Caesium formate brines used as workover, suspension fluids in HPHT field development

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TOTAL E&P IS engaged in the development of the Elgin and Franklin fields, which together represent the world's largest HPHT field development project. From October 1999 until the present, the preferred workover and suspension fluids used for remedial well operations in these fields have been caesium formate brines. Caesium formate brine has provided effective well control in more than 20 HPHT workover and suspension operations in Elgin/Franklin while creating new HSE standards for high-density brines. The deployment of this benign brine has also greatly reduced the risk of compromising well integrity and well productivity.

INTRODUCTION

Development activities in TOTAL's Elgin and Franklin fields in the UK North Sea started in 1997 and continue to the present. Seven production wells were initially drilled in the Elgin field to around 5,600 m TVD, with maximum deviations ranging from near-vertical to 45°. A further 6 production wells have been drilled in the Franklin field to deeper horizons.

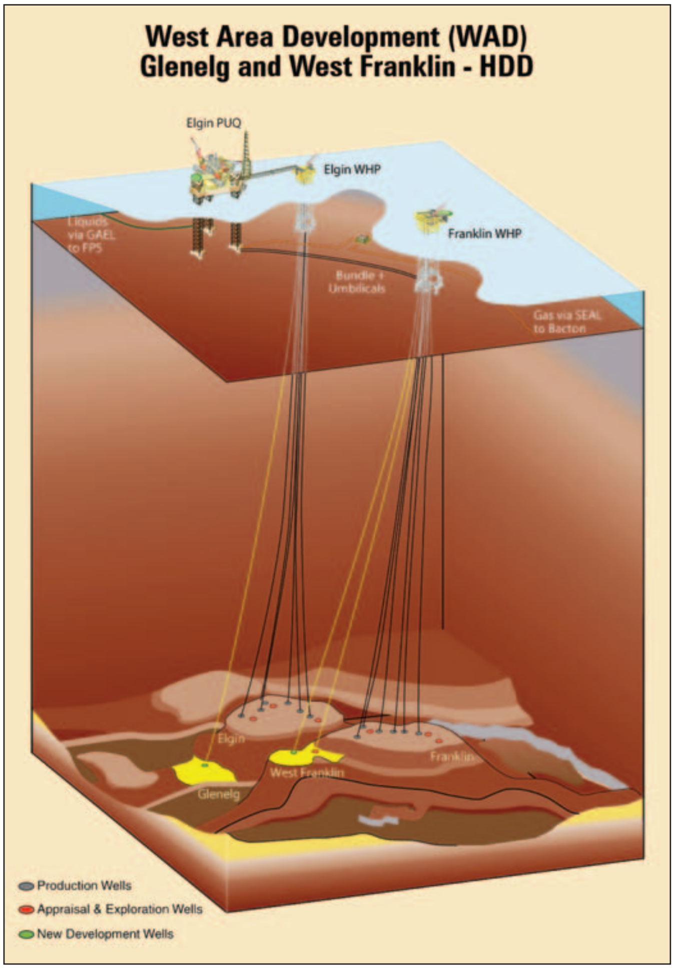
Initial reservoir pressures in Elgin and Franklin were around 1,100 bars, and maximum BHST was in the range of 190°C to 205°C. The 8 ½-in. reservoir intervals were drilled with synthetic oil-based mud (SBM) and completed with 7-in. liners before running production tubing. The wells were then temporarily suspended for eventual use as gas condensate producers. Design production rates for the combined fields were 14.6 million cu m/day of gas and 170,000 bbl/day of condensate.

During preparations to bring the Elgin wells into production in the latter part of 1999, it was discovered that incorrect heat-treatment procedures had been used during the production of the 10 ¾-in. tubing-hangers. A remedial 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 7 Elgin wells had already been perforated, making it imperative to kill them with a high-density workover fluid before removing the Christmas tree to allow replacement of the hangers.

