UNLOCK YOUR RESERVOIR’S VALUE

Cesium formate brine – an investment in your well, your reservoir and your bottom line.
WHAT IS CESIUM FORMATE BRINE?

Our high-density cesium formate brine forms unique non-damaging drilling, completion, workover and well suspension fluids. Its remarkable properties provide real benefits by giving operators the power to cut well construction costs, reduce SHE risk and maximize reservoir potential.

Cesium formate brine is ideal for tough jobs

- **Clear brine fluids** for upper completions, workovers and interventions
- **Enhanced reservoir fluids** for lower completions, horizontal drilling and reservoir drill-in fluids
- **Performance drilling fluids** for extreme narrow-window, extended-reach and shale drilling
- **Special application fluids** for releasing stuck pipe, breaking filter cake, dissolving hydrates, reservoir perforating and forming debris barriers

Cesium formate brine is simply cesium formate dissolved in water. The result is a heavy brine with densities that increase with the level of cesium formate in solution. It’s part of the formate brine family, together with sodium and potassium formate brines. We manufacture cesium formate in highly pure 80% w/w aqueous solution with density of 2.20 g/cm³/18.36 lb/gal.

Cesium formate brine differs from other high-density clear brines in a number of significant ways:

- In pure form, it’s highly compatible with reservoirs as it only contains monovalent ions and no halides
- Anti-oxidant and water-structuring properties help protect polymers against thermal degradation at high temperatures
- With a natural pH of 10 – 10.5, it’s well suited to metals and elastomers
- Full compatibility with water-soluble polymers, such as xanthan, means it can be used to formulate drilling fluid
- It’s safer to handle with less environmental toxicity than other high-density brines

Properties of 2.20 g/cm³/18.36 lb/gal cesium formate brine.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³) @ 15.6°C</td>
<td>2.20</td>
</tr>
<tr>
<td>Recommended pH range</td>
<td>9 – 11</td>
</tr>
<tr>
<td>Viscosity (cP) @ 25°C</td>
<td>5.4</td>
</tr>
<tr>
<td>Water activity (a_w) @ 25°C</td>
<td>0.33</td>
</tr>
<tr>
<td>Boiling point (°C)</td>
<td>131</td>
</tr>
<tr>
<td>True crystallization temperature (°C)</td>
<td>5.1¹</td>
</tr>
<tr>
<td>Coefficient of thermal conductivity (W/m/K) @ 10°C</td>
<td>0.338</td>
</tr>
<tr>
<td>Heat capacity (J/g/K) @ 10 – 70°C</td>
<td>1.38</td>
</tr>
<tr>
<td>Coefficient of friction, metal to metal ²)</td>
<td>0.16</td>
</tr>
<tr>
<td>Coefficient of friction, metal to sandstone ²)</td>
<td>0.14</td>
</tr>
<tr>
<td>Coefficient of friction, metal to shale @ 93°C</td>
<td>0.24</td>
</tr>
</tbody>
</table>

1) As the degree of supercooling is exceptionally high, 2.20 g/cm³/18.36 lb/gal cesium formate brine can be used at very low temperatures.
2) Average coefficients taken over years at all temperatures.

Major operational success for BP, the first HPHT horizontal well drilled.

BP, OTC 15322
THE INVESTMENT THAT KEEPS ON PAYING BACK

Cesium formate brine is an investment in your well, your reservoir and your bottom line. It’ll unlock the full value of your reserves and keep on paying dividends year after year. Cesium formate brine is proven to:

- Decrease well construction time and cost
- Maximize production rates and deliver recoverable reserves faster
- Facilitate better reservoir definition
- Eliminate expensive well interventions
- Reduce operational and SHE risk

Cesium formate brine is ideal for challenging high-pressure, high-temperature (HPHT) wells. It brings particular value as combined non-damaging drill-in and completion fluids, allowing operators to construct deep, high-angle HPHT gas wells completed in openhole for optimal reservoir drainage. Read on to discover how and why cesium formate will benefit the economics of your next HPHT field development.

"The deployment of this benign brine has greatly reduced the risk of compromising well integrity and well productivity."

