

• MR cementitious materials could potentially be used for abandonment purposes, e.g. to generate cost-effective annular barriers
New Materials: MR Cement - 2

- Preliminary work shows that strong annular magnetic field can be generated, even for carbon steel casing strings.
• Can the cementing sensor used for primary cementing and zonal isolation monitoring be used for long-term abandonment monitoring?

• Can the sensor function as a long-term sensor in the subsurface (under the influence of temperature, pressure, chemical attack, etc.)

• The coating of the sensor cable can selectively identify different gases / fluids and communicate their presence through an induced swelling / strain response

• Use as early indicator in case of problems, and to demonstrate regulatory compliance

Sensors & Measurements - 2
Novel Techniques: Shale as a Barrier - 1

• Shale behind casing could form an annular barrier that may simplify abandonment measures and cost
• Shale may seal (small) cracks in cement
• Shale could accomplish this through:
  • Creep
  • Smectite swelling
  • Yielding and collapse
  • A combination of these
• Sealing will be determined by factors included shale mineralogy, pore fluid chemistry, annular fluid chemistry, pressure and temperature
Novel Techniques: Shale as a Barrier - 2

- Proposed project revolves around delineating the effects on shale barrier formation
  - shale mineralogy
  - pore fluid chemistry
  - annular fluid chemistry / mud composition
  - pressure
  - temperature

- Phased study from small scale to large scale test set-ups
Novel Techniques: Shale as a Barrier - 3

• Feasibility study yielded highly promising results
Modeling: Geomechanical Loads on P&A’d Wells

• Model the effects of subsurface changes on abandoned wells and their isolation measures

• Take into account:
  • Prior production history, reservoir compaction and subsidence (if present)
  • In-situ stress changes
  • Temperature and pressure changes
  • Exposure to gases & fluids
  • Load shedding by cementation (see e.g. Jammer & Klever, SPE 173069)
New ANSYS Model for Mud Displacement:

- Two-phase immiscible flow
  - Mud / spacer or mud / cement displacement
- Extension to three-phase planned
- Newtonian and YPL fluid models
  - Most drilling / cementing fluids follow YPL model
- Effect of pipe rotation
- Concentric and eccentric pipe scenario’s
- No simplifying assumptions in solving the N-S equations!
Example: Deepwater Intermediate String Calculations

13 5/8” Casing in 16.5” hole

<table>
<thead>
<tr>
<th>Variables</th>
<th>Fluid Properties</th>
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<tbody>
<tr>
<td>Newtonian</td>
<td>( \rho = 1900 \text{ kg/m}^3, \eta = 0.05 \text{ Pa s} )</td>
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<tr>
<td>YPL (thin)</td>
<td>( \rho = 1850 \text{ kg/m}^3, K = 0.6 \text{ Pa s}, \eta = 0.54; \tau_0 = 1.2 \text{ Pa}; \text{ critical shear rate} = 10^{-5} \text{ (s}^{-1}) )</td>
</tr>
<tr>
<td>YPL (thick)</td>
<td>( \rho = 1800 \text{ kg/m}^3, K = 0.55 \text{ Pa s}, \eta = 0.57; \tau_0 = 1.5 \text{ Pa}; \text{ critical shear rate} = 10^{-5} \text{ (s}^{-1}) )</td>
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<table>
<thead>
<tr>
<th>Displacement Cases</th>
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</thead>
<tbody>
<tr>
<td>I Newtonian rheology used exclusively</td>
</tr>
<tr>
<td>II YPL (thin) is displacing YPL (thick)</td>
</tr>
<tr>
<td>III YPL (thick) is displacing YPL (thin)</td>
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<table>
<thead>
<tr>
<th>Pipe Eccentricity</th>
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<tbody>
<tr>
<td>Case 1 / 2 / 3</td>
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<table>
<thead>
<tr>
<th>Pipe Rotation</th>
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<tbody>
<tr>
<td>Case A / B / C</td>
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<thead>
<tr>
<th>Flow Rate</th>
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<tbody>
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<td>Case a / b / c</td>
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<tr>
<th>Casing Section Length Simulated</th>
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<td>Case I / II / III</td>
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<th>Eccentricity Case</th>
<th>Rotation Case</th>
<th>Flow Rate Case</th>
<th>Length Case</th>
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<td>A</td>
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<td>C</td>
<td>c</td>
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Combined Effect of Eccentricity & Pipe Rotation

Quiz: what are the possible implications of the results in these two graphs?
Cement Displacement Video
CODA R&D and Technology Development Plan

• Evaluate and develop new materials for P&A application:
  • Geopolymers & geopolymer hybrids
  • Magneto-rheological fluids
  • Other materials (e.g. resins)

• Evaluate and develop new sensors for P&A monitoring:
  • Starting with fiber-optic sensors

• Evaluate and develop novel abandonment methods:
  • Starting with “shale-as-a-barrier”
  • Non-conventional techniques using e.g. magnetic fields in combination with MR fluids

• Develop computational models & software, and study P&A cases for:
  • Geomechanical loads on abandoned wells and effects on isolation
  • Mud displacement and isolation plug placement

• Workscope and timing is determined by levels of industry funding and associated resourcing

• Software access is included as a part of CODA membership
CODA Communication

- 2 face-to-face meetings annually
- 2 virtual meetings annually
- Dedicated website
- Dedicated reports & software portal for members
- Journal & conference papers (incl. joint publications with members)
- Intellectual Property (IP)
  - Not the main goal of the consortium: main focus is on student education / talent development, meaningful deliverables for members, and publication of excellent R&D results
  - Any IP will be filed with UT Office of Technology Commercialization (OTC) and licensed back to members
    - Non-exclusive license if multiple members are interested
    - Exclusive license if only one member is interested

Quarterly Interaction with Members for:
- Progress reporting
- Reality check
- New ideas vetting & input
CODA Membership

• Launch date: May 2017
• CODA membership fee: $50K/yr
• RAPID membership fee: $75K/yr
• RAPID + CODA membership: $100K/yr
• Contact:

  tesse@mail.utexas.edu
  vanoort@austin.utexas.edu
Thank You & Questions