Cementing Deepwater Wells

Well Services – Schlumberger
Junichi Hagura
Presentation outline

- Specific deepwater challenges & Overview of geo-hazards
- Deepwater cement slurries requirements
- Deepwater Cementing Technology
What is Different in Deepwater?

- **Costs**
  - Operations take longer
  - Expensive Rig Time

- **Cold temperatures**
  - Fluids viscosity
  - Cement setting

- **Narrow margins between pore and fracture pressures**
  - Lost Circulation during drilling
  - Lost returns during cement jobs

- **Shallow Water/Gas Flow Hazards**
Deepwater temperatures

Mean Sea Level

Mud Line

Sea current velocity

Temperature profile

0.5 knots

0.2 knots

~ 4 °C
Temperature effects on fluids

- **Drilling fluids**
  - Rheology
  - Gelation → swab/surge
  - Increased ECD → loss of well control
  - Hole/riser cleaning with gumbo clays

- **Cementing fluids**
  - Long thickening times
  - Slow compressive strength development
  - Unpredictable gel strength development
  - Temperature prediction - **API tables not applicable**
Gas in Deep Water Drilling

- Gas hydrates near sea bed
  - Destabilization of hydrates by heat (drilling fluid, cement hydration)

- Shallow gas
  - Forming hydrates in well, pipes…

The Burning Snow Ball
Picture of burning methane hydrate mass supporting its own combustion
Gas Hydrates

Solid ice-like compounds of natural gas and water, formed in high pressure and low temperature conditions.

- Formation of Hydrates depends on:
  - Temperature and Pressure
  - Composition or type of gas
  - Composition of drilling fluids
  - One unit of hydrate can give 170 units of gas

- HAZARDS:
  - Plugging of BOP choke and kill lines
  - Dehydration of drilling fluids and/or cement
  - Overloading of Gas Separation Equipment
Shallow Water Flow Hazard

- Permeable sediments trapped under sliding deposits
- Usually present near the mouth of a major river

Turbidite Sand

Seawater Pore Pressure

Normal Drilling Margin

Frac Pressure

Actual (narrow) Drilling Margin
Shallow Water Flow Problems

- Safety and environmental concerns
- Flow during drilling or cement
  - Jeopardizes template stability
- Lost circulation during drilling or cement placement
  - Well Control
- Excessive hole washouts
  - Mud removal difficult
- Destabilization of near well bore formations
  - Integrity of BOP and Riser
- Breakthrough to the seafloor
  - Loss of drive pipe, conductor or the well
Deepwater Cementing

- Specific deepwater challenges & Overview of geo-hazards

- Deepwater cement slurries requirements
  - Objectives and challenges for DW cements
  - Cement requirements for shallow water/gas flow hazards

- Deepwater Cementing Technology
Deep Water Cementing:
Objectives & Requirements

**OBJECTIVES:**

- Provide Structural Support
  - Resistance to buckling and casing wear
  - Foundation for deeper strings of casing
- Obtain a Competent Hydraulic Seal
  - No fluid migration behind casing
  - Seal off shallow gas/water flow zones
- Short WOC
  - Despite cold temperature

**REQUIREMENTS:**

- Excellent mechanical properties combined with lightweight cement density (weak formations)
- Gas Migration Control
- Mud Removal Optimization
- Improved cement hydration at cold temperature
Paths for Gas/Formation Fluid Migration

Channel, during placement
- Due to incomplete Mud Removal
- Excessive Free Fluid

Loss of hydrostatic pressure, post-placement
- Poor Fluid loss Control
- Long Critical Hydration Period
- Free Fluid

- Loss of cement integrity over long term
  - Down hole stresses
  - Shrinkage
  - Permeability of set cement
Mechanism for fluid/gas migration in the cement before it sets

- Hydrostatic Pressure transmission is the key
- During the cement job:
  - Cement density insures hydrostatic pressure > pore pressure -> no invasion
- After placement, cement loses its ability to fully transmit Hydrostatic Pressure due to:
  - Static Gel strength development -> decay in HP transmission
  - Downhole volume variations: fluid loss, temperature and hydration volume reduction

Consequence:
- Pore pressure within the gelling cement is decreasing and may become smaller than formation pore pressure
- Gas/water can now possibly invade the annulus
4 Phases in the Setting Process of a Cement Slurry

1. Fully Liquid
2. Early Gelation
3. Hydration
4. Set Cement

After this point Gas can Invade, CWSS

Critical Hydration Period

Cement Set - No Gas can Invade
Definition of terms

- **Static Gel Strength (SGS)**
  - Measure of the attractive forces between the particles of a fluid under static (non flowing) conditions. The measure of these same attractive forces of a fluid under flowing (dynamic) conditions is what is commonly referred to as “yield point” of a slurry.

