

TIME FOR A CHANGE

JOHN DOWNS OF
FORMATE BRINE LTD,
UK, LOOKS AT
HOW FORMATE
BRINES ARE TAKING
WELL DRILLING
PERFORMANCE
AND RESERVOIR
EVALUATION INTO A
NEW DIMENSION.

“Be it known that I, Benjamin K. Stroud, a citizen of the United States... have invented the new and useful Improvement in Application of Mud Laden Fluids to Oil or Gas Wells, of which the following is a specification.” So began the introductory paragraph to US patent application 1 575 945, signed by the inventor on 18 November 1924, which launched the use of finely-ground minerals such as barite as the preferred weighting agents for drilling muds. While Benjamin Stroud’s powdered minerals have been of great service to

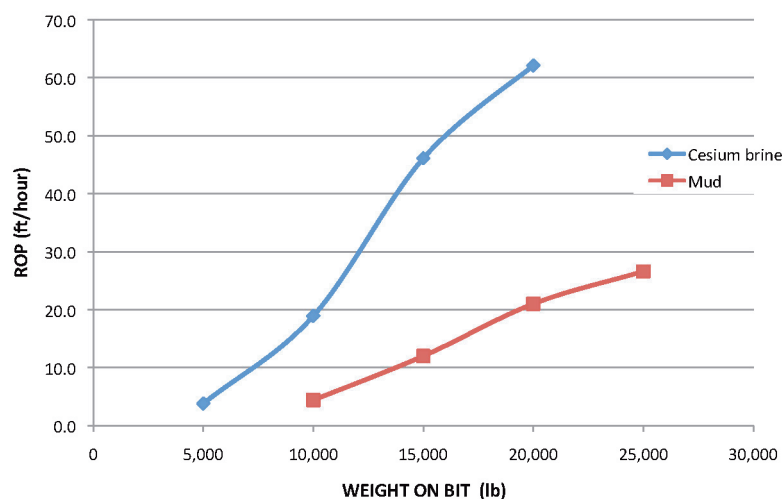


Figure 1. Rate of Penetration as a function of weight on bit in sandstone (from SPE 36425¹⁵).

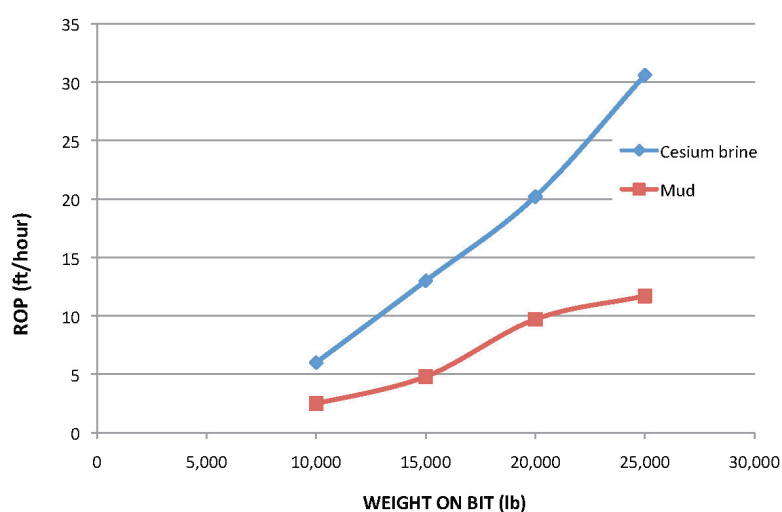


Figure 2. Rate of Penetration as a function of weight on bit in shale (from SPE 36425¹⁵).



