Laboratory optimization on performance of high density brine-based drilling fluid

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Abstract. The brine-based drilling fluid is paramount for drilling operation in the salt-anhydrite formations. In this work, a novel high density brine-based drilling fluid was designed and established, based on the features of salt-anhydrite formation in Missan Oilfields. A suite of laboratory tests has been carried out to comparatively evaluate effect of key additive amounts on standard properties of drilling fluids. The formula of the high density brine-based drilling fluid was optimized. The newly developed brine-based drilling fluid possesses excellent rheology, filtrate, thermal stabilization, inhibition and lubricity properties, which can provide an alternative to drilling through the salt-anhydrite formation in Missan Oilfields.

1. Introduction

The use of specialized brine-based drilling fluids for drilling salt-anhydrite formations has become practice in the last decade[1-4]. Fluids based on a clear brine to achieve the required density and a small dosage of chemicals have gained wide acceptance upon drilling. The appropriate density achievable with this type of drilling fluid has been limited by the chemistry and economics of potential base brines[5, 6]. Hence, the optimization of chemicals is necessary for the prominent performance and adapability. It will be useful to develop high performance of drilling fluid.

Despite a wide range of investigation on drilling fluid systems available in the salt-anhydrite formations, the previous achievements appear to be relatively limited to reserve in a certain environment. That is, while varying the formation environments, the properties of drilling fluid need to be specifically designed in terms of the corresponding downhole conditions, in order to meet individual drilling requirements. Undoubtedly, this procedure makes it possible to avoid various potential drilling accidents.

As an important ongoing study on drilling technique in Missan Oilfields, a high density brine-based fluid system has been specially developed according to features of salt-anhydrite formation. This newly constructed drilling fluid uses a combination of liquid and solid weighting manners for density control. In particular, high salinity univalent brines, (sodium chloride, potassium chloride, and sodium formate), are paramount for improving performance of drilling fluids. As anticipated, the combination of these two weighting manners, together with usage of viscosifier and filtrate reducer, cooperatively produces a suitable rheological, filtration, and weight profiles for the drilling fluid. In the present work, a suite of laboratory tests have been carried out to optimize the formula of brine-based drilling fluid by evaluating the standard properties.
2. Laboratory testing
The optimization process whereby the high density brine-based drilling fluid was chosen for this application required a series of laboratory tests to be carried out. Tests included: standard fluid properties (rheology and filtration) and effect of additive dosages for the system. In addition, stability and inhibition of the optimized system were also examined.

2.1. Fluid design
Missan Oilfields has a huge salt-anhydrite formation at the depth of about 2,000m. The wellbore was planned to be 12-1/4 in. in diameter by 600m. The bottomhole temperature was anticipated to be 100°C. The formation pressure required a mud weight of 2.3s.g. to drill the section.

Obviously, fluid selection for this type of formation is critical. Previous study confirmed that the saturated NaCl/KCl/HCOONa brine system is suitable inhibitive toward potential interstitial hydrating clays and rock creep deformation. Accordingly, a typical barite-weighted, inhibitive brine-based system (NaCl/KCl/HCOONa) is recommended. The compositions of brine-based drilling fluid are collected in Table 1. Dosages of viscosifier and filtrate reducers were optimized by testing the standard properties in the high density brine-based system.

After optimization tests, thermal stability for the final system was evaluated to examine its maintenance at the elevated temperatures (up to 120°C), and the lubricity was also explored for the in-field application.

Table 1. components and ratio of additives for high-density brine drilling fluid

| No. | compositions       | ratio /wt.% | functions                                |
|-----|-------------------|-------------|------------------------------------------|
| 1   | fresh water       | --          | pH adjusting agent                       |
| 2   | NaOH              | 0.1         | pH adjusting agent                       |
| 3   | Na₂CO₃            | 0.25        | hardness control (Mg²⁺ & Ca²⁺)           |
| 4   | viscosifier (VIS) | 0.2~0.5     | rheology control                         |
| 5   | main filtrate reducer (S-FLO) | 1.5~3.0 | filtration control                       |
| 6   | auxiliary filtrate reducer (TEX) | 0~2.0 | wellbore stabilization and filtration |
| 7   | HCOONa            | 8           | saturated brine system, weight and inhibition |
| 8   | NaCl              | 25          | saturated brine system, weight and inhibition |
| 9   | KCl               | 5           | saturated brine system, weight and inhibition |
| 10  | barite            | weighted to 2.3s.g. | density control |

2.2. Laboratory testing
Given the downhole pressure on-site, the density of brine-based fluid was increased to 2.3s.g, using solid weighting material of barite. Once the high density brine-based drilling fluid was selected as the fluid type, a suite of laboratory tests were carried out, including properties of drilling fluids after mixing and post heat-aging at anticipated temperature 100°C and effect of additive dosage on properties of fluids, for the purpose of optimizing performance of the formulated fluid.