Total, Drilling Contractor magazine, May/June 2007
HPHT well construction operations using cesium formate brine are faster and more effective than those using traditional fluids. In 29 North Sea deep-gas well constructions carried out in overbalance with cesium formate brine between 1999 and 2010 there were no differential sticking or well control incidents while drilling, logging or completing. Average completion time for these wells is 21 days against an average of 46 days for wells drilled with oil-based muds (OBMs). That’s 25 days of costs saved and 25 days closer to production revenues. Let’s look now at why such results are achieved.

Faster, safer drilling

Solids-free cesium formate makes the perfect base brine for low-solids drilling fluids. This extremely lubricious fluid with low viscosity, high thermal conductivity and good heat capacity is ideal for HPHT drilling. It delivers the following benefits:

- Low equivalent circulating densities (ECDs), better hydraulics and improved hole cleaning
- Enhanced bit performance and extended bit life results in fewer trips and greater rate of penetration (ROP)
- Elimination of differential sticking
- Minimal non-productive time
- Shale stabilization and wellbore strengthening as swelling inhibition and pore pressure are reduced
- Faster flow-check times
- Less time circulating to cool measurement-while-drilling (MWD) tools
- Low torque and drag values in extended reach and high-angle drilling
- Stabilizes viscosifiers and fluid-loss polymers at high temperatures
- Reduces mud-conditioning times
- Quickly reach operational flow after stoppages as no need to break gel
- Low gel strengths prevent surge and swab risks
- Excellent well control
- Faster kick detection due to low gas solubility and low gas diffusion rate

Fluid lubricity as measured by the HLT Lubricity Tester

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Metal-to-metal</th>
<th>Metal-to-sandstone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-based, 15.0 lb/gal 1)</td>
<td>0.264</td>
<td>0.338</td>
</tr>
<tr>
<td>Diesel-based, various weights 2)</td>
<td>0.180</td>
<td>0.223</td>
</tr>
<tr>
<td>Mineral-based, various weights 1)</td>
<td>0.223</td>
<td>0.231</td>
</tr>
<tr>
<td>Synthetic-based, various weights 1)</td>
<td>0.181</td>
<td>0.253</td>
</tr>
<tr>
<td>Potassium/cesium formate 2)</td>
<td>0.162</td>
<td>0.144</td>
</tr>
</tbody>
</table>

1) Average COFs over several years measured with same instrument.
2) Average COFs over all temperatures.

ROP was a major issue and the reduced ECD with cesium formate made a very significant contribution in improving ROP.

BP, OTC 15322

Cesium formate performs well at low temperatures. The graph shows true crystallization temperature (TCT) for cesium formate (single salt). Supercooling points indicate the temperature where the fluid has been successfully kept for at least two weeks in the presence of standard seeding material.
Problem-free completions

High-density cesium formate brine has been successfully used in hundreds of cased-hole and openhole completion operations since 1999, including many jobs where it has been deployed as the internal fluid phase of low-solids oil-based muds (LSOBMs). It delivers the following benefits for completions:

- Formation friendly cesium formate minimizes impact on the reservoir
- Clean, solids-free environment for problem-free operation of completion tools, valves and packers
- Easy to handle and safest environmental choice of all high-density fluids
- Highly durable – cesium formate brine is safely deployed in extreme HPHT wells, such as Mako-6 in Hungary with a BHST of 235°C/455°F
- Compatible with downhole metals and elastomers under HPHT conditions

Universal fluid saves time and costs of fluid displacements

Cesium formate brine’s unique properties make it a truly universal fluid for all applications requiring a dense, clear fluid to provide secure well control. It can be used as low-solids drilling fluid, screen-running fluid, completion brine and suspension fluid, which means your formation is only exposed to one filtrate. Furthermore, the absence of residues from traditional muds allows completion operations to be successfully concluded in record times.

