Advances in Ecological Drilling Fluids to Reduce the Volume and Toxicity of Drilling Wastes

John Downs
Cabot Specialty Fluids
Sustainable development, the environment and well construction activities

Sustainable development requires the oil industry to continually look for ways of minimising the environmental impact of its well construction operations, particularly with respect to:

- Volume and toxicity of emissions (to air, water and ground)
- Land (and sea/seabed) use – the footprint
Well construction activities generate chemical waste as an emission

Globally drilling and completion operations generate many millions of tonnes of chemical waste, including:

- Excavated rock blended with drilling fluid chemicals
- Dumped mud
- Interface spacers, rig- and well-wash fluids
- Solids filtered from completion brines
- Contaminated filtration media
- Production stream contaminated with drilling and completion fluid filtrate

The volume and toxicity of the waste produced is influenced by the nature of the drilling and completion fluids.
Why worry about chemical wastes from well construction?

The production of chemical waste costs you money and creates liability:

- Treatment costs
- Disposal costs
- Creates long-term liability
  - the waste and its effects remain your responsibility
  - environmental laws only get tougher and can impact retrospectively, e.g. drill cuttings piles left in the North Sea is now a big problem

Need to reduce the volume and toxicity of well construction wastes – and that means looking hard at your drilling/completion fluids.
What sort of treatment/waste disposal costs are we talking about here?

Typical costs* in North Sea operations for the CRI or ”skip and ship” disposal of drilled cuttings contaminated with OBM:

- US $ 700-1,000 /MT of cuttings
- US$ 240-400/metre of 12¼” hole drilled

Approx. 0.3 MT of OBM-contaminated cuttings produced per metre of 12¼” hole drilled

* Old (2002) figures from the Jade drilling campaign in North Sea – ref. paper by Palmer, Urban and Inman presented at IQPC Drill Cuttings Management conference, Aberdeen
How do traditional well construction fluids increase the volume of chemical waste?

Some sources of increased chemical waste production

- Dumping and dilution of mud to maintain mud properties
- Loss of weighting agents (with fluid) from solids control equipment
- Creation of mixed fluid interfaces from displacement operations
- Increased production of drill cuttings from well bore cavings
- Use of different drilling fluids for different hole sections
- Use of different drilling and completion fluid systems
- Use of toxic fluids (e.g. zinc bromide brine) that contaminate the production water for long periods
- Use of formation-damaging fluids that result in the need for remediation treatments or the drilling of more wells
How do traditional well construction fluids increase the toxicity of chemical wastes?

Some common compounds that contaminate well construction wastes making them more toxic:

- Oil and surfactants (e.g. emulsifiers/wetters) in OBM
- Halides in WBM and OBM, as well as completion fluids
- Heavy metals – predominantly barium, from barite
- "Additives" – lubricants, shale stabilisers, corrosion inhibitors, biocides

* Excluding the products of in-situ chemical reactions, synthesised downhole under hydrothermal conditions
Using barite in drilling muds – a collective madness?

Five million tonnes of barite used annually in drilling mud. It contains **59% w/w barium – a highly toxic heavy metal**

- 1 gram barium lethal to humans
- Highly toxic to aquatic organisms
- Bioaccumulates
- Mobilised from barite by SRBs
- Solubilised from barite by brines
- Elevated barium levels in:
  - contaminated soils
  - liquid seeping from waste pits
  - cuttings piles
- US EPA classifies any products containing > 100 mg/l of extractable barium as a D005 Hazardous Waste!
Ecological solutions in well construction

Development of new products and practices that tend to benefit or cause a lower level of damage to the environment