WORKOVER FLUID SELECTION

A workover fluid with an average downhole density of SG 2.14 was required to provide effective well control. The performance specification used to select the workover fluid was:

- Brine-based fluid: solids-free to minimise the risk of formation damage and solids settlement.
- Minimal damage to the formation (Sandstone – 1 Darcy permeability).
- Non-hazardous.
- Minimal impact on the environment.
- Maintains the integrity of sub-surface metal goods, even when contaminated with acid gases.



In the Elgin and Franklin fields, which together represent the world's largest HPHT field development project, caesium formate brine was used to provide effective well control.

Prior to 1999, the only solids-free brine available at this density would have been zinc bromide brine. This corrosive and hazardous product based on a toxic heavy metal did not meet any of the required performance criteria other than being a solids-free fluid. The use of zinc bromide brine in Elgin operations would have created a tangible risk of an HSE incident, in addition to possibly compromising well productivity and integrity.

Fortunately, the timing of the first workover on Elgin coincided with the arrival of commercial quantities of caesium formate brine in Aberdeen. Caesium formate brine is a benign product, with a good HSE rating, and is not aggressive towards the metals used in the construction of casing, production tubulars and packers.

Potassium formate brines had been successfully used by **ExxonMobil** and others for drilling and completing HPHT gas wells since 1996, and TOTAL had recently used caesium formate brine as a completion fluid in an HPHT well in the Dunbar field. Laboratory core flooding tests on Elgin reservoir core samples under simulated reservoir conditions showed that caesium formate brine caused only a 3% reduction in permeability after 6 days' of exposure.

Against this background, the TOTAL well engineering team selected caesium formate brine as their preferred HPHT work over fluid for the Elgin well intervention campaign.

INTERVENTIONS IN LIVE PERFORATED WELLS

•Elgin-G3

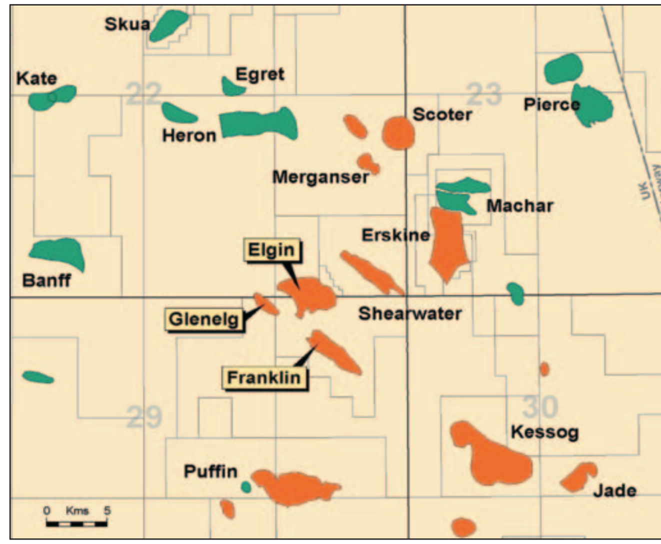
The decision to use caesium formate brine for the first time came while performing remedial work on Elgin-G3 with an SBM in the hole. Barite sag in this 45° well had been a problem throughout the re-entry programme, from casing-hangar replacement through to milling out various plugs and then during re-perforation.

It was decided to displace the well to clear caesium formate brine before running and setting the packer. The well was first displaced to surfactant-treated water-based mud, followed by a heavy viscous formate pill and then SG 2.19 caesium formate brine. This provided an average fluid density of SG 2.14 in the well bore. A flow-check performed before and after circulating bottoms-up confirmed that the perforated well was static, and the remaining brine on surface was filtered through filter-presses and cartridge filters while tripping out of the hole.

