Study on Experimental Construction of a Novel Brine-based Drilling Fluid for Salt-Anhydrite Formation

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Abstract. The salt-anhydrite formation has a highly negative impact on well construction, which can cause various drilling accidents upon drilling. In combination to salt-anhydrite characteristics of Missan Oilfields, a novel type of brine-based frilling fluid was established. The weighting manner of fixed salinity was evaluated, and key additives, viscosifier and filtrate reducer, were determined by single-factor experiments. The formula of brine-based drilling fluid was constructed as: fresh water + 0.6wt.% VIS + 2wt.% S-FLO+ (25wt.% NaCl + 5wt.% KCl + 8wt.% HCOONa) fixed salinity, which will be essential for further developing multifunctional high-density drilling fluids.

1. Introduction

Basing on the increasing hydrocarbon producing potential in Missan Oilfield, the demand for high-density drilling fluid technology toward salt-anhydrite formations, including stability and inhibition under the downhole conditions, has attracted wide interests. However, the discovery of producible reserves beneath vast, thick sheets of salt-anhydrite formations disables the regular drilling practices. The fact that development of the proper drilling fluid is very difficult in drilling industry can be attributed to the extreme complexity of formation characteristics. In this case, drilling through salt-anhydrite formation can become successful only when essential properties of this formation that cause instability are clearly understood.

Herein, some details of case history in past drilling operations is comprehensively provided, which should be meaningful as the first stage to develop a novel proper drilling fluid available in Missan Oilfield.

1.1. Distribution of salt-anhydrite formation

The Missan Oil Fields include three oilfields on production: Abu Ghirab, Buzurgan and Fauqi oilfields. From top to bottom, the strata drilled in Missan Oil Fields include Tertiary Upper Fars Fm, Lower Fars Fm, Tertiary Jeribe Fm to Cretaceous Nahr Umer Fm. While the Tertiary Upper Fars is mainly composed of mudstones interbeded with thin sandstone, anhydrite with thickness of over 2,000 m. The Lower Fars Fm consists of anhydrite and salt of approximately 800 m thick and is acting as regional caprock. Tertiary Jeribe Fm to Cretaceous Nahr Umer Fm mainly contains carbonate rocks of approximately 800m thick which is not drilled through.
Due to existence of massive, thick sheets of salt-anhydrite formation, instabilities of formation arising from the ability of the salt to flow under loading conditions and to dissolve at certain conditions will inevitably influence the drilling process. In particular, plastic deformation and cramping behaviors of formation caused by the horizontal stress (see Figure 1) can result in various drilling accidents. Understanding the essential properties of salt-anhydrite formation is indispensable for developing successful drilling technologies [1, 2].

1.2. Forms of salt-anhydrite formation
Salt-anhydrite formations are impermeable, and behave as a reservoir cap in Missan Oilfields. In principle, salt-anhydrite formations explored are subjected to three basic forms: (1) halite, or rock salt, forms in either thin or massive layer, which as a representative of evaporitic rocks is formed from the evaporation of salinity waters; (2) anhydrite occurs extensively in beds associated with halite deposits. It is harder and less soluble than halite and harder and denser than gypsum. It often occurs as fibrous, granular or more compact masses; and (3) gypsum is basically the hydrated version of anhydrite. It usually occurs in beds linked with layers of halite and dolomite.

Drilling through the complex salt-anhydrite formations poses challenges that stretch the technical limits of the planning wells. Drilling practices in Missan Oilfields depend on the essential properties peculiar to the formation within the zones. To clearly identify and understand the typical drilling problems caused by the instabilities in salt-anhydrite formations should be paramount to the design of drilling fluid.

1.3. Typical problems drilling through salt-anhydrite formation
According to drilling experience in Missan Oilfield, it is deemed that the salt-anhydrite formations are easy to dissolve, leading to necking, plastic flow, and salt re-crystallization, which further led to pipe-stuck, casing damage and deterioration of drilling fluid properties. While the interval soft mudstone often lost its support due to the potential slat dissolution and collapse, a significant threat to drilling.

Recently, a number of technical advances in the drilling industry have created cost-effective methods for the exploration and development of salt-anhydrite formation. One result of these developments is an increased demand for higher density drilling fluids [3-5]. However, the density attainable for economically viable, brine-based drilling fluids is limited under current technology. Constructing a new and proper brine-based drilling fluid meeting the density requirement on-site, as well as exceptional rheological and filter cake qualities, will be substantially important to enable economic, safe and successful drilling in Missan Oilfields.
2. Construction of proper drilling fluid in salt-anhydrite formation

In order to solve these problems faced to the drilling in salt-anhydrite formations, the key work is to choose the rational and right drill fluid systems, which is necessary to meet the strict technical requirements.