- **Critical Wall Shear Stress (CWSS)**
  - A measure of the amount of gel strength that must develop to cause hydrostatic decay to allows gas entry
  - Not a slurry property
  - Totally dependent on well geometry & pressures

- **Critical Hydration Period (CHP)**
  - Period of time when gas/water can enter the annulus
  - Begins when CWSS is achieved
  - Ends when matrix permeability is sufficient to stop flow
Static Gel Strength measurement

Vane Rheometer

Chandler’s SGSA
(Static Gel Strength Analyzer)
Transition Time (Time from 100-500 lb/100ft²)

Gel Strength (lb/100ft²) vs. Time (x10 mn)
Critical hydration period (CHP)

\[ CWSS = 0.25 \left( \sum (\rho_x g L_x \cos \Theta) - P_f \right) \frac{[D_h - D_c]}{L_{cm}} \]

where:

- \( \rho \) = fluid density
- \( g \) = gravity
- \( L \) = length of column
- \( \Theta \) = angle of inclination
- \( P_f \) = pore pressure
- \( D_h \) = hole diameter
- \( D_c \) = casing diameter
Controlling shallow water/gas flows

Slurry requirements

- Low density slurry (low frac gradient)
- Excellent fluid loss control (< 50 ml)
- No free water/sedimentation (no path for gas/fluid)
- Rapid setting at low temperature (WOC time)
- Short critical hydration period (gas/fluid migration)
- Low set cement permeability (no path for gas/fluid)
Consequences of gas migration

- Blow-out: surface or underground
  - Danger to personnel
  - Lost rig

- Less dramatic but important consequences
  - Lost production
  - Treatment fluids injected in wrong zones
  - Annular pressure on surface
  - Damage to the environment

- Repair required: prevention is better than cure
Deepwater Cementing

- Specific deepwater challenges & Overview of geo-hazards

- Deepwater cement slurries requirements

- Deepwater Cementing Technology
  - Liquid additives for cold temperatures
  - Foamed cement
  - PSD Slurry for Deepwater
Liquid Additive Package for Cold Environments Offshore (DeepCEM)

Two components liquid additives system:
- D185 : Non Retarding Dispersant
- D186 : Cement Set Enhancer
Liquid additives for cold temperatures

→ Slurries for low temperature, unconsolidated and unstable environments (potential shallow gas/water flows)

- 1.38 – 1.97 SG: neat cements + DeepCEM liquid additives (extended with conventional additives or foamed)
- 1.26 – 1.62 SG: PSD blends (with DeepCEM liquid additives)
- 0.96 – 1.26 SG: low-density PSD blends with DeepCEM liquid additives
## Typical DeepCEM properties

**Thickening time and compressive strength**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Density (kg/m³)</strong></td>
<td></td>
<td>1900</td>
<td></td>
<td></td>
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<tr>
<td><strong>Cement</strong></td>
<td></td>
<td>Class A</td>
<td></td>
<td></td>
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<tr>
<td><strong>D500 (gal/sk)</strong></td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>D185 (gal/sk)</strong></td>
<td></td>
<td>0.1</td>
<td></td>
<td></td>
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<tr>
<td><strong>D186 (gal/sk)</strong></td>
<td></td>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
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<tr>
<td><strong>Thickening Time at 18°C &amp; 10.3 MPa (hr:min)</strong></td>
<td>8:31</td>
<td>5:03</td>
<td>4:15</td>
<td>3:58</td>
</tr>
<tr>
<td><strong>UCA at 13°C and 10.3 MPa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Time 50 psi (hr:min)</strong></td>
<td></td>
<td>13:37</td>
<td>10:00</td>
<td>7:12</td>
</tr>
<tr>
<td><strong>Time 500 psi (hr:min)</strong></td>
<td></td>
<td>22:31</td>
<td>16:21</td>
<td>13:38</td>
</tr>
<tr>
<td><strong>Compressive strength @ 24 hrs (MPa)</strong></td>
<td>4.6</td>
<td>8.1</td>
<td>9.1</td>
<td>9.1</td>
</tr>
<tr>
<td><strong>Compressive strength at 24 hrs (psi)</strong></td>
<td>660</td>
<td>1170</td>
<td>1330</td>
<td>1330</td>
</tr>
</tbody>
</table>