Drilling and completion times for Kvitebjørn HPHT wells

<table>
<thead>
<tr>
<th>Well</th>
<th>A-4</th>
<th>A-5</th>
<th>A-6</th>
<th>A-10</th>
<th>A-15</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section length (meters)</td>
<td>290</td>
<td>302</td>
<td>583</td>
<td>513</td>
<td>376</td>
<td>412.8</td>
</tr>
<tr>
<td>Drilling/logging time (days)</td>
<td>13.5</td>
<td>11.5</td>
<td>35.1</td>
<td>13.9</td>
<td>14.5</td>
<td>17.7</td>
</tr>
<tr>
<td>Completion time (days)</td>
<td>17.5</td>
<td>17.8</td>
<td>12.7</td>
<td>15.9</td>
<td>14.8</td>
<td>15.7</td>
</tr>
<tr>
<td>Total time (days)</td>
<td>31</td>
<td>29.3</td>
<td>47.8</td>
<td>29.8</td>
<td>29.3</td>
<td>33.4</td>
</tr>
</tbody>
</table>

Reference: SPE/IADC 105733
There have been no well control incidents in any HPHT deep-gas well drilled and completed with cesium formate brine, including 14 wells drilled and completed in openhole at overbalance for a total of 432 days in Statoil’s Huldra and Kvitebjørn fields. This remarkable ‘zero incidents’ record set in hostile environments is proof of the improved HPHT well control environment provided by cesium formate drilling and completion fluids.

The specific well-control benefits of cesium formate brines in challenging HPHT wells are:

- Elimination of weighting agents and associated sag
- Virtual elimination of gas diffusion into high-angle wells during circulation breaks
- No solids and low gel strengths mean lower ECDs and reduced swab/surge pressures, reducing risk of kicks, losses and destabilization
- Excellent kick detection as hydrocarbon influxes are not solubilized and show an immediate volume increase at the surface as pit gains. This gives drilling crews an ‘early warning system’ and more time to safely neutralize kicks
- Hydrate plug formation is inhibited and well control improved due to cesium formate brine’s hydrate-inhibiting properties
- Reliable operation of isolation valves – solids-free cesium formate creates a safe environment for dependable operation of isolation valves

Cesium formate brine has provided effective well control in more than 20 HPHT workover and suspension operations in Elgin/Franklin.

Total, Drilling Contractor magazine, May/June 2007
The driver for this drilling fluid choice was improved well control. The high-density, solids-free nature of the potassium/cesium formate brine provides low ECD, eliminates the risk of barite sag, and dissolves very low amounts of reservoir gases.

Tackling narrow drilling windows

In at least three offshore fields drilled with cesium formate – Kristin, Huldra and Kvitebjørn – the drilling window between pore pressure and formation fracture pressure in the reservoir sections was very narrow. For example, in Kristin the riser margin of 0.09 g/cm³ reduced the already narrow drilling window to only 0.09 g/cm³. High ECD of an oil-based mud (OBM) in this environment would have been very difficult to endure while maintaining a riser margin. Actual ECD measured with pressure-while-drilling (PWD) sensors when drilling the Kristin wells with cesium formate brine was only 0.05 – 0.06 g/cm³ higher than the static mud weight.

In the Huldra and Kvitebjørn wells, cesium formate drill-in fluid combined with reduced pumping rates and capped ROP kept ECD between 0.04 and 0.06 g/cm³ over the static mud weight, although excursions up to 0.09 g/cm³ could occur when drilling shale from temporary increases from low-gravity solids.
Cesium formate brine’s monovalent nature and mildly alkaline pH mean it’s highly compatible with polymers, elastomers and downhole metals.

**Elastomers and seals**

Numerous field cases and research studies conducted by Baker Oil Tools, Shell Research, ourselves and others show that formate brines are well suited to the vast majority of elastomers and seals used in downhole applications. Risks of leaks, equipment damage and safety breaches are significantly reduced, leaving operations running smoothly without concern. Formate brines’ compatibility is largely due to three reasons:

- Unlike divalent brines, cesium formate does not cross-link nitrile elastomers
- Corrosion inhibitors – a common cause of elastomer incompatibility – are not required
- pH – most elastomers are relatively stable in the mildly alkaline pH environment provided by formate brines

The table below shows some typical elastomer test results with buffered formate brines.