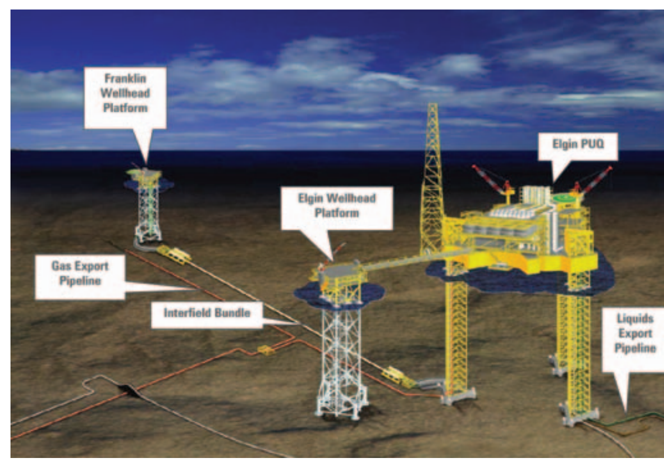
The tail-pipe of the packer was filled with a viscous gel debris barrier designed to prevent solids entering the tool while it was being run in the hole. The packer was set without incident, and a 3,500 psi pressure-test confirmed the effectiveness of the seal. The brine was filtered clean again, and the production tubing was run without incident. The tubing-hanger was successfully landed, and the caesium formate brine in the well was displaced to inhibited, filtered drill water. The BOPs were removed so that the Christmas tree could be installed and the well was successfully flowed before temporary suspension while working on adjacent wells.

• Elgin-G1

As with G3, this well had been perforated and suspended with SBM in the hole. The production string had not been run, and the hanger was replaced with the old SBM still in the hole. A milling assembly was then run to drill out the bridge plugs and cement plugs, exposing the perforations in the reservoir. Barite sag was evident, as in G3, but it was easier to remedy since this well was near-vertical. The 2-stage displacement to caesium formate brine was then performed, and flow-check confirmed that the well was static.



The Elgin and Franklin fields are located in the UK North Sea. Development began in 1997.



Production and pipeline installations are illustrated above for the Elgin and Franklin fields.

A **Schlumberger** pressure-logging tool (PLT) run was performed to measure downhole pressures and temperatures with the SG 2.188 brine in the hole. The measured pressure and equivalent average brine density results were compared with

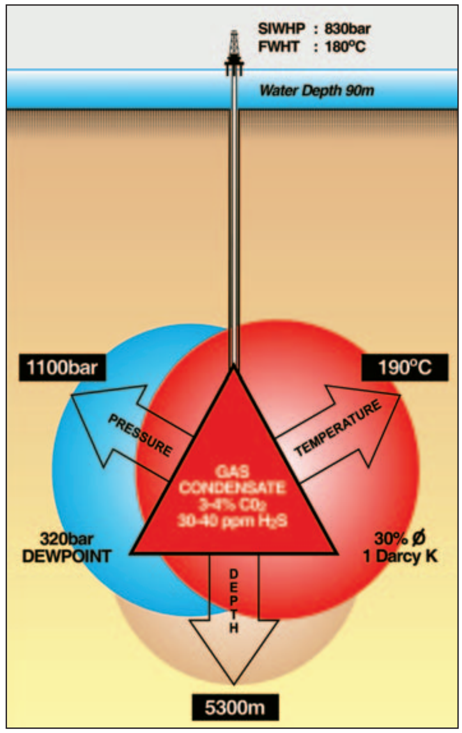
	Schlumberger PLT Log			Densicalc Projection	
TVD (m)	Temp. (°C)	Pressure (psi)	EBD (SG)	Pressure (psi)	EBD (SG)
987.67	41.6	3,090	2.200	3,069	2.183
997.64	41.8	3,121	2.200	3,100	2.183
1,984.97	87.3	6,163	2.184	6,120	2.166
1,994.91	87.5	6,192	2.183	6,151	2.166
2,982.29	127.3	9,185	2.166	9,137	2.152
2,993.14	127.5	9,215	2.165	9,170	2.152
3,979.70	152.1	12,180	2.152	12,157	2.146
3,989.58	152.2	12,208	2.152	12,187	2.146
5,505.74	188.9	16,719	2.136	16,750	2.137

Measured pressure and equivalent average brine density results from the Schlumberger pressuring-logging tool and the theoretical figures obtained from Cabot's Densicalc software were very close.

the theoretical figures obtained using **Cabot Specialty Fluid**'s Densicalc software, and the agreement was very close at TD.