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Static Gel strength development

"Cement Set Enhancer" concentration effects

Gel strength (Lbf/100ft²) vs. Time (minutes)

Lehigh Class H Cement
0.5 gps D500
0.06 gps D185
density = 1970 kg/m³
T = 18°C P = 2760 kPa

Concentration effects:
- 0.4 gps D186
- 0.2 gps D186
- 0.15 gps D186
- 0.1 gps D186
- 0.05 gps D186
- No D186
Reducing CHP by slope change of Static Gel Strength
Benefits of “Liquid additives for cold temperatures”

- Improved setting characteristics in cold water
- Effective shallow water and gas flow prevention (in combination with fluid loss or GASBLOK additive)
- Simplified logistics
- Quick static gel strength development (short transition time i.e. short time from 100 to 500 lb/100ft² gel strength)
- Fast compressive strength development
  - short WOC time before casing release
- Compatible with any type of cement (foamed or non-foamed neat cements, PSD blends cements, etc..)
Foamed cement systems

● Pro’s
  – Proven technique for controlling Shallow Water Flow
  – Adjustable slurry density (nitrogen controls density)
  – Flat displacement profile - good mud removal

● Con’s
  – Equipment and personnel intensive
  – Variable deck load considerations
  – Relatively high permeability
  – Safety concerns with pumping energized fluids
  – Environmental impact of surfactants
Process controlled foamed cement

Cement Unit

Foamer Pump

Check Valve

Recirc Tub

Slurry Chief

N₂ Pump

N₂ Tank
2000 gals
180 MSCF

N₂ Tank
2000 gals
180 MSCF

N₂ Isolation Valve

Foam Generator

Check Valve

N₂ Isolation Valve

Bleedoff w/N₂ Choke

Micromotion Flowmeter

Restricted Area

Process Control Computer

Bleedoff w/Choke

Wellhead
Foamed cement process control

26" Conductor, Process Controlled Foam Cement, Gulf of Mexico April 7, 1996

- Base Slurry rate
- Foamer rate
- N2 stroke rate
- Foamer ratio
- N2 ratio

Time (sec)
Example of Foamed Cement Slurry

**Base System:**
- Class G cement
- 15.8 lb/gal
- 1.89 S.G.
- D500 (Fluid Loss/GASBLOK Additive)
- D185 (DeepCEM Dispersant)
- D186 (DeepCEM Low Temp Enhancer)
- F104 (Foaming Agent)
- D139 (Foam Stabilizer)

**Thickening Time:**
- 4:02 @ 50°F (10 °C)

**Fluid Loss:**
- 42 mL/30 min @ 50°F (10 °C)

**Foamed Fluid Loss:**
- 5 gm/30 min @ 50°F @ 11.0 lb/gal

**Base Rheology:**
- PV = 76, Ty = 19

**Free Water:**
- None

**Compressive Strength:**
- 1000 psi / 24 hrs @ 50°F (10 °C)
PSD Slurry for Deepwater

- Combines the advantages of Particle Size Distribution Technology with DeepCEM additives properties for enhanced slurry performance at low temperature

- A better alternative to foamed cement for controlling shallow water/gas flow hazards

<table>
<thead>
<tr>
<th>Property</th>
<th>Specifications</th>
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<tbody>
<tr>
<td>Density</td>
<td>8.5 – 14.0 ppg (1.0 – 1.7 SG)</td>
</tr>
<tr>
<td>Salinity</td>
<td>Fresh Water to 37% salt</td>
</tr>
<tr>
<td>Temperature</td>
<td>0º - 55ºC</td>
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Conventional Cement Slurries

To be able to mix and pump cement, we need cement + water

By adding more water, we get:
- lower density
- lower viscosity

but we also get:
- longer working time
- lower compressive strength
- higher permeability

Good slurry properties ≠ Good mechanical properties
Conventional cement slurries

Cement particles must be surrounded by water to flow as a slurry – Sufficient water must first be added to fill the void between the cement grains

PDS slurries

Particle size distribution technology is used to maximize solid and liquid content: less water wasted in voids. Slurry properties and mechanical properties are optimized.
Advantages of “PSD Slurry for Deepwater”

