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Innovative High-Density, Non-Zinc, Solids-Free Completion Fluid for Ultra Deepwater Environments

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Abstract

Traditional high-density, solids-free completion fluids have relied upon the use of zinc bromide or caesium formate. These technologies have environmental, technical, and economic limitations. A novel high-density, non-zinc, solids-free completion fluid (HDNZ) has been developed to meet the challenges and requirements of ultra deepwater environments for fluid densities between 14.5 and 15.4 lb/gal. The paper presents an overview of the challenges encountered, including density, crystallization temperature (PCT and TCT), corrosion, and compatibility with elastomers, formation fluids, and control line fluids. It then presents the solutions considered and the solution selected, then compares the new system with existing technology. Case studies are provided.

Introduction

Aqueous halide and formate solutions have been utilized in completion fluid applications for over thirty years[1].

Today's ultra deepwater (UDW) production and regulatory environments present a unique set of challenges, calling for fluid systems capable of providing high fluid densities and low crystallization temperatures, both True Crystallization Temperature (TCT) and Pressure Crystallization Temperature (PCT) without the use of zinc bromide.

In June 2014, TETRA was charged with developing a non-zinc and non-formate completion fluid system capable of providing densities up to 15.4 lb/gal. Additional design considerations included system compatibility with formation fluids, drilling fluid systems, control line fluids, formation minerology, tubulars and elastomers, as well as thermal stability, minimized health, safety and environmental risks, and the ability to use conventional completion fluid additives for displacement systems, sweeps, and fluid loss control.

Several systems were evaluated, and the optimal system was selected. The system selected behaves very similarly to conventional calcium bromide systems with respect to most of these considerations.

Product Development

The primary criteria established called for fluid densities between 14.5 and 15.4 lb/gal, and pressure crystallization temperatures of 30°F or lower at 15,000 psi. A number of aqueous and non-aqueous solutions were evaluated, and a limited number of solutions were identified for further testing.

Thermal Stability

Products that passed the preliminary screening were evaluated for thermal stability. Initial testing was conducted at 265°F, and, based upon those results, the optimal solution was selected. The HDNZ system selected showed no signs of thermal decomposition at 265°F. Further testing at 300°F and 325°F showed no evidence of thermal degradation.

Compatibility

The HDNZ system was tested for compatibility with a variety of fluids, tubulars, and elastomers, and with the formation itself.

Formation Fluids

The HDNZ system was compatibility-tested with synthetic formation water at ambient temperatures in the following ratios: 25:75 brine/formation water, 50:50 brine/formation water, and 75:25 brine/formation water. The samples were shaken vigorously and allowed to sit for 24 hours. There was a small amount of sodium chloride precipitate in similar concentrations to that expected from comparable solutions of calcium bromide exposed to formation water.

Similar testing was conducted using crude oil samples. The HDNZ system was tested at ambient temperatures in the following ratios: 25:75 brine/crude oil, 50:50 brine/crude oil, and 75:25 brine/crude oil. The samples were shaken vigorously to form an emulsion, and allowed sit for four days. The system performed similarly to comparable solutions of calcium bromide mixed with crude oil under similar circumstances. Lower concentrations of crude oil created some emulsion stability, while higher concentrations formed stable emulsions that did not break after four days.

The test was repeated using a 0.5% concentration of emulsion preventer at ambient temperature and 180°F. The presence of the emulsion preventer resulted in a complete break after 24 hours at ambient temperature and less than 24 hours at 180°F.

Control Line Fluids

The HDNZ system was tested with a number of control line fluids at ambient temperature in the following ratios: 25:75 brine/control line fluid, 50:50 brine/control line fluid, and 75:25 brine/control line fluid. The samples were shaken vigorously and allowed to sit for 72 hours. Solids formed in all samples as soon as the two fluids were mixed. The amount of solids generated corresponded directly with the amount of control line fluid present in the sample. The precipitate floated to the top of the sample approximately 30 minutes after agitation, but was easily redistributed into the fluid with light agitation. The behavior of the system was similar to comparable solutions of calcium bromide mixed with control line fluids under similar circumstances.

Synthetic Oil-Based Mud

The HDNZ system was tested with a commercially available synthetic oil-based mud (SBM) system at ambient temperatures in the following ratios: 25:75 brine/SBM, 50:50 brine/SBM, and 75:25 brine/SBM. The samples were shaken vigorously and allowed to sit for 17 hours. The 75:25 brine/SBM blend stratified into three layers: a cloudy, colorless middle layer consisting primarily of completion fluid, a light, hydrocarbon-based top layer, and a dense lower layer consisting primarily of settled barite. The 50:50 brine/SBM sample segregated into two layers, with barite settling in the bottom layer, as expected. The 25:75 brine/SBM formed a stable, homogenous mixture. Again, the system performed similarly to comparable solutions of calcium bromide mixed with synthetic oil-based muds under similar circumstances.