While the drilling fluid meets the density requirement, in principle, chemicals are of importance to gain better drilling properties. Generally, rheology and filtration are the major concern and, in this case, the influence of viscosifier and filtrate reducer on properties was chiefly investigated. Crucial characteristic parameters such as apparent viscosity (AV), plastic viscosity (PV), yield point (YP), and filtrate loss (FL API), have been obtained to optimize the formula of fluid system constructed here. In addition, inhibition and lubricity of the drilling fluid were also tested to evaluate its adaptability.
3. Results and discussion

3.1. Effect of viscosifier concentration on drilling fluid properties

Rheology and filtration tests were carried out in the brine-based fluid, and the formula is: fresh water + 0.1wt.%NaOH + 0.25wt.%Na₂CO₃ + (25wt.% NaCl + 8wt.% HCOONa + 5wt.%KCl)fixed salinity + VIS + barite. The VIS amount changes from 0.2wt.% to 0.4wt.%.

Table 2 collects the rheology data, AV, PV, YP, 6 & 3 rpm readings and YP of the studied systems with different VIS amounts. While VIS amouts vary in the range of 0.2~0.4wt.%, the rheological readings gradually increase. For example, AV, PV, YP, Φ6/Φ3 values after heat-aging separately increase by 43.1%, 35.7%, 77.8%, 100%, and 100%, as the VIS amount increases from 0.2wt.% to 0.4wt.%.

Clearly, VIS performs very well in increasing viscosity of brine system. On the contrary, filtration value somewhat decreases with increasing VIS amout, suggesting that VIS should be limited in enhance filtration for the studied system. Considering the pump pressure and economic requirements, the VIS amount is proposed to be 0.2%. Furthermore, the optimization tests of filtrate reducer amount is conducted on the basis of this result.

Table 2. Rheology and filtrate readings of the brine drilling fluid at different VIS contents

| VIS amounts (wt.%) | Heat-aging | AV (mPa·s) | PV (mPa·s) | YP (Pa) | Φ6/Φ3 | FL_API (mL) |
|-------------------|------------|------------|------------|--------|-------|-------------|
| 0.2               | Before     | 58         | 44         | 9      | 3/2   |             |
|                   | After      | 51         | 42         | 9      | 3/2   | 15.6       |
| 0.3               | Before     | 70         | 53         | 17     | 7/5   |             |
|                   | After      | 61         | 47         | 14     | 5/4   | 15.4       |
| 0.4               | Before     | 85         | 63         | 22     | 12/10 |             |
|                   | After      | 73         | 57         | 16     | 6/4   | 14.2       |

3.2. Effect of main filtrate reducer concentration on drilling fluid properties

S-FLO behaves as the main filtrate reducer, which plays key role in filtration control for the investigated system. Laboratory tests were carried out in the brine-based fluid, and the formula is: fresh water + 0.1wt.%NaOH + 0.25wt.%Na₂CO₃ + (25wt.% NaCl + 8wt.% HCOONa + 5wt.%KCl)fixed salinity + 0.2%VIS + S-FLO + barite. The S-FLO amount changes in the range of 0~0.4wt.%. Table 3 outlines rheology parameters and filtration values at different S-FLO amounts. It is clear that all rheology parameters display a slight rise with an increase of S-FLO. This variation trend indicates that S-FLO can increase viscosity to some degree. As for filtrate values, it is not surprising that FL_API displays a remarkable decline with increasing S-FLO amount, and rate of decrease arrives at 23.4%.

Table 3. Rheology and filtrate readings of the brine drilling fluid at different S-FLO contents

| S-FLO amounts (wt.%) | Heat-aging | AV (mPa·s) | PV (mPa·s) | YP (Pa) | Φ6/Φ3 | FL_API (mL) |
|----------------------|------------|------------|------------|--------|-------|-------------|
| 1.5                  | Before     | 58         | 48         | 10     | 7/5   | 9.4         |
|                      | After      | 50         | 43         | 7      | 3/2   |             |
| 2.0                  | Before     | 60         | 48         | 12     | 7/5   | 8.4         |
|                      | After      | 52         | 44         | 8      | 4/3   |             |
| 2.5                  | Before     | 62         | 48         | 14     | 8/6   | 8.8         |
|                      | After      | 51         | 42         | 9      | 5/4   |             |
| 3.0                  | Before     | 66         | 50         | 16     | 8/6   | 7.2         |
|                      | After      | 53         | 44         | 9      | 5/4   |             |
3.3. Effect of auxiliary filtrate reducer concentration on drilling fluid properties

Laboratory tests were carried out in the brine-based fluid, and the formula is: fresh water + 0.1wt.%NaOH + 0.25wt.%Na₂CO₃ + (25wt.% NaCl + 8wt.% HCOONa + 5wt.%KCl) + fixed salinity + 0.2%VIS + 3.0%S-FLO + TEX + barite. The TEX amount varies in the range of 0~2.0wt%.