“PSD Slurry for Deepwater” is particularly suitable at cementing weak deepwater zones with or without shallow water/gas flow hazards

- Simplified logistics and improved safety (no need for foamed cement equipment to achieve low densities)
- Low densities maintain returns.
- Rapid strength development minimizes waiting-on-cement (WOC) time.
- Combined with GASBLOK additive, It is an improvement over foam cement for shallow water/gas flow hazards, thanks to its lower permeability, very quick gel strength development and excellent mechanical properties
“PSD Slurry for Deepwater” performance

For a typical “PSD Slurry for Deepwater” of 12.5 lbm/gal (1.50 SG)

- Slurry composition
  - PSD Blend (Porosity: 45%):
    - DeepCEM and GASBLOK LT Additives

- Slurry properties
  - Plastic viscosity: 105 cp
  - Yield point: 19 lbf/100 ft$^2$
  - Fluid loss: 23 mL/30 min

- Set cement
  - Thickening time: 4:00 at 50°F (10 °C)
  - Transition time: 12 minutes (2 hrs conditioning)
  - Compressive strength at 50°F (10 °C):
    - Time to 50 psi: 5:30
    - Time to 500 psi: 13:20
“PSD Slurry for Deepwater” performance

- **Solid Fraction (%)**
  - DeepCRETE @ 12 ppg
  - Conventional G @ 15.8 ppg
  - Extended Lightweight @ 12 ppg

- **Compressive strength (psi)**
  - DeepCRETE @ 13.5 ppg
  - Conventional G @ 15.8 ppg
  - Extended Lightweight @ 13.5 ppg

- **Permeability (mD)**
  - DeepCRETE @ 12 ppg
  - Conventional G @ 15.8 ppg
  - Extended Lightweight @ 12 ppg

- **Natural Fluid Loss (ml)**: no FL additive
  - DeepCRETE @ 13.5 ppg
  - Bentonite Extended @ 13.5 ppg Lightweight
  - Sodium Silicate Extended @ 13.5 ppg

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“PSD Slurry for Deepwater”
vs foamed cement

![Graph showing compressive strength and log permeability](image)
“PSD Slurry for Deepwater” vs foamed cement
“PSD Slurry for Deepwater” Case History

Shallow Water Flow Hazard

- Located in 1204 metres of water in Trinidad
- Set 26” casing at 1692 metres RKB (462 metres BML)
- Shallow water flow and gas hydrates were encountered
- CemCADE temperature simulator predicted BHCT = 8°C
- Operator wanted alternative to foamed cement
- Pumping Sequence:
  - 32 m³ MUDPUSH XL @ 1500 kg/m³ (with green dye)
  - 78 m³ of “PSD Slurry for Deepwater” with DeepCEM @ 1515 kg/m³
  - Displacement with seawater
- Full returns observed at wellhead with ROV – TOC @ mudline
- No Flow after cementing
- Drilled out hard cement at 26” shoe 14 hrs after placement
Other System Case History
Conventional (Low S.G. Glass Bead Extender)

- Located in 750-1000 metres of water in Brunei (3 wells)
- Set 13 3/8” casing at 1177, 1716, 1598 metres RKB (673, 748, 351 meters BML)
- No Shallow water flow and gas hydrates were found by site survey
- Surface BOP system (Semi sub rig) used and Lead slurry early strength development was not required at near sea bed
- CemCADE temperature simulator predicted BHCT = +/- 19°C
- Pumping Sequence:
  - 10 m³ Drill Water
  - Lead Slurry @ 1.6SG
  - Tail Slurry @ 1.90SG (50-150m column)
- Full returns observed at wellhead with Camera – TOC @ mudline
- Drilled out hard cement at 13 3/8” shoe without problems
Summary

Deepwater cementing solutions

- **Rig time costs**
  - Reduced WOC → Liquid additives for cold temp. & PSD Slurry for Deepwater
  - Improved logistics → Liquid additives for cold temp.

- **Well control (lost circulation & shallow water/gas flows)**
  - Low density systems → Foamed cement & PSD Slurry for Deepwater
  - Short critical hydration period → Liquid additives for cold temp.
  - Low fluid loss and gas-tight → GASBLOK LT

- **Cold temperatures**
  - Temperature modeling → Computer temperature simulator
  - Low temperature performance → Liquid additives for cold temp. & PSD Slurry for Deepwater

- **Need to evaluate well condition including rig day rate, then optimize cement system**