OESI Zonal Isolation R&D Effort

OESI Webcast, 13 October, 2015

Dr. Eric van Oort
Lancaster Professor, UT Austin
10:00 AM – 11:30 AM  
**OESI Zonal Isolation R & D Effort**

- **Introduction**
  - EVO Introduction
  - UT R&D Program
  - Why care about zonal Isolation?

- **Industry Developments & State-of-the-Art**
  - Novel cementing systems
  - Novel cementing techniques

- **UT - Austin / UoH Efforts**
  - Lab Capabilities
  - General ZI R&D program
  - OESI effort: Improving Displacements

- **Q & A Session**
Dr. Eric van Oort

- B.J. Lancaster Professor - UT Austin
- Co-PI, OESI
- CEO, EVO Energy Consulting
- Chairman, Board of Directors, & Co-Founder Genesis RTS
- 20 year veteran of Shell Oil Company

Credentials

- UT R&D Director (25 person R&D group)
  - Drilling fluids and nano-materials
  - Cementing and zonal isolation
  - Drilling-related rock-/geo-mechanics
  - Drilling Automation – RAPID consortium
UT Austin Drilling & Completion R&D Program

Drilling Automation

RAPID

drilling.utexas.edu

Zonal Isolation Cementing

Drilling Fluids & Nano-Particles

Wellbore Strengthening & Fracturing

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Zonal Isolation Problems: Land

Figure: Sources of Groundwater Pollution

Sources: Leak paths adapted by Michael Holgate\textsuperscript{Ref 36} adapted from US EPA Hydraulic Fracturing Research Study – Scoping Backgrounder, 2010. Casing & cementation courtesy of Talisman Energy.
DW Well Design Evolution

Normal Clearance Well

Tight Clearance Wells

Adopted from API RP 96, courtesy John Gradishar

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Casing Program Example: Offshore GOM/Macondo

36” Conductor / Jet Pipe

28” Surface Casing

22” Surface Casing

18” Drilling Liner

16” Intermediate Casing

13 5/8”, 11 7/8”, 9 7/8” Drilling Liners

7” Production Casing (Long String)
Mars B – Olympus
Well Design

Work by van der Haak, Grant, Japar and Reagins - Shell

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Mars B – Olympus Well Design

Work by van der Haak, Grant, Japar and Reagins - Shell

Picture adopted from OTC 25437

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Casing – Hole Clearances

<table>
<thead>
<tr>
<th>Annulus</th>
<th>Description</th>
<th>Clearance (inch)</th>
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<tbody>
<tr>
<td>A</td>
<td>22” x 18”</td>
<td>0.510</td>
</tr>
<tr>
<td>B</td>
<td>18” x 16.264”</td>
<td>0.120</td>
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<tr>
<td>C</td>
<td>16.264” x 14”</td>
<td>0.347</td>
</tr>
<tr>
<td>D</td>
<td>14” x 11 7/8”</td>
<td>0.178</td>
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<tr>
<td>E</td>
<td>14” x 10 3/4”</td>
<td>0.780</td>
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<tr>
<td>F</td>
<td>11 7/8” x 9 3/8”</td>
<td>0.5</td>
</tr>
<tr>
<td>G</td>
<td>9 3/8” x 7”</td>
<td>0.645</td>
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BSEE Database on Offshore Blowouts

Barrier verification to help prevent major well control incidents:
- BOP Reliability Verification
- Casing & Cement Evaluation
- Formation Strength Evaluation
- Drilling Event Detection

U.S. Offshore Blowouts – Contributing Factors
1992-2006
(by percent occurrence)

- Swabbing
- Formation fracture
- Equipment failure
- Cementing
- Casing failure
- Drill into other well
- Stuck pipe

Note: Some incidents had multiple contributing factors. (From Booth, 2010)
Deepwater Zonal Isolation Challenges & Gaps

**Challenge**

To develop and apply cementing and zonal isolation technologies to:
- Reduce risk and improve safety
- Enable conformance and regulatory compliance
- Improve the quality and reliability of wells

**Business Impact**

- Recent studies on well integrity and well reliability have shown that a large part of wells drilled and completed have lost some degree of well integrity.
- Zonal isolation and barrier placement that result from cementing operations are key elements in the well construction process and are fundamental components of delivering safe and compliant wells
- As we drill deeper in larger water depths (ultra-deepwater wells) the zonal isolation challenge is becoming larger, requiring novel solutions