The packer was successfully run, set and pressure-tested in the formate brine. The production tubing was run without incident. The tubing-hanger was successfully run and landed, and pressure testing confirmed the integrity of all the sealing surfaces. The rest of the caesium formate in the well was then displaced to inhibited, filtered drill-water, and the BOP was removed and replaced with a Christmas tree before temporary abandonment.

It was then discovered that a packer was leaking (due to a manufacturing fault), and the escaping reservoir gases had created a hydrate plug with the drill-water in the upper annulus. The well was killed with SG 2.19 caesium formate brine after sealing off the perforations with an LCM pill and circulating hot caesium formate brine into the annulus with coiled-tubing to melt the hydrates. A cement plug was set above the packer, and the well was temporarily abandoned.



Depth, pressure and temperatures were high in both the Elgin and Franklin fields.

UN-PERFORATED CASED HOLE

The 5 remaining Elgin wells (G4-G8) requiring re-entry were not so demanding because they had not been perforated and had been suspended with inhibited drill water. These re-entries involved displacing the wells to SG 2.19 caesium formate brine, recovering the completion strings, replacing the casing-hangers, re-running the completion strings and displacing the wells back to inhibited drill water.

After landing the completion string, a pressure-testing program was performed to ensure the seals were good, and the well was suspended in preparation for perforation and production.

Good displacements with minimum dilution and contamination of the caesium formate brine were achieved using a SG 1.57 potassium formate brine spacer, preceded by a slug of viscosified potassium formate brine.

FORMATE BRINE LOSSES

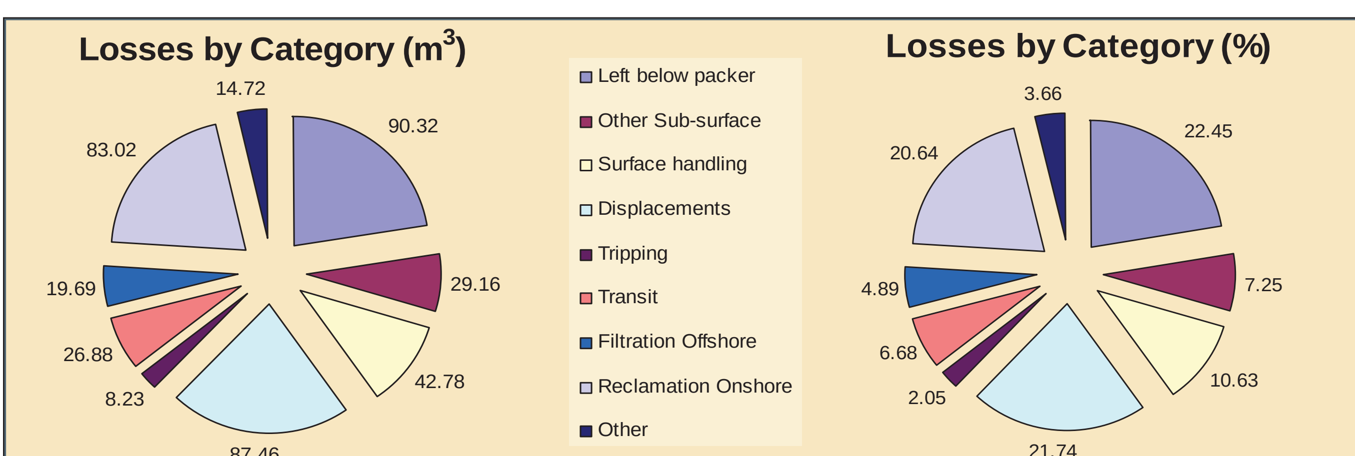
Caesium formate brine is a high-value fine chemical, made in quite small quantities (only 1,270 cu m/year of SG 2.2 brine), and is provided by Cabot on a rental basis. Losses of this rare product during use must be minimised. Measures also need to be taken to avoid accidental dilution of the brine during use because loss of density devalues the brine considerably.