2.1. Design of high-density drilling fluid

There are three requirements for salt-anhydrite layer drilling fluid in Missan Oilfields. Firstly, its components should be effective restrain the dissolution of salt rock for the sake of stability of wellbore. Secondly, the additives should attain salt-resisting to assure effectively to maintain properties of drilling fluid (e.g., rheological stability, fluid loss control, and lubrication). Lastly, the density of drilling fluid can balance the creep deformation of salt-anhydrite formations, to avoid drilling accidents such as wellbore collapse, fluid leakage, and sticking of drill pipe [6, 7].

Figure 2. Schematic of constructing the brine-based drilling fluid

Figure 2 presents the design process of high-density drilling fluid. To meet drilling requirements, dense brine fluid system was proposed, through which the density adjustments and salt dissolution control can be realized. Moreover, the unique high-density drilling fluid can be built by selecting the anti-salt additives. As a result, extensive screening should be conducted on viscosifiers and filtrate reducers for improving compatibility, viscosity, and stability of fluid system.

2.2. Experimental procedure

To determine the proper additive, single-factor experiments have been designed to investigate rheology and filtrate loss of the brine-based fluids with different additives before and after ageing treatment.

According to the previous results, the basic formula of dense brine fluid with additives was: fresh water + 0.6wt.% viscosifier + 2wt.% filtrate reducer + fixed salinity solution. Note that, all of tests associated with the rheological and filtrate properties were conducted on the brine-based fluid aged for 16h at 100 ℃, which would be effective to comparatively evaluate the stability and adaptability for the formulated system.

3. Results and discussion

3.1. Analysis on brine-based weighting materials

On the basis of previous results [8], the different salt can be mixed to build complex brine system for improving properties of brine-based fluid such as shale inhibition, weighting capability, and saturation of based fluid. Further, the solid weighting materials, e.g., barite and hematite, can be introduced to obtain extreme density.
Herein, three monovalent cation salts, sodium chloride (NaCl), potassium chloride (KCl), and sodium formate (HCOONa), which have been confirmed to be fairly cost-effective in the density control, are used to formulate brine-based fluid. The formula of brine-based fluid with fixed salinity is: fresh water + 25wt.% NaCl + 5wt.% KCl + 8wt.% HCOONa, through which the saturated brine can be attained. In the formulating system, NaCl is used as the basic salt of the complex brine system, and makes the system in the partially saturated state; KCl is induced to enhance the inhibition against salt and anhydrite formation; HCOONa can not only increase the density, but also cooperatively work to reinforce the inhibition of system. The pre-salt treatment by incursion of fixed salinity can enhance fluid inhibition against salt rock while having minimal effect on fluid properties.

Undoubtedly, the formulated system with fixed salinity provides key advantages: on one hand, the system would be of extreme lower solubility to external salts due to the saturated state; on the other hand, the solid concentration required to weight-up to a high density can be reduced, which would facilitate the stability of wellbore.

3.2. Screening of viscosifiers

Three common kinds of viscosifiers, polyacrylamide (PHPA, PLH, and PLUS), cellulose (PAC and CMC), and biopolymer (VIS, XC, XAN, and MC-VIS), have been involved to evaluate their rheological modification in the brine-based fluid, in order to select the appropriate viscosifier. The formula of brine-based fluid is: fresh water + 0.6wt.% viscosifier + (25wt.% NaCl + 5wt.% KCl + 8wt.% HCOONa) fixed salinity.

The rheological data associated with different viscosifiers are listed in Table 1. It is clear that biopolymers exhibit better rheology than other types of viscosifiers collected here. As for the polyacrylamide and cellulose types, both AV and PV are relatively lower and display a large variation before and after ageing, suggesting worse rheological stability in the brine-based system. In the brine-based fluid with polyacrylamide type, for example, the average rates of changes for AV and PV upon ageing treatment are up to 58.0% ± 3.3% and 52.3% ± 3.1%, respectively. Meanwhile, readings of low-shear-rate viscosity (LSRV) are relatively low and close to 0, indicating bad particle suspension and hole-cleaning for the formulated system. However, in the brine-based fluid with biopolymer type of viscosifiers, the AV and PV value are all larger relative to others, especially the values tested upon ageing treatment, whose average values are 12.5 ± 1.5 mPa·s and 6.3 ± 0.9 mPa·s, respectively. In addition, high readings of LSRV can be observed in Table 2, which are in the certain range meeting the rheological requirement on-site.