<table>
<thead>
<tr>
<th>Elastomer type 1)</th>
<th>Test conditions</th>
<th>Recom-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>FEPM (Aflas®) (TFE/P)</td>
<td>204</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>175</td>
<td>347</td>
</tr>
<tr>
<td>FFKM (Kalrez® Chemraz®)</td>
<td>191</td>
<td>375</td>
</tr>
<tr>
<td>EPDM</td>
<td>120</td>
<td>248</td>
</tr>
<tr>
<td>NBR 2)</td>
<td>120</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td>191</td>
<td>375</td>
</tr>
<tr>
<td>HNBR</td>
<td>175</td>
<td>347</td>
</tr>
<tr>
<td>FKM (Viton®) 3)</td>
<td>120</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td>163</td>
<td>325</td>
</tr>
<tr>
<td>Base-resistant FKM (Viton® ETP) 3)</td>
<td>170</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td>177</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>392</td>
</tr>
<tr>
<td>PEEK</td>
<td>180</td>
<td>356</td>
</tr>
<tr>
<td>Grafoil</td>
<td>170</td>
<td>338</td>
</tr>
</tbody>
</table>

The following acceptance guidelines have been used:
- < 15% volume (or hardness) change
- < 35% tensile strength (or elongation) change.

1) Elastomer type – relates to this entire group of elastomers.
2) As NBR and FKM elastomers are not compatible with alkaline pH they should not be used with formate brines buffered to alkaline pH.
3) Also denoted as FEPM by ASTM D140, although its structure and physical and chemical property profiles are significantly different.

**Stabilizes polymers at high temperatures**

Extensive tests have proven that our formate brines raise polymer stability by around 85°C/153°F through extending polymer transition temperature and scavenging hydroxyl (OH) free radicals. Special HPHT-stable polymers can be used to formulate formate drilling fluids for use at temperatures greater than 200°C/392°F. Formate brines are natural antioxidants with the ability to scavenge OH radicals that cause polymer degradation at high temperatures.
Cuts corrosion risk

Laboratory and field experience has shown that buffered formate brines without corrosion inhibitors are considerably less corrosive than other brines at high temperatures, even after exposure to large influxes of acid gas. Since 1999, cesium formate brine has been regularly exposed to HPHT conditions up to 225°C/437°F – often for long periods – without initiating general corrosion, pitting or stress corrosion cracking in downhole metals.

Cesium formate brine’s low corrosivity is due to its unique properties. Being a monovalent fluid with an alkaline pH means it can be buffered with carbonate/bicarbonate buffers to maintain favorable pH even after large influxes of acid gas. In fact, pH in buffered formate brine never drops below around 6 to 6.5 when contacted by acid reservoir gases. Furthermore, corrosion inhibitors should not be used in formate brines and biocides are not required. The halide content of cesium formate brine is very low, which reduces risk of catastrophic and fast-acting corrosion attacks associated with halides, such as pitting and stress corrosion cracking. And finally, the formate ion is an antioxidant, which limits the need for oxygen scavengers and avoids problems that often occur when these scavengers become depleted.

Six-year corrosion test

After six years immersed in formate brine, the production string was pulled from High Island A-5 well #1 off the Texan coast. Remarkably, identification markings on the pipe were still intact despite combating pressures of 14,000 psi and temperatures of 350°F/177°C.

The last and deepest joint of production string was examined thoroughly by metallurgical experts and pronounced to be in excellent condition. Testing indicated that the strength and toughness of the 13Cr tubular was unaffected. The entire tubular length was crack-free, with no corrosion or signs of embrittlement.

When the packer was set in 2002, High Island A-5 belonged to BP and is now owned by Apache. After one to two weeks, rapid cracking of 13Cr tubulars at fairly low temperatures and depths with halide brines led the operator to change the packer fluid to formate brine. Its compatibility with SM13Cr steel pipe proved this was the right decision to make.
Cesium formate brine helps deliver HPHT wells that routinely meet or exceed production performance expectations. Experience shows that this is particularly true in deep gas wells drilled and completed in openhole entirely with cesium formate brine.

**Kind to formations and screens**

Cesium formate minimizes damage to formations and screens. By using cesium formate brine, hydrocarbon flow rates are increased, risk of interventions reduced and production life and durability of the well maximized. It can be formulated with acid-soluble calcium carbonate particles and formation-friendly polymers to make low-solids drilling fluids, which are used as screen-running fluids. In these cases, upper completions using cesium formate brine usually follow. On conclusion of a well-construction operation, the well can be safely suspended for long periods with the same fluid. Whichever scenario is chosen, the reservoir is only exposed to one filtrate – cesium formate brine.