<table>
<thead>
<tr>
<th>Objective</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in well numbers</td>
<td>Reduction in formation damage</td>
</tr>
<tr>
<td></td>
<td>Horizontal wells</td>
</tr>
<tr>
<td>Reduction in surface footprint</td>
<td>Extended and multilateral wells</td>
</tr>
<tr>
<td></td>
<td>Coiled tubing drilling</td>
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<tr>
<td>Reduction in waste volume</td>
<td>Slim hole and stable hole</td>
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<td></td>
<td>Improved solids control</td>
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<td></td>
<td>No solid weight agents</td>
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<td></td>
<td>Universal drilling/completion fluid</td>
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<td></td>
<td>Cuttings re-injection</td>
</tr>
<tr>
<td>Reduction in waste toxicity</td>
<td>More benign well construction fluids</td>
</tr>
</tbody>
</table>
How drilling and completion fluids influence the outcome of a well construction operation

Fluids have a critical influence on well economics, safety, liability and reservoir evaluation.

- Time to drill and complete
- Well integrity and lifetime
- Logging capability and interpretation
- Rate of production
- Well control
- Waste management costs
- Environmental impact and liability
Drilling and completion fluids – general specification

Multiple functionality required in one fluid

- Shale stabilisation
- Low ECD
- Stable well control
- Fluid loss control
- Non-corrosive
- Minimise formation damage
- Safe
- Good power transmission
- Lubricating
- Low waste management costs
- Enables formation evaluation
- Good hole cleaning
- Low environmental impact and liability
Specification for an ecological drilling and completion fluid

Must be benign, but must also enable the implementation of ecological solutions –

- Dual functionality: combined drilling and completion fluid
- Must not cause formation damage
- Optimal hydraulic properties for drilling long, narrow wells
  - maximum power transmission
  - minimal pressure losses; low ECD
- Must minimise waste production
  - stabilises well bore and cuttings
  - low dilution rates (no dump and dilute)
  - no solid weighting agents
  - capable of simple re-cycle with low losses
What do we mean by a **benign** well construction fluid?

A fluid that reduces waste toxicity and environmental burden –

- No barium or other toxic heavy metals
- No hydrocarbons, surfactants or halides
- Low toxicity to living organism of all kinds/types
- Highly biodegradable with low BOD/COD
Severe and long-lasting skin injuries due to contact with halide brines and powders

- Deep skin necrosis injuries taking up to five months to heal
Profile of the ideal ecological drilling and completion fluid

Solids-free water-based solution of benign biodegradable solutes providing the following essential properties:

- Fluid density to SG 2.3
- Shale stabilisation
- Fluid loss control
- Causes no/minimal formation damage
- Solids suspension and hole cleaning
- Compatible with elastomers and all metals used in well construction
- Allows accurate reservoir evaluation
- Lubricating
- Optimises the 5R approach to waste management
New drilling and completion fluid development in Shell, 1990-97

**Objective**: Design an improved HPHT drilling-in and completion fluid that was free of troublesome components

- Free of barite
- Free of oil
- Free of halides
Shell’s research strategy – base the new fluid on a non-halide brine

Required brine properties

- Density to at least 19 ppg
- Safe
- Minimal environmental impact
- Non-corrosive
- Compatible with elastomers
- Minimal formation damage
- Shale stabilising

Similar in many ways to the desired properties of an ecological drilling and completion fluid
The formate brine family

<table>
<thead>
<tr>
<th>Cation</th>
<th>Brine</th>
<th>S.G.</th>
<th>Ppg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺</td>
<td>NaCOOH</td>
<td>1.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Na⁺</td>
<td>KCOOH</td>
<td>1.3</td>
<td>10.8</td>
</tr>
<tr>
<td>K⁺</td>
<td>RbCOOH</td>
<td>1.57</td>
<td>13.1</td>
</tr>
<tr>
<td>Rb⁺</td>
<td>CsCOOH</td>
<td>2.3</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Offshore Drilling Operations, Kuala Lumpur, 17-18 June 2008
Formate brines as ecological drilling and completion fluids