Comparing the rheological features in the formulated system with biopolymers, VIS can be finally determined as the viscosifier in the formulated brine-based fluid and, in this aspect, this viscosifier not only exhibits desirable viscosity profile but also is environment-friendly due to its degradation. VIS will be further used for screening of filtrate reducer in the constructed brine system.
3.3. Screening of filtrate reducers

Three conventional kinds of filtrate reducers, celluloses (PAC-LV, MIL, and CMC-LV), starch (FLO, S-FLO, B-LOSE, HPS, CMS), and sulphonated series (TEMP, TX, SMP-1, SMP-2, and SMPC), have been employed here to examine their rheology and filtration, for the purpose of screening the proper filtrate reducer for the brine-based drilling fluid. The formula of brine-based fluid is: fresh water + 0.6wt.% VIS + 2wt.% filtrate reducer + (25wt.% NaCl + 5wt.% KCl + 8wt.% HCOONa) fixed salinity.

Table 2. Rheological data tested in the formulated brine with different filtrate reducers

| Terms          | AV (mPa·s) | PV (mPa·s) | YP (Pa) | Φ6/Φ3 |
|----------------|------------|------------|---------|-------|
| PAC-LV         | --         | --         | 5.9 ± 4.0 |       |
| MIL            | 33         | 17         | 12      | 8/6   |
| CMC-LV         | 29         | 12         | 15      | 16/14 |
| FLO            | --         | --         | 2.4 ± 1.7 |       |
| S-FLO          | 24.5       | 12         | 15.5    | 10/9  |
| B-LOSE         | 29         | 12         | 17      |       |
| HPS            | 36         | 15         | 13/11   |       |
| CMS            | 32.5       | 13         | 9       | 5/4   |
| TEMP           | 26.5       | 12         | 14.5    |       |
| TX             | 21         | 10         | 12      |       |
| SMP-1          | 24         | 12         | 13      |       |
| SMP-2          | 25         | 11         | 12      |       |
| SMPC           | 24         | 11         | 12      |       |

Table 2 presents the rheological data associated with different filtrate reducers. One can readily find that for all of the samples tested here, variations of rheological data upon ageing appear to be lower, displaying suitable rheology and stability caused by filtrate reducers. For instance, the average values of AV, PV, YP in the formulated system with three kinds of reducers are 5.9 ± 4.0 mPa·s, 3.6 ± 2.1 mPa·s and 2.4 ± 1.7 Pa, respectively. In addition, LSRV can be seen in the suitable range, which would meet the drilling demands. The fact that all formulated samples exhibit relatively good rheology could be attributed to an incursion of proper viscosifier. Herein, it is limited to select the filtrate reducer only by rheological data.

Figure 3. Comparison of filtrate volumes of the formulated brine-based system with different filtrate reducers
To determine the suitable filtrate reducer, fluid loss of the formulated brine-based system after heat-aged treatment are further compared, as shown in Figure 3. It can be found in Figure 3 that cellulose types present the largest filtrate volume, implying the worse filtrate inhibition in the formulated brine-based system. In contrast, the sulphonated types exhibit consistently lower fluid-filtrate results, and the filtrate volumes are less than 20ml. Note that, the potential environmental risk arising from treatment of sulphonated products can, to some degree, limit its application. As for starch types, a larger variation of filtrate can be seen, wherein S-FLO, a modified starch, performs better in filtrate inhibition and the loss volume is only 10ml. Given the dual functionality, herein, VIS is termed as the filtrate reducer for the brine-based fluid.

To sum up, the basic formula of brine-based drilling fluid is termed as follows: fresh water + 0.6wt.% VIS + 2wt.% S-FLOr + (25wt.% NaCl + 5wt.% KCl + 8wt.% HCOONa) fixed salinity. The constructed brine-based drilling fluid will be not only tolerant of the incursion of extra salts but also inherently inhibitive toward salt-anhydrate formations.

4. Conclusion
In combination to the features of salt-anhydrate formation in Missan Oilfields, a novel brine-based drilling fluid has been preliminarily constructed by means of systematically screening of the weighting manners, viscosifier, and filtrate reducers, together with evaluation on the application properties. The newly formulated brine-based drilling fluid exhibits moderate rheology and filtrate inhibition, which will be fundamental for developing multifunctional high-density drilling fluids available in salt-anhydrate formation.

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