Specifically, solids-free cesium formate brine enables good in-flow performance in the following ways:

- No weighting agents to reduce formation permeability and block sand screens
- No scale precipitation from reservoir fluids and gases
- No emulsion blocking resulting from mixing fluid with reservoir fluids
- Stabilizes interstitial clays
- Minimal migration of fines through the formation
- No wettability changes as wetting agents are not required
- Ultra-thin filter cakes lift off and backflow easily at low drawdown pressures saving time and cost

**The proof**

Cesium formate brine has been used successfully in numerous high-angle, HPHT, open-hole completions on fields such as Huldra, Tune, Kvitebjørn and Kanowit. Wells completed with cesium formate in these fields have shown low skins in low-permeability sandstone and limestone without any need for clean-up or stimulation treatments. Very thin filter cake residues left on the borehole wall lifted off easily or were naturally breached, and allowed free flow of hydrocarbons through sand screens on production start-up.

*The well is now flowing at levels above expectations at 79 mm/scf/day, proving that no significant skin damage to the well has occurred.*

George Lumsden, Marathon
Outstanding well performance and reserve recovery

- Good well flow performance at production start-up
- Wells cleaned up naturally during early production phase
- 7-8 MMm³/day average gas production rates from 2002 to 2003
- By end of production year seven, the six Huldra field wells had delivered almost 80% of recoverable gas and almost 90% of condensate reserves
- After ten years, cumulative production is close to 100% of original estimates of recoverable reserves ¹

¹ Huldra is estimated by the Norwegian Petroleum Directorate to have recoverable reserves of 16 billion m³ of gas and 5 million m³ of oil/condensate.

Field: Huldra. Operator: Statoil

- Recovering reserves – a North Sea comparison
  - Tune and Huldra were both drilled and completed in openhole with high-density formate brines
  - Marnock wells were completed in openhole with OBM, suffered sand-screen blocking and needed stimulating. Shearwater and Erskine were drilled with OBM and completed as cased holes
  - Over 50% of recoverable gas and condensate reserves were recovered from Tune and Huldra within four years. At the eight-year mark, the fields had already produced close to 90% of gas reserves and 95% of condensate reserves
  - Shearwater, Marnock and Erskine all performed poorer than Huldra and Tune

Source: Norwegian Petroleum Directorate

The use of cesium/potassium formate mud with standalone screen sandface completions has resulted in highly productive wells with low skin.

Statoil, SPE/IADC 105733

% of original reserves in place

Cumulative production of reserves from the Huldra field, 2001 to 2011.

Source: Norwegian Petroleum Directorate

The kill pill has therefore been non-damaging and the perforation program has achieved the desired productivity.

Statoil, SPE/IADC 105733

% of estimated original reserves in place

Fields: Huldra and Tune. Operator: Statoil

Recovering reserves – a North Sea comparison

- Tune and Huldra were both drilled and completed in openhole with high-density formate brines
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- Shearwater, Marnock and Erskine all performed poorer than Huldra and Tune

Source: Norwegian Petroleum Directorate

Percentage of reserves recovered from five North Sea HPHT fields with estimated recoverable gas reserves of 10 – 24 billion m³.
The unique properties of cesium formate brine-based drill-in fluids give better decision-making data for planning and executing well construction operations.

- Helps reservoir evaluation through high-quality data generated by acoustic, resistivity and nuclear logging tools
- Includes better definition of rock layers containing movable hydrocarbons, i.e. net reservoir
- Allows better visualization of rock structural and depositional details for creating accurate reservoir models

Cesium formate brines make very conductive drilling fluids that contain few solids, creating the ideal medium for all acoustic measurements and high-resolution resistivity image logging. The high-quality image logs obtainable in cesium formate brine reveal sedimentary features on a centimeter scale, providing geo-modelers with important information on structural dip, depositional environment and orientation of sand bodies. This detailed information allows the creation of superior reservoir models.

Cesium formate brine is unique among HPHT drilling fluids by having a very dense filtrate (up to 2.30 g/cm³/19.2 lb/gal) that has a stunningly high photoelectric cross section (Pe) of up to 259 barns/elec. Any invasion of this mud filtrate into the formation around the well bore becomes highly visible to nuclear logging tools against a background Pe of 2 – 6 barns/elec for common rock materials and formation fluids.