Figure 3. Full-scale high-pressure drilling simulator (from SPE 173138¹⁷).

the oil industry over the past 90 years, their legacy has been a host of well construction and production problems. These long-standing problems include reduced drilling rates, well control difficulties, wellbore instability, stuck pipe and formation damage. The industry continues to develop a whole raft of special procedures and technologies for managing or mitigating the problems created by drilling fluids weighted with powdered solids. For example, a search of the SPE publications database indicates the existence of 370 papers on the subject of managing barite sag, including 39 papers published in the last year. The latter figure suggests that, despite 90 years of trying to remedy the problem, the issue of micronised weighting solids sagging in drilling fluids is still a subject of some concern for the drilling community.

Brine time

Despite their many failings, micronised mineral particles remained pretty much unchallenged as the primary drilling mud weighting agents until 1979 when Connors and Bruton¹ showed what clear heavy halide brines could offer as an alternative. Their field trials in four wells in California at 11 - 12 000 ft TVD showed that solids-free SG 1.62 calcium chloride/bromide ($\text{CaCl}_2/\text{CaBr}_2$) brines drilled 300 m mixed sandstone/shale reservoir sections three times faster than solids-weighted oil-based mud.¹ Six years later Doty's drilling tests with SG 1.56 $\text{CaCl}_2/\text{CaBr}_2$ brine in a wellbore simulator produced some even more astonishing results, showing that the clear heavy brine drilled sandstone rock 5 - 10 times faster than solid-weighted drilling muds.² Doty's pioneering work also demonstrated the powerful borehole-stabilising and anti-bit balling properties of heavy brine in shale, which were comparable with those of oil-based mud.

These remarkable drilling results opened the way for the introduction of the formate brines,³⁻⁵ which were more suited to drilling operations than heavy halide brines and became commercially available in 1990s.

The results of extensive use of formate brines as drilling fluids over the past 20 years show that they have effectively resolved most of the problems caused by solid weighting agents and opened up a new era of improved drilling performance.⁶⁻¹⁴

Clearly faster

Just as with the clear high-density halide brines, the formate brines generate much higher drilling rates of penetration than water-based and oil-based muds of the same density in Terratek's full-scale wellbore simulator.¹⁵⁻¹⁷ In 1996 Ramsey et al.¹⁵ showed that a standard J-33 roller cone bit could drill shale and sandstone 3 - 4 times faster in a solids-free 18.7 ppg cesium formate brine than in a 18.3 ppg water-based mud (Figures 1 and 2). The absence of bit-balling while drilling shales with the cesium formate brines was a notable finding from these tests. The ROP versus torque and hydraulic horsepower data suggested that the formate brine would give a longer bit life and extended mud motor life.

The authors also found a direct correlation between ROP and the Fann 600 readings of the drilling fluids. So a cesium formate drilling fluid with a Fann 600 reading of 35 drilled five times faster than a water-based mud with a Fann 600 reading of 65.

A later set of Terratek drilling tests with PDC bits in a wellbore simulator run at bottom hole pressures in excess of 10 000 psi showed that a low-solids 16 ppg cesium formate fluid drilled 2 to 5 times faster than oil-based mud (OBM) in Mancos Shale and 1.5 to 4 times faster than OBM in Carthage marble.¹⁶ The simulator ROPs of 32 ft/hr to 112 ft/hr obtained with formate brine in shale are a good match with ROP figures of 49 ft/hr to 107 ft/hr obtained with formate brine in shale formations in the field, offshore Norway.¹⁸ Terratek attributed the ROP increases in formate brines to improved drilling efficiency (as measured by Mechanical Specific Energy, MSE) and bit aggressiveness. Unfortunately the same low-solids cesium formate fluid, containing 20 ppb of sized calcium carbonate particles, was not tested in a sandstone rock to provide a comparison with previous test results obtained at lower pressures.

Very recently van Oort et al have conducted more full scale drilling tests with formate brines in a high pressured drilling simulator, shown in Figure 3.¹⁷ Cylindrical rock samples were drilled with a 8 3/4 in. PDC bit at the bottom hole pressure of 6000 psi. Their tests confirmed ROP enhancement in Mancos Shale with formate brines, which they linked to the anti-accretion activity of these fluids. They proposed that the anti-accretion activity was a result of osmotic dehydration of the clay fabric to provide better lubrication and cleaning on the cutter faces, possibly combined with strengthening of the outer layers of the shale making it less prone to sticking.