**DW Zonal Isolation Technology Gaps**

<table>
<thead>
<tr>
<th>Well Barrier Placement</th>
<th>Cement, Spacer and Mud Separation</th>
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<tr>
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<td>Lost Circulation While Cementing</td>
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<td>Narrow Annulus Cementing</td>
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<td>Casing Centralization</td>
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<td>Cementing Fluid Property Measures During Job Execution</td>
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<td>Mud to Cement Conversion</td>
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<tr>
<th>Well Barrier Integrity</th>
<th>Shoe Track Integrity</th>
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<tr>
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<td>Casing and Formation Interface Bonding</td>
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<td>Mechanical Properties and Initial Stress State of Cement</td>
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<td></td>
<td>Cement Shrinkage and Expansion</td>
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<td>Foam Cement Characterization at Pressure and Temperature</td>
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<tr>
<th>Well Barrier Evaluation</th>
<th>Wait on cement (WOC) optimization</th>
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<td>Formation Impact on Cement Bond Log Evaluation</td>
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<td>Real-Time Evaluation of Well Barrier Placement</td>
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<td>Cement Evaluation in Large Diameter Casing</td>
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<td>Annular Imaging, Barrier Permeability Evaluation</td>
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<td>Cement Evaluation Inside Casing</td>
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<th>Well Barrier Remediation</th>
<th>Curing Sustained Casing Pressure</th>
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<td>Sealants for Micro-annulus and Small Defects</td>
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<td>Placement of Remediation Sealant Behind the Casing</td>
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<td>Comprehensive and Durable Solutions for Well Abandonments</td>
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Cementing technology has not kept pace with advances in well design, drilling fluids and drilling technologies

- Industry can design and drill wells that cannot be cemented with the current industry state-of-the-art cementing process and materials
- Cementing service providers can design cementing operations that cannot be executed ‘as designed’ on-site for the well
- Little or no cementing research since mid-1990’s (aside from additive development)
- No research on alternative or advanced cementing technology in over 20 years
- Competency level of cementing expertise in the industry is at a 30 year low

The alternative offered by academia compared to the service industry: advanced and unbiased cementing technology (systems, methods, know-how, etc.) overcoming the limitations of conventional cementing technology and practice which no longer support/guarantee offshore safety
Agenda

10:00 AM – 11:30 AM OESI Zonal Isolation R & D Effort

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  - EVO Introduction
  - UT R&D Program
  - Why care about zonal Isolation?
- **Industry Developments & State-of-the-Art**
  - Novel cementing systems
  - Novel cementing techniques
- **UT - Austin / UoH Efforts**
  - Lab Capabilities
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- **Q & A Session**
Self-Healing Cement

- Piloted by Schlumberger as potential remedy to sustained casing pressure (SCP) and surface casing vent flow (SCFV)
- Incorporation of materials that are swellable in presence of hydrocarbons
- A “brute force” method ....but apparently effective (field cases by Suncor, Total, PDO etc.)

Check out papers:
- IPTC-14279
- SPE-105781
- SPE-128226
- SPE-174892

Source: SPE-105781

Fig. 5a—Example of hydrocarbon flow tests at room temperature and constant injection pressure with neat cement and the SHC system using a branded dearomatized oil.
Alkali-Activated Materials (Geopolymers)

- Non-Portland base material (slag, fly ash, pozzolan, etc.)
- Alkali-activated (MOH, M₂O.SiO₂, M₂CO₃, M₂SO₄ - M = alkali-metal)
- Considerable expertise in Civil Engineering, now being transferred to Petroleum Engineering
- Work by SFI Drillwell for plug and abandonment operations
- Work by Halliburton on lost circulation pills

Check out papers:
- OTC-23915
- SPE-166123
- SPE-169231

Source: Alkali-Activated Materials, Provis et al., Springer

Fig. 1.2 Classification of AAMs, with comparisons to OPC and calcium sulfoaluminate binder chemistry. Shading indicates approximate alkali content; darker shading corresponds to higher concentrations of Na and/or K (Diagram courtesy of I. Beleña)
Managed Pressure Cementing (MPC)

- Extending MPD and DGD drilling technology to cementing
- Pioneers in AGR / BP in Caspian (tophole applications)
  - Riserless Mud Recovery (RMR) system
  - EC-Drill riser pumping system
- Pressure of rising cement columns can be removed (“pumping off the ECD”)
- BHP held constant at point of interest – active PPFG margin management
- SBP MPC reported by BP in Harding Field, Petronas in the TA field, Halliburton in Unconventionals

Check out papers:

- OTC-25462
- SPE-155516
- SPE-156889
- SPE 166170
- SPE-168945
- SPE-173080

Source: AGR / Enhanced Drilling, RMR System

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Reverse Cementing

- Solution being developed by Shell with suppliers for 18” and 16” casing sections on Mars B / Olympus
- Inner-string cementations coupled with new reverse cementing tool
- Application of new thermal fluid for pre-heating rock
- Significant reduction in ECD (~2 ppg)
- Statement of Requirements (SoR) published

Check out papers:
- OTC-25437
- SPE-170977

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“Why Do Not Disturb is a Safety Message”

- Recent paper by Sweatman, Mitchell and Bottiglieri
- Focus on flow after cementing (FAC)
- Critical look at WOC practices, particularly associated with:
  - Setting wellhead casing seal assemblies (WCSA)
  - Heating and cooling of fluids above the top of cement (TOC)
- Exploring role this may have played at Macondo

Source: SPE 174891, Sweatman et al.
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- **Q & A Session**
UT Cementing – ZI Lab Capability

• UT is one of the very few academic research institutes in the world with a state-of-the-art zonal isolation lab and an active (ultra-) deepwater cementing R&D program

• UT lab equipment (consistometers, curing chambers, ultra-sonic cement analyzers etc.) can simulate the downhole environment of all current and future (ultra-) deepwater wells:
  – Pressures up to 40,000 psi
  – Temperature up to 600°F
  – All conventional and alternative cement slurry types

• Custom equipment for bonding evaluation of cement-to-rock (shale, sandstone, limestone etc.) and cement-to-steel, tensile bond evaluation

• Staff: 1 Research Scientist, 1 Post-doc, 1 Lab Technician, 2 Graduate Students, all female team

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UT Cementing / ZI Efforts

• Deepwater ZI Improvement
• Novel Test Methods (Bond Strength Testing)
• Novel Materials for ZI and Abandonment
• Thermal Pre-Heating of Formations
• Cementing Sensors
• OESI Effort: Displacement Modeling

\[ \sigma_{shear} = \frac{4F_{peak} \sin 60^\circ \cos 60^\circ}{\pi d^2} \]

*Shear bond strength*
Effect of SBM Contamination

Ratio w.r.t. slurry with no mud (%)

C_1  H_1  H_2  L_1

SPE-170325-MS • Contamination of Deepwater Well Cementations by Synthetic-Based Drilling Fluids • K. Aughenbaugh, R. Nair and E. van Oort

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The Benefit of Slag Cement

SPE-170325-MS • Contamination of Deepwater Well Cementations by Synthetic-Based Drilling Fluids • K. Aughenbaugh, R. Nair and E. van Oort

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Effects of Additives, Spacers

SPE-170325-MS • Contamination of Deepwater Well Cementsations by Synthetic-Based Drilling Fluids • K. Aughenbaugh, R. Nair and E. van Oort
Effect of Changing SBM Formulation

SPE-170325-MS • Contamination of Deepwater Well Cementsations by Synthetic-Based Drilling Fluids • K. Aughenbaugh, R. Nair and E. van Oort

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Conventional Bond Strength Tests

Figure 1—Schematic drawing of (a) “push-out” shear bond test cell (Nelson and Cullot, 2006) and (b) shear bond tester using cylindrical composite cores.

Figure 2—Schematic drawings of the adhesion test cell measuring tensile bond strength developed by (a) Peterson (1983), (b) Latriva (2004).
New UT Bond Strength Tests - I

Figure 3—Cement-to-rock shear bond strength testing method. (a) Illustration of the testing method. (b) Example of load vs. displacement data obtained from the test.

Paper 173802 • A Novel Method to Evaluate Cement-Shale Bond Strength • Xiangyu Liu et al.
© Dr. Eric van Oort
Results: Shear Bond Strength (Surfactant Slurries)

- **Class H (neat)**
- **Surf A**
- **Surf B**
- **Surf C**

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<tr>
<th></th>
<th>70°F</th>
<th>150°F</th>
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<tbody>
<tr>
<td>Class H (neat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surf A</td>
<td></td>
<td></td>
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SPE 173802 • A Novel Method to Evaluate Cement-Shale Bond Strength • Xiangyu Liu et al.