- Sodium, potassium or cesium formates dissolved in water
- Density up to 19.2 ppg
- Non-toxic
- Safe to handle, pH 9-10
- PLONOR and biodegradable
- **No limitations on cuttings disposal** (except in GOM)
- Non-corrosive, no SCC
- Protect against CO$_2$ corrosion
- Minimise formation damage
- Provide protection for polymers against thermal degradation
## Traditional formate drilling and completion fluid formulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formate brine</td>
<td>Density</td>
<td>1 bbl</td>
</tr>
<tr>
<td></td>
<td>Lubricity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polymer protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biocide</td>
<td></td>
</tr>
<tr>
<td>Xanthan</td>
<td>Viscosity</td>
<td>1 – 2 ppb</td>
</tr>
<tr>
<td></td>
<td>Fluid loss control</td>
<td></td>
</tr>
<tr>
<td>PAC or modified starch</td>
<td>Fluid loss control</td>
<td>4 – 8 ppb</td>
</tr>
<tr>
<td>Sized calcium carbonate</td>
<td>Filter cake agent</td>
<td>15 – 20 ppb</td>
</tr>
<tr>
<td>( \text{K}_2\text{CO}_3/\text{KHCO}_3 )</td>
<td>Buffer</td>
<td>2 – 8 ppb</td>
</tr>
<tr>
<td></td>
<td>Acid gas corrosion control</td>
<td></td>
</tr>
</tbody>
</table>
Toxicity of formates to aquatic and marine organisms

<table>
<thead>
<tr>
<th>Species</th>
<th>Test type</th>
<th>Sodium formate (ppm)</th>
<th>Potassium formate (ppm)</th>
<th>Cesium formate (ppm)</th>
<th>Zinc bromide (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scophthalmus maximus</td>
<td>LC50 96 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acartia tonsa</td>
<td>EC50 48 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skeletonema costatum</td>
<td>EC50 72 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oncorhynchus mykiss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daphnia magna</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mysidopsis bahia</td>
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</tr>
</tbody>
</table>
Formate brines as ecological drilling and completion fluids

- Lubricating
- Hydrate inhibition
- Compatible with Aflas, Kalrez and Chemraz elastomers
- Not compatible with elastomers that are sensitive to alkaline fluids (e.g. Nitrile, Viton)
- Positive influence on shales
  - reduce shale swelling
  - reduce filtrate invasion
  - reduce pore pressure penetration
  - induce osmotic back-flow

Cesium formate 2.3 s.g.
Formate-based drilling fluids
Formate brines – hydraulic benefits enabling ecological solutions (SH, ERD, CTD, etc.)

• Lower Surge and Swab Pressures
  - Faster tripping times
  - Reduced risk of hole instability or well control incidents

• Lower System Pressure Losses
  - More power to motor

• Lower ECD
  - Drill in narrower window between pore and fracture pressure gradients
  - Less chance of fracturing well and causing lost circulation

• Higher Annular Flow Rates
  - Better hole cleaning
Clear formate brine being reclaimed from used formate drilling mud, using an RVF
Formates and the Marine Environment

- Formate ion is readily biodegradable to CO₂ and H₂O
- The alkali metal ions are all prevalent in seawater
  - 2nd (Na), 6th (K) and 29th (Cs) most abundant
- One cubic mile seawater contains 1,700,000 tonnes of K ion!
- Full wellbore of K formate brine contains 170 tonnes of K ion
- Discharge of wellbore full of 13 ppg K formate brine:
  - Increase K levels by 1.7 mg/l in 1 km³ sea
  - Temporary increase of 0.45% above base levels
Formates – environmental risk assessment

- METOC plc* carried out a comprehensive (350-page) environmental risk assessment on formate brines

**Main conclusion:**
“The discharge of moderate amounts of formate brines into the marine environment is not likely to cause significant environmental impacts …”

* Environmental risk management consultants – www.metoc.co.uk
Environmental impact of formate brines – Barents Sea case study (SPE 94477)

• ENI drilled four exploration wells in Barents sea over period 2000-2005, discovering the Goliat and Gamma fields

• Top hole sections drilled with seawater/bentonite/ilmenite mud

• All sections below top hole drilled with same formate/XC/PAC mud (re-cycled, stored and re-used again over five-year period)