Quite a bit better

Since June 2013, solids-free potassium formate brine has been used to drill over 140 long lateral wells in the Montney Shale formation and other unconventional shale fields in Western Canada for operators such as Paramount Resources, EnCana, Shell Canada and Progress Energy.¹⁷

It is reported by van Oort et al that Montney shale laterals were originally drilled with OBM and suffered from slow ROP and multiple (average = 8) bit runs were required to reach TD. On changing over to solids-free potassium formate brine as the drilling fluid the average ROP typically doubled to 16 m/hr and only 2 or 3 bit runs were required to reach TD (e.g. Figure 4) – validating Ramsey's 1996 prediction of extended bit life in formate brine.

Potassium formate brine is now being used to drill the intermediate and main hole sections of the Montney Shale wells, saving 10 - 15+ days in drilling time versus OBM (see Figure 5). A Canadian operator has calculated that using potassium formate brine for drilling their shale wells has reduced their overall total well drilling costs by 27%.¹⁷

Logging with a difference

The improvement in drilling efficiency from changing to formate drilling fluids has not been without some interesting side effects. Perhaps the most notable of these is the impact of formate brines on logging tool response and logging data interpretation.^{11,19-26} The formate brines differ significantly from conventional drilling fluids by exhibiting the following petrophysical properties:

- ▶ High filtrate density – approximately the same density as bulk drilling fluid in the wellbore.
- ▶ Very high conductivity.
- ▶ Fast acoustic travel times – faster than in water.
- ▶ Low hydrogen index, HI.
- ▶ High gamma photon emission from the decay of K40 (only in potassium formate).
- ▶ High photoelectric factor, Pe, (only in cesium formate).

Each of these properties has an influence on the response of one or more of the numerous logging tools deployed downhole in LWD and MWD assemblies, requiring corrections for their effects in the borehole and within the invasion zone in the formation. Without these corrections traditional petrophysical models could give pessimistic porosity and permeability estimates and inaccurate mineralogy determinations. The more recent papers published on the characterisation of nuclear logging tool responses for formate drilling fluids seem to agree that only minor corrections are needed for the borehole environmental effects.^{23,24} The logging companies also appear

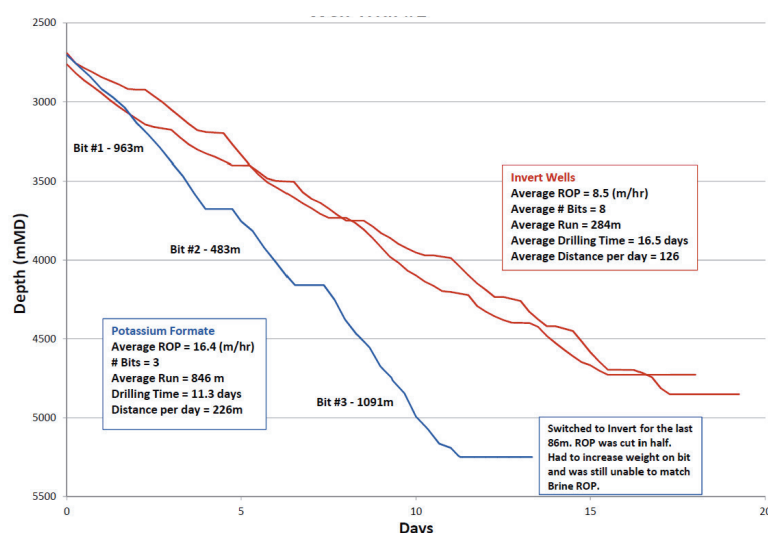


Figure 4. Example of the drilling performance of potassium formate brine (blue line) compared to invert OBM (red lines) in Montney shale wells drilled from the same pad (from SPE 173138¹⁷).