The logged photoelectric effect provided by the invasion of cesium formate filtrate is extremely useful for correcting the density curve for mud/borehole effects and mud filtrate invasion, and for estimating filtrate saturation. It is also ideal for defining permeable sands. Combining the photoelectric effect and its high vertical resolution with resistivity measurements from both the drill pass and ream pass of a logging-while-drilling (LWD) tool produces a very reliable and accurate net reservoir definition.

“This low-solids and very conductive drilling fluid has been found to be ideal for all acoustic measurements and for electrical image logging...The logged photoelectric factor is not only useful for correcting the density curve and to estimate Sxo, but it is also ideal for defining permeable sands.”

Statoil, SPE/IADC 105733
FMI resistivity image obtained in cesium formate drilling fluid, showing fine structure of laminated mudstone with drill-induced fractures along a 50 cm length of borehole. Ref. SPE/IADC 105733

Combining resistivity log responses from LWD drill-pass (P16_1) and ream-pass (P16_2) with photoelectric effect (PEB_1) provide a powerful technique for defining permeable sand intervals (SAND_FLAG). Ref. SPE/IADC 105733

Delivers a reliable and consistent net reservoir definition, formation porosity, and HC saturation by taking advantage of the unique nuclear properties of cesium formate.

Erik Sandtorv Pedersen, Petrophysicist, Statoil ASA, Formate Matters no. 2, April/May 2008

The results (from cesium formate-based fluid LWD data) match core porosity from different lithologies in three different wells, so we’re very confident that this new approach works. Furthermore, cesium formate brine helps us better define the net reservoir and produce improved reservoir models.

Erik Sandtorv Pedersen, Petrophysicist, Statoil ASA, Formate Matters no. 2, April/May 2008
Cesium formate brine reduces operators’ risk of environmental damage and personal injury. If there is an accidental release or spill, effects are minimal and liability is reduced accordingly.

**Reducing environmental impact**

Cesium formate is the safest environmental choice of all high-density brines with the formate ion biodegrading entirely when diluted in the ocean. It meets the demanding environmental standards set by CEFAS (Centre for Environment, Fisheries and Aquaculture Science) in the UK, the Norwegian Environment Agency and other environmental authorities across the world. Used in highly sensitive environments from the Barents and North Seas to onshore use in Hungary and Alaska, formate brines reduce the environmental effect of hydrocarbon exploration.

Intertek Metoc conducted an extensive environmental impact assessment study and found that “Quantitative risk assessments, following OSPAR recommended approaches, indicate that the use and discharge of formate brines, in a manner similar to several test cases, does not pose a significant risk to the environment.” Intertek Metoc concluded by stating “Formate brine drilling and completion fluids presents the operators with opportunities for minimizing the environmental impact of a well construction operation.”
**Safer working environment**

Cesium formate brine is not only the preferred choice for minimizing environmental impact, but it’s also the best option for rig crews compared to all other high-density brines. It’s achieved excellent test results against conventional fluids for dermal toxicity, eye irritation, skin sensitization and mutagenicity, which is supported by an impressive safety record in the field. In almost twenty years, there are no recorded incidents of personal injury caused by cesium formate.

No rubber suits or respirators are required when handling cesium formate brine.

**Sustainable operations**

Operations are based on leasing, reclamation and reuse of cesium formate. This sustainable business model reduces operating costs and minimizes environmental impact. By careful management, the majority of brine is recovered and reused. This approach encourages better chemical management, where operators join with us in a common cause to conserve chemicals and minimize waste.

Cabot’s unique reclamation technology turns used drilling and completion fluids into clean brines, allowing the fluids to be used in multiple wells with significant cost savings.

The HSE risks of working with zinc bromide were deemed as unacceptable therefore cesium formate became the only fluid capable of delivering this objective.

BP, OTC 19242
We lease cesium formate to our clients, retaining stewardship and ownership of the brine throughout all projects. Upon completion, we transport used fluid back to one of our recycling centers, reclaim the cesium formate for use in further wells and charge clients for any loss in brine value.

Helping to reduce cesium formate brine losses during operations is an essential feature of our unique brine-leasing business model. We advise and work together with clients to maximize value and minimize wastage, an approach that benefits everyone.

Our chemical-leasing business model has been recognized with an award from the United Nations Industrial Development Organization (UNIDO) for its pioneering role in introducing sustainable chemical leasing to the upstream oil and gas industry. This forward-thinking, sustainable approach allows clients to concentrate on their projects knowing that we are responsible for cleaning the fluid and recycling it into clean brine at the end of operations.