• Cuttings and mud from all sections were discharged into the sea (water depth 370-400 metres)
Environmental impact of formate brines – Barents Sea case study (SPE 94477)

ENI chose 10.8 ppg formate brine for drilling the Goliat and Gamma wells because:

- The fluid contains only "naturally-occurring materials"
- No barium or other heavy metals
- No oil, no surfactants, no lubricants, nothing "unnatural"
- Shale stabilisation better than glycol muds
- "Overwhelming environmental advantages"
- Ability to re-cycle and re-use the same brine many times over
Environmental impact of formate brines – Barents Sea case study (SPE 94477)

- In 2003, ENI decided to do a high resolution environmental survey around Goliat well 7122/7-1 drilled in 2000.
  Discharges at this site, in metric tonnes:
  - Ilmenite 95.2
  - Bentonite 73.5
  - Na/K formate 142.8
  - Mud and cement additives 8.6
  - Drill cuttings 484.1
  - Total discharges 804.8

- Objective was to check the conclusions of METOC’s EIA
Environmental impact of formate brines – Barents Sea case study (SPE 94477)

- Sea bed samples taken at 27 stations, 24-50 metres from wellhead
- Five biological samples and three chemical grabs taken at each station
- Found area of slightly disturbed fauna at some points 25-50 metres from the well head. Still high diversity in disturbed area
- ENI concluded that these findings were in line with METOC’s EIA, namely that discharge of formate muds and cuttings has only minor environmental impact
Shell’s conclusion at the end of their laboratory testing of formate brines in 1996

In theory, formate brines should make greatly improved HPHT drill-in and completion fluids

- Solids-free: better hydraulics, no sag, lower sticking risk
- Oil-free: better well control
- Halide-free: better corrosion control
- Stability: viscosity and FLC stable to at least 170°C
- Non-damaging: better well productivities
- Low environmental impact: no need to treat cuttings
- Lubricious: lower torque and drag

Validated by first HT drilling trials with potassium formate in 1996 (see SPE 59191 by Mobil)
– but …. no cesium formate available for HPHT wells requiring > SG 1.57/13.1 ppg
1993 – Cabot buys tantalum mine at Lake Bernic, Canada
1996 – Cabot invests $ 50 million in cesium mining and extraction plant at site
1998 – Producing ~700 bbl/month of cesium formate brine
Cesium formate produced in Canada from pollucite ore

Pollucite ore
Cs_{0.7}Na_{0.2}Rb_{0.04}Al_{0.9}Si_{2.1}O_{6}\cdot(H_2O)
- Mined at Bernic Lake, Manitoba
- Processed on site to Cs formate brine
- Cs formate brine production
  700 bbl/month
- Brine stocks > 30,000 bbl
## Cesium brines for HPHT and extreme HPHT well operations

<table>
<thead>
<tr>
<th>Cesium salt</th>
<th>Formula</th>
<th>Max. density (SG)</th>
<th>Temp. limit? (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium formate</td>
<td>CsCHO₂</td>
<td>2.3</td>
<td>&gt; 235 *</td>
</tr>
<tr>
<td>Cesium acetate</td>
<td>CsC₂H₃O₂</td>
<td>2.2</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>Cesium carbonate</td>
<td>CsCO₃</td>
<td>2.2</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>Cesium citrate</td>
<td>CsC₆H₈O₇</td>
<td>2.4</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>Cesium tungstate</td>
<td>Cs₂WO₄</td>
<td>2.9</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>Cesium molybdate</td>
<td>Cs₂MoO₄</td>
<td>2.7</td>
<td>&gt; 300</td>
</tr>
</tbody>
</table>

* Currently being used in Mako-6 well, Hungary: BHST 235°C
First field trials of cesium formate brine by Shell September 1999 – August 2002

17.20 – 18.86 ppg completion and workover fluid in six wells

- Shell Shearwater field – UK North Sea
- Gas condensate reservoir
- 15,000 psi
- BHST 365°F
Elgin and Franklin – HPHT fields
Elgin and Franklin – HPHT fields