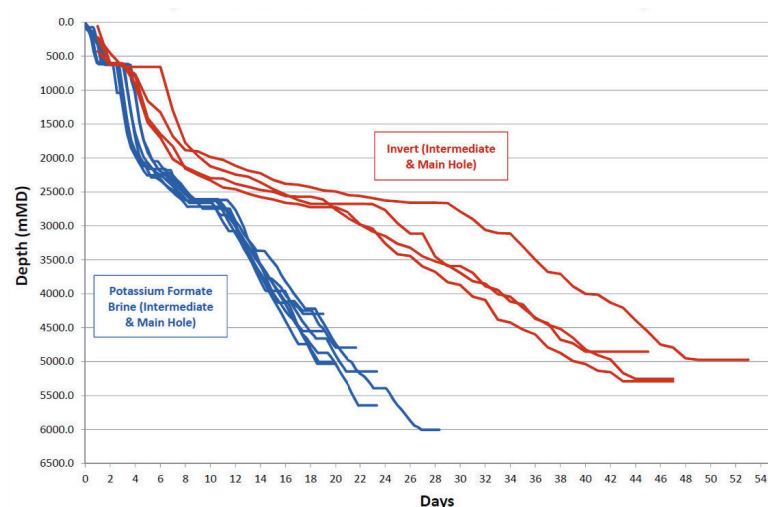


Figure 5. Drilling performance of potassium formate brine (blue lines) compared to invert OBM (red lines) in intermediate and main hole sections of Montney Shale wells (from SPE 173138¹⁷).

to have corrections available for LWD responses obtained in gas-bearing sandstone formations invaded by formate brines – calibrated by using Pe measurements in cesium formate brines, and long-space density measurements in other formate brines, to estimate the depth of filtrate invasion.^{11,22,23} The logged Pe 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 the saturation of the filtrate.¹¹ 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 an LWD produces a very reliable and accurate net reservoir definition (Figure 6).¹¹

Clear vision

The high-quality image logs obtainable in formate brines reveal rock features on a centimetre scale, providing geo-modellers with important information on structural dip, depositional environment and orientation of sand bodies (Figure 7). This detailed information allows the creation of superior reservoir models.¹¹

Time and space

In 2006 it was noted by Statoil and Schlumberger that the influence of formate brine filtrate invasion on wireline logs in sandstone gas reservoirs was much reduced when compared with LWD drill pass logs.²² They suggested that this effect is caused by the combined effect of i) gas diffusing back into the zone invaded by the formate filtrate and ii) the formate filtrate migrating away from wellbore area under the influence of gravity.^{11,22} They subsequently exploited the time-lapse measurement capabilities provided by tracking the movement of the formate filtrate in the formation between the LWD drill- and ream-passes to visualise the net reservoir.¹¹

Very recently Saudi Aramco and Schlumberger used time-lapse (i.e. drill and ream/wipe pass) LWD logging measurements to create what they describe as a step change in petrophysical analysis for wells drilled with formate brines.^{25,26} Their approach has been to consider the different time-lapse LWD measurements as representing different axes in measurement space, and then rotating the axes to reduce the number of rotated measurements affected by formate filtrate invasion to just one. They then discard that particular measurement and use the remaining rotated measurements in their analysis. Using this technique they claim to have built a robust, but remarkably simple petrophysical model with some very interesting characteristics:

- ▶ It does not require any knowledge of formate filtrate characteristics or its volume.
- ▶ It does not require resistivity input, but produces results that are comparable with models using resistivity as input.
- ▶ Data from the drill- and the wipe-pass produce identical results, independent of formation invasion.