We operate an innovative, award-winning leasing scheme as part of our sustainable business policy.

"Chemical leasing provides practical solutions for industry to become more efficient and green. At the same time, it reduces the unnecessary consumption of hazardous chemicals and protects human health and the environment."

Kandeh K. Yumkella, Director-General, UNIDO
A WEALTH OF KNOWLEDGE

We are the leading global authority on formate brines. Since our incorporation in 1996, we have built up a wealth of knowledge and expertise in this specialist area from hundreds of challenging jobs around the world, the majority of which are HPHT drilling, completion and intervention operations. We operate our own research laboratory in Aberdeen and have invested extensively in external research. The result is valuable collateral, such as the Formate Technical Manual, case histories, environmental assessment reports, DensiCalc™ density and pressure calculator and the BrineWise™ costing tool, all of which can be downloaded from our informative website, cabotcorp.com/cesiumformate.

GLOBAL SUPPORT

We are headquartered in Aberdeen, Scotland and operate globally, with sales offices/stock points in the UK, Norway and Singapore, and additional stock points in Canada, Belgium and the United States.

With close to 100 staff devoted to formate brines, no other company matches our experience, expertise and pure dedication to this product. A skilled team of field engineers is waiting to assist operations anywhere in the world and well-equipped laboratories in Aberdeen and Bergen provide customized fluid formulations, fluid analyzes, trouble-shooting and technical advice.

ASSURED SUPPLY

We are part of the publicly listed Cabot Corporation, which owns and operates the Tanco mine at Lake Bernic, Canada, where 80% of the world’s known pollucite deposits are located. Pollucite is mined and processed into cesium formate and fine cesium chemicals.

Cabot Corporation is a global specialty chemicals and performance materials company headquartered in Boston, USA, with a history spanning more than 130 years. Our customers know us for high-quality products, innovative solutions and a commitment to helping make their businesses successful. We have operations in more than 20 countries and employ some 4,500 people worldwide.

In addition to being used in the 7 Kvitebjørn wells, cesium/potassium formate brine has been the HPHT completion fluid of choice in all 6 Huldra wells and in 7 Kristin wells.

Statoil, SPE/IADC 105733

Our Operations and Technical Support Laboratory in Aberdeen is always ready to help with fluid testing and formulation.
TXM Mako-6, southeast Hungary
HPHT gas/condensate well
235°C/455°F – 96+ MPa/14,000+ psi

Two records were broken during this challenging well kill and suspension operation using 2.15 g/cm³/17.94 lb/gal cesium formate brine – the deepest packer ever set in Hungary at 5,198 m/17,054 ft and the highest temperature for cesium formate brine use at 235°C.

Mako-6 was drilled, completed and temporarily abandoned with 1.33 g/cm³/11.1 lb/gal calcium chloride brine in the hole. Log analysis revealed significant gas from numerous intervals and an extensive frac ing operation was initiated. This was successful at first, but after discovery of H₂S gas M-I SWACO, TXM’s fluid-technology consultants, initiated a well kill operation with cesium formate brine. A total of 57 m³ cesium formate brine at 2.15 g/cm³ / 17.92 lb/gal was bull-headed down the 5 1/2” casing to the bottom of the perforated zone at 5,300 meters to minimize wellhead pressure and enable snubbing of a packer and test string into the hole.

High-density cesium formate was chosen as alternative brines with lower densities develop much higher surface pressures, which place more wear and tear on the snubbing equipment and increase operational risk. Cesium formate remained in the well for 39 days before a reverse circulation displacement to a packer fluid enabled well-test operations to begin. The brine was sampled when circulated out.

1) SPE 145562, 2007

Shell Shearwater, North Sea
HPHT gas/condensate well
185°C/365°F – 103 MPa/15,000 psi

As an emergency response to Shell’s request, over 2,500 barrels of cesium formate and a cesium/potassium formate blend kill fluid were quickly heading out to Shearwater. Wellhead pressure had risen dramatically and a well kill operation was needed. The cesium formate successfully reduced pressure at the wellhead from over 758 bar (~11,000 psi) to around 103 bar (~1,500 psi), just as Shell had planned.