Initial Reservoir Pressure (bar)

Temperature (C)

Other Operator
Elf Operator
Elf Non-Operating Partner

Norphlet 863
Thomasville
Shearwater
Trecate
Franklin
Elgin
Malossa
Tenguiz
West Cameron
Puffin
Erskine
Eugene Island
F15
Lacq
Lille Frigg
Kotelnevsko
North Ossum
Arun
Mary Ann
Block 823

Offshore Drilling Operations, Kuala Lumpur, 17-18 June 2008
Use of cesium formate by TOTAL in the Elgin/Franklin field November 1999 – present

18.2 ppg completion fluid in eight wells

- UK North Sea
- World’s largest HPHT field
- Gas condensate reservoir
- 16,000 psi @ 20,000ft
- BHST 400°F
- 140,000 bbl/day of condensate
- 13 million m³ gas /day
- Brine left in wells for up to 24 months (well suspension)
First drill-in and completions by Statoil with cesium formate brine January 2001 – April 2002

- **Huldra field**, offshore Norway, Gas condensate
  - BHST: 297°F
  - Fluid density: 15.75 ppg
  - Six wells – 600 ft reservoir sections 5-7/8” at 45-55°
  - 1–2,000 mD sandstone
  - Open hole, wire wrapped screens

- **Justification for using formate**
  - Improve well control
  - Lower ECDs
  - Run completion in same fluid
  - Low risk of screen plugging
  - Shale stabilisation
  - Lubricating
  - Safe for crews
  - Environmentally benign
Highlights of Huldra drill-in and completion
(ref: SPE 74541)

- Good well control (e.g. no barite to sag)
- Low ECD
- ROP similar to OBM
- Stable hole in reactive shales
- Good hole cleaning – slick hole on trips
- Smooth sand screen run in
- Faster tripping
- Rig time savings
- Log interpretation “manageable”
- **Plateau production from first three wells**
  - 10 MM m³ gas /day and 30,000 bbl/day condensate
Current drill-in and completions by Statoil with cesium formate brine  June 2004 – present

- **Kvitebjørn field**, 16-well programme
  - BHST: 311°F/155°C
  - Fluid density: 17.40 ppg
  - Eight wells so far – 1000 ft reservoir sections at 24-30°
  - Long interbedded shale and coal sequences
  - Two completed with liners, six with screens

- **Justification for use** (see SPE 105733):
  - Increase production (see Huldra production)
  - Improve well control
  - Lower ECDs
  - Good Health and Safety (safe to handle)
  - Low environmental impact (see Agip’s use of formate brines in the Barents Sea)
Highlights of Kvitebjørn drill-in and completion  (see SPE 105733)

- Good HPHT well control – no incidents in two years
- Low ECDs (lower than OBMs)
- Moderate to high ROPs
- Excellent well bore stability
- Good hole cleaning
- No stuck pipe. Low torque and drag
- Smooth sand screen run ins (4 out of 5)
- Good wireline logging runs (22 out of 24)
- LWD drill and ream pass data gives reliable and consistent net reservoir definition
- Log interpretation matches core porosity
- High production rates with low skin
Perforating in solids-free oil-based kill pill weighted with cesium formate brine

- **Visund field**
  - BHST: 118°C
  - Fluid density: SG 1.65
  - 13 wells – 1000-2000 metre horizontal sections
  - Drilled with OBM, completed with perforated liners

- **Justification for use**
  - First 3 wells badly damaged by CaBr$_2$ kill pill
  - PI only 60-90 m$^3$/bar/day
Perforating in solids-free oil-based kill pill weighted with cesium formate brine

- Visund – Change to formate-based kill pill
  (see SPE 73709, 58758 and 84910)
  - Next three wells perforated in formate fluid
  - Also used new perforating guns, in dynamic underbalance