It looks like time may be on the side of formate brines as the oil industry moves towards a new and better future in which the only solids found in drilling fluids will be rock cuttings created by the drill bit. ■

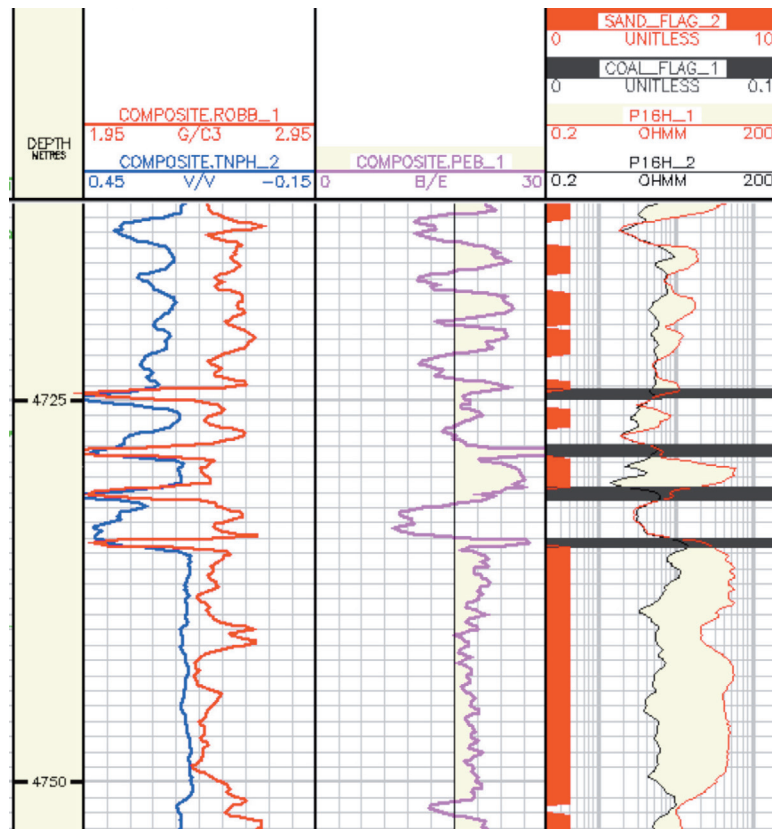


Figure 6. Time-lapse K/Cs formate filtrate invasion: Comparing the LWD resistivity log responses from drill-pass (P16H_1 red) and ream-pass (P16H_2 black) provides a powerful technique for defining liquid permeable sand (SAND_FLAG) and minimum net gas reservoir (ref. SPE 105733¹¹).

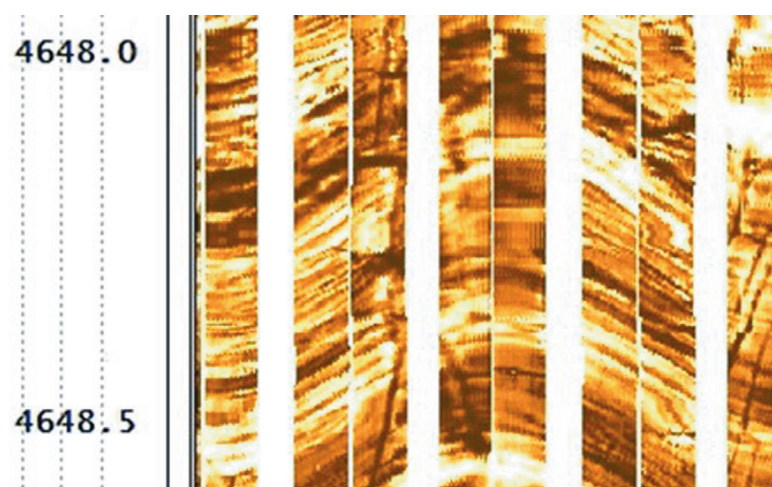


Figure 7. FMI resistivity image obtained in a K/Cs formate drilling fluid, showing fine structure of laminated mudstone with drill-induced fractures along a 50 cm length of borehole (ref. SPE 105733¹¹).

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