A thorough rig audit was performed by Cabot engineers on the rig's fluids handling and transfer system to identify operations and hardware that could create the risk of brine contamination and loss. Following the rig audit, a detailed Fluids Management Manual was prepared and circulated.

As a result of this fluid management, the total volume of brine lost during the initial Elgin re-entry campaign (18 re-entries in 7 HPHT wells, Elgin G1-G8) was only 402.26 cu m, or 10.5% of the total volume handled on the rig. The largest category of loss was the unrecoverable caesium formate brine abandoned below the packers at the end of each well re-entry operation. The volumes ranged from 6.15 cu m to 15.14 cu m, and a total of 90.32 cu m brine was lost this way.

FORMATE STABILITY

Initial field trials with caesium formate brine in HPHT wells in the Shearwater and Dunbar fields had indicated that the brine was completely stable and not prone to any chemical transformation under downhole conditions. Nevertheless, soluble bicarbonate and hydrogen gas can be produced from formate brines at high temperatures in laboratory autoclaves, especially if catalytic metal surfaces are present (e.g. alloys with high Ni and Cr content). On the other hand, it is also known that bicarbonate and hydrogen can be converted back to formate and



The total volume of brine lost during the initial Elgin re-entry campaign was only 10.5% of the total volume handled on the rig. The breakdown of the losses by source (in volume and percentage terms) is tabulated in the pie charts above.

graphite under HPHT conditions in the presence of magnetite (mill scale) that is commonly formed on the surface of carbon-steel tubulars during manufacture.

To find out which reactions might dominate in the Elgin wells, a series of thermal stability experiments were conducted with caesium formate brine at 204°C in magnetite-coated carbon steel autoclaves containing galvanically-coupled rods of 25Cr (simulating the presence of production tubing). There was no evidence of hydrogen gas production in these tests, and the surfaces of the 25Cr were coated with a carbon film, indicating that magnetite-mediated reactions were probably dominating.

A hydrogen detector was regularly used in the field to check the caesium formate brines for the presence of hydrogen gas whenever fluid circulation took place. Only trace levels of hydrogen were ever detected, and the concentration of bicarbonate in the brine hardly moved above the levels added to provide pH buffering.

The results of the metallurgical qualification tests on 25Cr tubular material that had been exposed to caesium formate brine for 15 months in Elgin-G3 showed that the hydrogen levels in the metal were still at the original 2-3 ppm level compared with levels of up to 7 ppm for the tubing sections that had been exposed to SBM. This provided further indirect evidence that hydrogen production from the formate brine was not significant.

BRINE COST

Caesium formate brine is provided by Cabot on a daily rental basis. The total cost is a function of brine density; number of rental days; amount of brine lost during transport/handling/use; any loss of value of the brine through dilution during use; cost of any brine clean-up at the end of the job. On average, it cost just under $1 million per well to use caesium formate brine in the first year of the Elgin well workover campaign.

CONCLUSIONS

Caesium formate brine has provided the hydrostatic well-control required for safely carrying out essential remedial work on the casing hangers of 7 offshore HPHT wells and in a number of further interventions in Elgin, Franklin and Glenelg wells over a period of 7 years. In deploying caesium formate brines in these fields, TOTAL has created new health, safety and environmental standards for completion and workover 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.

In addition to providing clear HSE benefits, the high-density formate brines are less likely to compromise well integrity and well productivity than conventional halide-based brines under HPHT conditions. The adoption of rigorous fluid management procedures restricted average brine losses in the initial workover campaign in 7 HPHT Elgin wells to just 57 cu m per well, representing 10% of the total brine volume handled on the rig. Almost a quarter of these losses relate to brine intentionally left below packers. The average cost of using caesium formate brine in this multiple well re-entry programme in Elgin was just under $1 million per well.

This article is based on a presentation at IADC World Drilling 2007, 13-14 June 2007, Paris.