- Results
  - Eliminated formation damage problem
  - PI increased up to 900 $m^3/bar/day$
  - 300-600% PI improvement
  - Best well: 53,000 bbl/day
Cesium formate applications 1999-2008

Over 140 HPHT jobs in 28 fields – N. Sea, Europe, GOM, South America and Asia Pacific. Five jobs in progress last month

- Drill-in
- Completion/workover
  - as a brine and in LSOBM formulations (13.8 ppg)
  - stand-by kill pill
  - outstanding as HPHT perforating kill pill (Visund, Braemar, Judy, Rhum)
- Long-term well suspension
- Well testing
- Stuck-pipe release pill (OBM drilling)
- Melting hydrate plugs
Cesium formate
– use segmented by application
Cesium formate brine – use segmented by operator
Feedback from users
– extracts from SPE papers

General

• “Major operational success”
• “Drilling benefits have given rig time savings”
• “Reduced the time to complete well”
• “Transition from drill-in fluid to completion fluid was simple”
• “For our specific well conditions there was no other alternative”
• “Selected cesium formate to minimise well control problems and maximise well productivity”
Feedback from users – Extract from TOTAL presentation to IADC*

HSE

“By deploying cesium formate brines in the Elgin, Franklin and Glenelg fields, TOTAL has created new health, safety and environmental standards for completion and work over brines in the North Sea”

“Other oilfield operators have followed suit, and to our knowledge zinc bromide brines are no longer used anywhere in Europe.”

* Presentation to IADC World Drilling conference, Paris, June 2007 and article in Drilling Contractor magazine, June 2007 issue
Feedback from users
– extracts from SPE papers

Well control

• “No well control or loss situation”
• “Extremely good well control environment”
• “No sag potential”
• “Elimination of gas diffusion into horizontal wells”
• “Well stabilises quickly during flow checks”
• “Unique track record: 15 HPHT wells drilled and completed with cesium formate brine without one well control incident”
Feedback from users – extracts from SPE papers

Hydraulics

• “ECD is s.g. 0.04 – 0.06 (0.30 – 0.50 ppg) lower than OBM”
• “Reduced ECD improved ROP in hard formations”
• “Fast tripping speeds”
• “ECDs higher when drilling clay than when drilling sand”

Lubrication

• “Torque values indicate friction factors as low as 0.22”
• “No need to add lubricants”
• “Low torque and drag”
Feedback from users — extracts from SPE papers

Hole stability and cleaning
- “Good hole stability in interbedded sand and shales”
- “Good hole stability”
- “Caliper log of 8-1/2” hole shows 9” in shale sections..”
- “Good hole cleaning”
- “Wash-outs up to 20” in 8-1/2” hole at 45° inclination”
- “Even after a few weeks of open hole, hole sizes over 9.5” have been very rare”

Differential sticking
- “Low potential for differential sticking”
- “No incidence of stuck pipe”
Feedback from users – TOTAL’s presentation to IADC on the cost* of using Cs formate brine

<table>
<thead>
<tr>
<th>Elgin well</th>
<th>Brine costs* ($, ’000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3</td>
<td>913</td>
</tr>
<tr>
<td>G4</td>
<td>830</td>
</tr>
<tr>
<td>G5</td>
<td>602</td>
</tr>
<tr>
<td>G6</td>
<td>879</td>
</tr>
<tr>
<td>G7</td>
<td>807</td>
</tr>
</tbody>
</table>

* Includes all brine rental, losses and reconditioning charges
Conclusions

• Cesium formate brine represents the 4th revolutionary innovation in well construction fluid technology

• Original innovation from Shell but produced, marketed and serviced by Cabot Specialty Fluids

• Field use has proven that cesium formate brine provides important benefits in challenging HPHT well constructions:
  - Enhanced drilling performance
  - Improved well control
  - Good well productivity
  - Enhanced formation evaluation with LWD tools
  - And an excellent HSE profile!
Cesium formate is available and being used in Asia Pacific

The West Prospero rig used for three completions with Cs formate brine in ExxonMobil’s Tapis field, Malaysia, 2007