Table 4 collects the rheology and filtration parameters for the considered fluid. As follows from the data, all the rheology data exhibit a little variation while increasing TEX amount to 2.0wt%, which agrees well with the trend caused by S-FLO. Similarly, TEX can apparently decrease the filtrate volume. However, one can readily find that the decline appear to markedly mitigate while the TEX amount exceeds 1.0wt%. for instance, FL_{API} decreases by only 5% while the TEX amount raises two times. Therefore, the TEX amount is proposed to be 1.0wt.% in the brine-based fluid.

The optimized formula of high density brine-based drilling fluid is determined as: fresh water + 0.1wt.%NaOH + 0.25wt.%Na₂CO₃ + (25wt.% NaCl + 8wt.% HCOONa + 5wt.%KCl) + fixed salinity + 0.2%VIS + 3.0%S-FLO + 1wt.%TEX + barite. To evaluate the applicability of the formulated system, its inhibition and lubricity properties are further examined.

Table 4. Rheology and filtrate readings of the brine drilling fluid at different S-FLO contents

| TEX amounts (wt.%) | Heat-aging | AV (mPa·s) | PV (mPa·s) | YP (Pa) | Φ6/Φ3 | FL_{API} (mL) |
|--------------------|------------|------------|------------|--------|-------|--------------|
| 0                  | Before     | 59         | 47         | 12     | 8/6   | 5.0          |
|                    | After      | 52         | 44         | 8      | 4/3   |              |
| 1.0                | Before     | 66         | 50         | 16     | 9/7   | 4.0          |
|                    | After      | 51         | 42         | 9      | 5/4   |              |
| 1.5                | Before     | 70         | 54         | 16     | 9/7   | 4.0          |
|                    | After      | 55         | 44         | 11     | 5/4   |              |
| 2.0                | Before     | 77         | 57         | 20     | 10/9  | 3.8          |
|                    | After      | 60         | 47         | 13     | 5/4   |              |

3.4. Analysis on thermal stability of drilling fluid

Thermal stability of the optimized drilling fluid system was tested in the temperature range of 90~120°C, as graphically illustrated in Figure 1. The established system delivers relatively steady values and variation seems to be in a little range. For example, the rheological parameter variations are less than 10% and filtrate volume is less than 1ml with temperature up to 120°C. Given thermal dynamics of fluid and polymer molecule, these variation trend should be reasonable and fairly limited under the temperature range. These conclusions disclose that the optimized drilling fluid system is well tolerant to the elevated temperature, and exhibits rheological and filtrate stabilization, especially rheology.

Figure 1. Comparisons of rheology and filtrate data for the optimized high density brine-based drilling fluid in the temperature range of 90~120°C
3.5. Analysis on inhibition adn lubricity of drilling fluid

In view of industrial applications, typical tests associated with the inhibition and lubricity property were performed on the final brine-based drilling fluid. These two performances are essential reference. In general, the former contributes largely to maintain wellbore stability, and the latter is closely related with torque and drilling efficiency.

The standard recovery rate for the established fluid is as high as 93.35%, reflecting a strong capability of favoring the cutting dispersion and preventing the cutting hydration. On the other hand, this drilling fluid yields a lower coefficient of friction (0.17), which is slightly larger than that (0.08–0.09) of the OBM systems, but is far smaller than that (0.20–0.35) of the common water-based systems. Laboratory investigation reflect that the novel high density brine-based drilling fluid can meet the high demands of drilling in salt-anhydrite formations.

4. Conclusion

In the present work, a novel high density brine-based drilling fluid has been established by a suite of laboratory optimization tests. This fluid system exhibits excellent properties, including rheology, filtration, thermal stability, inhibition and lubricity. These conclusions should be instructive to understand profiles of high density brine-based drilling fluid, which will also provide key technical support for drilling through salt-anhydrite formations in Missan Oilfields.

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References

[1] R. L. Horton, K. O. Tresco, J. W. Dobson Jr., G. K. Bye, D. A. Knox, C. F. Svobosa, W. E. Foxenberg and T. C. Green, A new biopolymer-free, low solids, high density reservoir drilling fluid: laboratory development and field implementation, SPE Drilling & Completion. SPE 19(2004)29-39.
[2] H. Jia, Y. X. Hu, S. J. Zhao and J. Z. Zhao, The feasibility for potassium-based phosphate brines to serve as high-density solid-free well-completion fluids in high temperature/ high-pressure formations, SPE Journal. (2018)1-14.
[3] P. Yang, K. H. Lv, P. P. Zhen and W. Hong, Laboratory research on saturated salt water based clay-free drilling fluids with thermal stability, Oilfield Chemistry. 4(2013) 482-485.
[4] O. O. Emmanuel, O. O. Ssamuel and A. Ramadan, Properties of salt formations essential for modeling instabilities while drilling, SPE Conference. SPE 150801(2011).
[5] D. Knox, G. K. Bye, R. Horton, C. Svoboda, W. Foxenbr, K. Tresco, Application of a novel, high-density, brine-based, biopolymer-free reservoir drilling fluid: a case study, SPE Conference. SPE 73765(2002).
[6] R. G. Ezell, D. J. Harrison. Design of improved high-density, thermally stable drill in fluid for HP/HT applications, SPE Conference. SPE 115537(2008).