Statoil Kvitebjørn, North Sea
HPHT gas/condensate field
155°C/311°F – 81 MPa/11,700 psi

Twelve reservoir sections have been drilled and ten completed with cesium/potassium formate brine in the Kvitebjørn field since 2004.

Prior to 2007, all Kvitebjørn reservoir intervals were successfully drilled using conventional techniques to TD with inclinations ranging from 23 – 46°. Drilling performance was very good with moderate to high ROPs, good hydraulics, no stuck pipe, low torque/drag and excellent hole cleaning. One of the wells was completed in a North Sea record time of 12.7 days with an operation factor of 98.1%.

Due to reservoir depletion, Managed Pressure Drilling (MPD) was introduced in 2007. MPD uses reduced mud weight and surface controlled back-pressure to manipulate the downhole pressure profile. To combat BHP variations from temperature changes, drill-pipe rotation, swab/surge and other phenomena, a drilling fluid designed to improve fracture gradient was needed. A ‘designer mud’ with density of 1.82 g/cm³/15.2 lb/gal was introduced by M-I Swaco based on low ECD cesium/potassium formate brine with a controlled particle size distribution blend of calcium carbonate and graphite. Wells were completed in overbalance with cesium/potassium formate completion fluid using standalone screens. The result is highly productive wells with low skin.

Full openhole formation evaluation of the Kvitebjørn reservoir has been carried out with LWD tools. The evaluation has been aided by the development of an innovative logging interpretation solution for a LWD density tool, which makes unique use of the extremely high photoelectric effect from cesium-rich filtrate.

Per Cato Berg, Lead Drilling Engineer for Kvitebjørn, says: “Supported by our tests and data, we feel that cesium formate gives the best productivity for the wells. We have tested formation damage with water- and oil-based alternatives, and cesium formate comes out best.”

The Kvitebjørn operations add to Statoil’s unique track record – 15 HPHT wells drilled and 22 completed using high-density cesium/potassium formate brines without one single well-control incident.²

²) SPE 145562, 2007
of the hole after the 39-day suspension. Despite lengthy exposure to hydrothermal conditions, laboratory analyses showed no significant changes in fluid properties or composition.

Don Wright, operations manager for TXM, comments: "Successfully setting the packer in Mako-6 at a record depth was a significant achievement for us. Cesium formate provided stable well conditions and enabled operations to progress safely and smoothly. Crew only needed to wear standard personal protective equipment, something that made working conditions much more comfortable, especially since outdoor temperatures rose to 40°C/104°F on occasion."

The well was later suspended three times using cesium formate, including a six-month period. Again, due to extreme temperatures, the brine was thoroughly analyzed after it was circulated out of the well. No significant changes in fluid properties and composition were found.

The 8½” reservoir intervals were drilled with synthetic oil-based mud (SBM) and completed with 7” liners before running production tubing and suspending them. Prior to the Elgin wells being brought onto production, it was established that incorrect heat-treatment procedures had been used during production of the 10½” casing-hangers. A workover plan was prepared to re-enter the wells, recover the production strings, replace the hangers and re-run the production strings.

Two of the seven Elgin wells (G1 and G3) had already been perforated, making it imperative to kill them with a high-density workover fluid before carrying out remedial work. Total first tried OBM as workover fluid, but barite sag problems turned their attention to brine. Cesium formate was selected due to its benign nature and compatibility with metals used in casing, production tubulars and packers.

Elgin G1 and G3 were displaced to 2.19 g/cm³ cesium formate brine prior to running and setting the packer. The production tubings were run without incident, followed by the tubing hangers. The wells were then displaced to inhibited drill water. In G1, a faulty packer leaked causing hydrate formation. This well was killed again with cesium formate brine and the hydrate plug melted by circulating hot cesium formate brine into the annulus.

The remaining re-entries (G4 – G8) involved simply displacing the wells to 2.19 g/cm³ cesium formate brine, recovering completion strings, replacing casing-hangers, re-running completion strings and displacing the wells back to inhibited drill water.
FORMATE TECHNICAL MANUAL

Split into three parts – Chemical and Physical Properties, Compatibilities and Interactions, Formate Field Procedures and Applications – the Formate Technical Manual is the world’s definitive work on formate brines. Growing every year, it currently holds over 400 pages and is available for free download at cabotcorp.com/manual.