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New UT Bond Strength Tests - II

Figure 6 — Photograph of splitting tensile bond strength test

Figure 7 — Example of (a) load vs. displacement data and (b) derivative of load vs. time data obtained from the tensile bond strength test
Self-Healing Cements

- Materials that re-heal after failure under downhole pressure and temperature
- Not based on swellable elastomers, presence of hydrocarbons not required
- Excellent application for string cementations as well as abandonments

3 day compressive strength = 1100 psi @ failure
Failed sample retested at 21 days = 1200 psi
Magneto-Rheological Cements

SPE-173124-MS Cement Displacement and Pressure Control Using MR Fluids Sriramya Nair et al.

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Thermal Heating: “Texas Heat Wave”

- Thermal wellbore strengthening through heating of near-wellbore zone to prevent losses while drilling and/or cementing
- Accomplished by use of delayed exothermal reaction that releases heat in delayed fashion (allowing for sufficient pump time) to heat the rock
- UT has applied for IP for the particular way of delaying the exothermal reaction and trademarked the term “Texas Heat Wave” for this technology
Drilling Safety – Zonal Isolation Overview

Research Statement

To conduct meaningful, applied research and technology development that helps to improve the integrity and reliability of casing and cement barriers in offshore wells

- Addresses BSEE Director Salerno’s grand challenge on integrity of shallow liners and sub mudline casing hangers, and BSEE concerns about cementing
- Addresses issues associated with achieving, maintaining and verifying lasting zonal isolation (ZI) in offshore wells. Note that ZI problems are historically the leading cause of offshore blowouts, and were a lead cause of the Macondo/DW Horizon event

Research Plan

- R&D work will be coordinated between UT Austin (E. van Oort, PI, 1.0 FTE) and UoH (V. Cumaraswamy, co-PI, 0.5 FTE), $80K total budget
- Plan being developed for independent, applied basic R&D into hanger reliability and improving the quality of offshore cementations, addressing such issues as improved displacement & cement placement, minimizing cement contamination, etc.

Desired Value to Stakeholders

- Very little independent ZI R&D work is currently ongoing in the industry. UT Austin and UoH intend to execute original work with a strong applied focus to help deepwater operators improve their cementations, particularly across high-pressured / hydrocarbon-bearing zone, and be able to verify their barriers (cement, hangers, seals) better. This will help them improve drilling safety and reduce their exposure to uncontrolled well events.

OESI

http://oesi.tamu.edu

...enabling safe and environmentally responsible offshore energy operations
OESI Effort: Cement Displacement

1. Few good 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, 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, casing rotation / reciprocation
   - Etc.

3. Modeling requires sophisticated software (which we have: ANSYS FLUENT)

4. Modeling requires relevant expertise (which we have: Dr. Saeid Enayatpour)

https://www.youtube.com/watch?v=M-Z-wzyTs04
https://www.youtube.com/watch?v=wys3qiBQzYY

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Displacement with Concentric Hz Pipe

Result – Flow pattern

Case I:

- Inlet Velocity = 0.1 m/s
- Gravity activated
- No eccentricity

Fluid Properties:

**Phase I:** (displaced fluid)
- Density : 1500 (kg/m³)
- Viscosity: 0.003 (kg/(m.s))

**Phase II:** (displacing fluid)
- Density : 1500 (kg/m³)
- Viscosity: 0.002 (kg/(m.s))
Displacement with Fully Eccentric Hz Pipe

Result – Flow pattern

Case II:

- Inlet Velocity = 0.1 m/s
- Gravity activated
- Eccentricity: 1 in

Fluid Properties:

Phase I: (displaced fluid)
Density: 1500 (kg/m$^3$)
Viscosity: 0.003 (kg/(m.s))

Phase II: (displacing fluid)
Density: 1500 (kg/m$^3$)
Viscosity: 0.002 (kg/(m.s))
Pressure Contours

Result – Pressure Contours

**Case I:**

- Maximum inlet pressure: 72 Pa

**Case II:**

- Maximum inlet pressure: 88.7 Pa

**Conclusion:** As a result of eccentricity, fluid injection pressure is increased by

\[(88.7-72)/72*100 = \%23\]
New UT Initiative: AWC
Advanced Well Construction

• The AWC objective is to combine drilling and cementing R&D with geophysical, geo-mechanical, and formation evaluation measurements for optimal well construction, well completion, and hydrocarbon production using a synergistic, multi-disciplinary approach

• Multidisciplinary collaboration between Professors Nicolas Espinoza, Carlos Torres-Verdin, Zoya Heidari and Eric van Oort, and Drs. Ali Karimi and Saeid Enayatpour
Thank you!

State-of-the-art Zonal Isolation Laboratory

Contact:

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The Cementing Ladies with Dr. van Oort