SBM Base Oil

The HDNZ system was tested with the base oil used in the synthetic oil-based mud system at ambient temperatures in the following ratios: 25:75 brine/base oil, 50:50 brine/base oil, and 75:25 brine/base oil. The samples were shaken vigorously and allowed to sit for 24 hours. In all cases, the two fluids separated quickly, as expected.

Elastomers

Elastomer testing was conducted using a broad variety of elastomers and thermoplastics, comparing the performance of the HDNZ system against a conventional calcium bromide/zinc bromide solution of the same density and a 14.1 lb/gal calcium bromide solution. Testing was conducted at 265°F, with a test length of 30 days. Compatibility was determined by several criteria, including swelling, hardness, 50% modulus, and elongation at break. Performance of the system was comparable to similar calcium bromide and calcium bromide/zinc bromide solutions.

Corrosion

The HDNZ system was tested using a variety of tubulars. General corrosion studies were conducted using Q125 metallurgy and Environmentally Assisted Cracking (EAC) studies were conducted using Q125, 13Cr, and 15Cr materials.

General Corrosion

General corrosion testing was conducted using Q125 materials, comparing the performance of the HDNZ system against a conventional calcium bromide/zinc bromide solution of the same density. The system was evaluated using both a neat solution, as well as a solution containing a corrosion control agent.

Testing was conducted at 265°F, with test durations of 7, 14, and 21 days. As expected, higher corrosion rates were experienced with the calcium bromide/zinc bromide solution, followed by the uninhibited HDNZ system, with best results obtained with the inhibited HDNZ system. 21-day corrosion rates for the fully inhibited HDNZ system were extremely low at 0.17 mils/year.

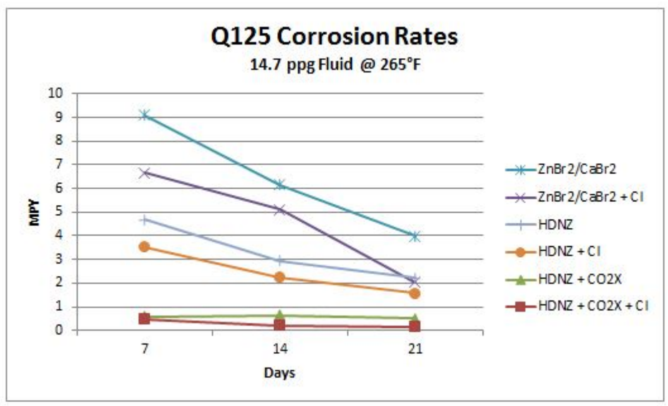

Figure 1: General Corrosion Rates

Environmentally Assisted Cracking (EAC)

Environmentally Assisted Cracking (EAC) studies were conducted using Q125, 13Cr, and 15Cr materials. Testing was conducted for thirty (30) days in the HDNZ system at 265°F in a naturally deaerated, 30 psia CO_2, N_2 to 1000 psig environment. C-Ring and crevice specimens were used for the high alloy steels and tensile specimens were used for the Q125 samples.

No cracking of the 13Cr, 15Cr, or Q125 metallurgies was observed in the HDNZ system environment. Crevice corrosion appeared to be negligible in all cases.

Formation Damage

Return permeability testing was conducted to compare the performance of the HDNZ system against a conventional calcium bromide/zinc bromide solution of the same density.

Testing was conducted using cores of comparable permeability and minerology. The cores were vacuum saturated with completion brine, then heated to 265°F with a confining pressure of 1500 psi. Formation brine was flowed in the production direction until permeability stabilized, then 10 pore volumes of completion brine were introduced in the injection direction, and shut in for 60 minutes. Formation brine was again introduced in the production direction and allowed to flow until permeability had re-stabilized.

As expected, the HDNZ system outperformed the conventional calcium bromide/zinc bromide solution, offering return permeability of 60%, compared to 41% for the calcium bromide/zinc bromide.

Temperature & Pressure Effects

As with all clear brine fluids, the fluid density of the HDNZ system is a function of temperature and pressure. Due to the unique nature of the constituents of the HDNZ system, the thermal expansion and pressure compression coefficients utilized in API Recommended Practice 13J[2] do not apply. Several downhole density models were developed, and the model selected offers a high degree of correlation with both experimental and field data.

Environmental

The HDNZ system was tested to ensure compliance with GOM and North Sea environmental regulations.

The system was tested to ensure that it met the Free Oil and Oil & Grease requirements of Section 6 of the EPA NPDES permit for Gulf of Mexico (GOM) discharges, using EPA Method 1617, Static Sheen, and EPA Method 1664A, Oil and Grease. Testing revealed no static sheen under Method 1617 and less than 5 mg/L oil and grease using Method 1664A, demonstrating compliance with the applicable sections of the NPDES permit, as well as the Oil and Grease requirement of Section 4 (Produced Water) of the NPDES permit. It was also verified not to contain any of the priority pollutants listed in Section 307 of the Clean Water Act and 40 CFR 401.1, thus meeting the Priority Pollutants requirement of Section 6 of the EPA NPDES permit.

7-Day Toxicity testing was conducted on both the HDNZ system and a 14.1 lb/gal calcium bromide solution, using Menidia beryllina and Mysidopsis bahia populations according to EPA-821-R-02-014 methodology. There was no notable toxicity difference between the HDNZ system and the conventional 14.1 lb/gal calcium bromide solution.

The system earned a Gold environmental rating for compliance with North Sea regulations.

Field Performance

The system was evaluated in two Gulf of Mexico wells between February and October 2015. The average water depth was in excess of 7000 ft., with mudline temperatures of approximately 40°F. Bottomhole temperatures (BHT) were approximately 265°F and the formation pressures were in excess of 21,000 psi.

Density

Surface densities were maintained at 14.5 lb/gal with additions of dry calcium bromide and 15.1 lb/gal HDNZ spike fluid. Due to the halide concentration, the system was extremely hygroscopic, and frequent additions of weighting material were required.

The downhole density matched predicted values, yielding an effective bottomhole density of 14.49 lb/gal.

Crystallization Temperature

Crystallization temperatures, both true crystallization temperature (TCT) and pressure crystallization temperature (PCT), remained stable and met expectations, The HDNZ system was extremely stable and maintained PCT values of 30°F at 15,000 psi and TCT values between 6 and 9 °F with very little maintenance.

Compatibility

The compatibility of the HDNZ system met expectations under field conditions. No significant incompatibility with formation fluids was observed. There was minor salt (NaCl) precipitation when the HDNZ system encountered formation water influx, but it was removed with normal filtration operations.

Compatibility of the HDNZ system with drilling fluids was consistent with that of conventional calcium bromide solutions and was minimized by effective displacement system design. The displacement systems used were very similar to those used with conventional systems.

The behavior of the system when exposed to control line fluids was similar to comparable solutions of calcium bromide under similar circumstances.

There were no unforeseen compatibility issues with elastomers. In over 175 days of exposure under wellbore conditions, no incompatibility issues have been observed.

Corrosion

The HDNZ system exhibited no scaling, pitting, or stress cracking corrosion (SCC) issues with the Q125, 13Cr, and 15Cr materials at bottomhole temperatures ranging between 250 and 265 °F.

Thermal Stability

The HDNZ system showed no signs of thermal decomposition at 265°F bottom hole temperatures or at elevated temperatures encountered during perforating operations.

Workability

Workability is defined as applicability of conventional completion fluid additive systems with the HDNZ system, as well as critical system characteristics. During the field trial, several criteria were monitored, including filtration, displacement systems, sweeps, fluid loss pills, viscosity, and friction.

The system viscosity and friction characteristics were extremely stable and met design criteria. The polymer systems utilized in displacement systems, fluid loss control packages and viscous sweeps performed well with respect to yield, yield time, temperature stability, and serviceability.

The HDNZ system was used as an integral component of the displacement systems. In this capacity, it performed well. No incompatibility with other system components was observed, and all field performance criteria were met.

Standard high-flow, high-capacity filtration systems were used with the HDNZ system and flow rates, solids retention, and clarity all met expectations. The filtration process had no impact on the HDZF fluid system characteristics, nor did the addition of oil adsorption materials.

Environmental

The HDNZ system met all HSE design criteria, and no system-specific issues related to GOM environmental regulation compliance were observed.

Lessons Learned

During the field evaluation, several key observations were made:

First, the HDNZ system is extremely stable. The fluid was stored on a workboat for over six weeks with no loss of density or attrition of properties. The fluid was pumped from the workboat through over 20,000 ft. of wellbore and 7,000 ft. of riser, without a non-density-related impact on the crystallization temperature. The system was exposed to a broad range of temperatures and pressures, and experienced no loss of fluid properties.

The system met all crystallization temperature requirements under the full range of operating conditions and was used to test the BOP stack to over 14,000 psi @ <40 °F.

Conclusions

Lab-scale performance testing indicates that the novel high-density, non-zinc, solids-free completion fluid (HDNZ) meets the challenges and requirements of ultra deepwater environments for fluid densities between 14.5 and 15.4 lb/gal, offering significant performance improvements over conventional aqueous halide and formate completion fluid systems.

Testing of the HDNZ system under actual field conditions has confirmed the lab-scale performance testing and revealed that the system is extremely stable and robust, and thus offers a viable alternative to conventional completion fluid systems.

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Nomenclature

HDNZ = *High-Density, Non-Zinc Completion Fluid*
TCT = *True Crystallization Temperature*
PCT = *Pressure Crystallization Temperature*
HSE = *Health, Safety & Environmental*
UDW = *Ultra Deepwater*
SBM = *Synthetic Oil-Based Mud*
EAC = *Environmentally Assisted Cracking*
DE = *Diatomaceous Earth*
CBF = *Clear Brine Fluids*
NTU = *Nephelometric Turbidity Unit*
BHT = *Bottomhole Temperature*
BHP = *Bottomhole Pressure*

References

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