Formulating Inhibited Fluids for Stable Drilling Operations into Tanuma and Zubair Shales, Zubair Oilfield, Southern Iraq

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Abstract
Tanuma and Zubair formations are known as the most problematic intervals in Zubair Oilfield, and they cause wellbore instability due to possible shale-fluid interaction. It causes a vast loss of time dealing with various downhole problems (e.g., stuck pipe) which leads to an increase in overall well cost for the consequences (e.g., fishing and sidetrack). This paper aims to test shale samples with various laboratory tests for shale evaluation and drilling muds development. Shale's physical properties are described by using a stereomicroscope and the structures are observed with Scanning Electron Microscope. The shale reactivity and behavior are analyzed by using the cation exchange capacity testing and the capillary suction test is utilized for selecting shale inhibitor base. As a result, four drillings muds are formulated with different additives and approved by using the Linear Swelling Meter and the Hot Rolling experiments. Tanuma’s shale is at higher reactivity level, where it is moderate to high active shale than Zubair’s shale, which is at a low to moderately reactive formation. Microfractures and micropores are excited in both formations and potentially in Tanuma’s shale. The shale stability can be achieved by adding 8% of KCl for Tanuma’s mud and 4% of KCl for Zubair’s mud. The filtration controls are contributed to seal the shale open structures and adding the Poly amino acid hydration suppressant reduced the risk of shale swelling significantly. The results can be used for designing drilling mud to reduce shale instability issues and the cost.

Keywords: Shale problems; Shale instability; Shale inhibition; Shale rocks; Shale-Fluid interactions

1. Introduction

The shale rocks represent 75% of the drilled formations and whenever it is encountered, it may cause unexpected downhole issues as wellbore instability and delays the progress of drilling and loss of the overall cost control. The shale is causing about 90% of the wellbore stability in oil and gas industry (Asef and Farrokhrour, 2013). These issues can appear in many different forms such as breakouts, lost circulation, stuck drill pipe and hole collapses, and inaccurate quality of logging interpretation (Abbas et al., 2018). The causes of shale instability can be mainly encountered due to the interactions of chemicals between drilling mud and formations. Particularly, the shales contain clay minerals affected by fluid and are lowering rock strength and causing failures by altering the shale pore pressure and the shale stress state. When the fluid penetrates the shale rock, the pore pressure will be increased and the shale strength will be decreased as a result and which causes the shale to disintegrate and fail (Caen et al., 2011;
Awadh et al., 2019). There are other root causes for the occurrence of shale failures such as the earth’s stress (or the mechanical failure of unbalance stresses between the formation and the drilled hole), and thermal effect, but it is beyond the scope of this paper.

Historically, Weiss et al. (1959) stated that the wellbore instability issues are associated with the shale formations which disperse unrestrainedly when contacting with drilling fluid or water, based on the selected shale samples from the Gulf coast. The interaction between the shale and fluids causes the shale to become sensitive and soft because it is imbibing fluid which leads to mechanical disintegration. The study revealed that the instability issue can be overcome by studying the chemistry of the clay to establish a mud system by coupling the high filtration calcium with the alkalinity environment controllers to flocculate the mud system. The flocculation is controlled by a desperation agent to keep the mud’s physical properties stable. Abdulzahra (2016) studied the shale stability of Tanuma (Rumaila Oilfield) and Zubair (East Baghdad Oilfield) formations by analyzing the shale compositions and the shale interaction with different fluids. The experimental works were conducted with different salt concentrations and increasing the salt percent had improved the shale recovery percentages. Additionally, the polymer muds showed less erosion to the shale than the water-based mud and the maximum recoveries were obtained from polymer muds when adding 10% Sodium silicate or KCl 10% . In the south of Iraq, Abbas et al. (2018) tested and evaluated the Zubair shale Formation with various laboratory testing. It was found that Zubair shale is sensitive to freshwater, and it has low to moderate active clay. The shale swelling and dispersion tests were conducted with Four fluids (Freshwater, 20 wt.% NaCl brine, 7 wt.% KCl brine, and a combination of 3 vol.% glycols with 7 wt.% KCl) and the last fluid has shown the lowest swelling percent (4%) (recovery of 95%) while the other ranged between 6% with brins to 12% with freshwater (recovery 88%).

Drilling operations continue to be challenged by shale instability in Zubair Oilfield, and because of the high costs of drilling, these issues should be thoroughly addressed as part of development planning. To minimize the risks of shale instability, research into the nature and core causes of shale failures is critical. As a result, the operation will be recovered quickly, resulting in stable shale horizons and safe drilling. (Abbas et al., 2018; Mohammed et al., 2018). The experimental work is designed for two main concepts which are examining shale’s physical properties and testing shale reactivity when it exposes to fluids. As a result, the muds are developed to reduce the shale reactivity, achieve safe drilling operations, and minimize the cost. Description tests were carried out to provide information about the characteristics and structures of the shale. The shale-fluid interaction tests were implemented to get knowledge about the reactivity of shale with fluids. The shale samples were investigated for the presence of the micro-fractures by Scanning Electron Microscope (SEM) technique. It will help to decide whether specific mud chemicals are required as shale inhibitors or not. The category of the shale reactivity level was then enhanced with the Cation Exchange Capacity (CEC) test on both formations. The capillary Suction Timer (CST) test was implemented with various concentrations of Potassium Chloride (KCl). The CST and SEM are used to select the shale inhibition and additives to reduce the instability issues in shale formations. The KCl was selected because of the effects of the K⁺ on shale swelling and shale mechanical properties in the solution. The formulated muds were tested to check the effectiveness of the selected additives to reduce the shale instability by using shale-fluid compatibility tests (Linear swelling test and hot rolling techniques).

2. Area of Study

The Zubair Oilfield is a major oilfield in the south of Iraq and it consists of four anticline domes: Safwan, Rafdiya, Shauaiba, and Hammar domes (Fig.1) (Al-Jafar and Al-Jaberi, 2019). It has two main reservoirs which are Mishrif and Zubair formations. Mishrif reservoir is underlying by Khasib and Tanuma formations and Zubair reservoir is interbedded with shale layers, as shown in Fig.2 (Ismail and
Al-Najam, 2019). The shale instability is the most severe problem in Zubair Oilfield (Awadh, 2018; Awadh et al., 2019), especially while drilling Tanuma and Zubair Shale, as shown in Fig. 3, and to reach the reservoirs for producing oil, these two formations must be penetrated. By checking the drilling reports, the average thickness of Tanuma’s shale is about 50 m and Zubair’s shale is about 200 m (Jassim and Goff, 2006; Al-Jaberi and Al-Jafar, 2020).

Fig.1. Zubair oilfield map (Al-Jafar and Al-Jaberi, 2019)

Fig.2. Zubair Oilfield Stratigraphic column (Modify from Ismail and Al-Najam, 2019)
Fig.3. The total drilling operations time distribution which includes the productive and the non-productive times: (a) shows the 16% of NPT due to instability in Tanuma Formation; (b) shows the 40% of NPT due to instability in Zubair Formation a (End of Well Report, 2021)

3. Materials and Methods

Various laboratory tests are conducted to investigate the shale-fluid interactions to help design the required shale inhibition, as follows:
- The shale cuttings are gathered, washed, and prepared at the drilling rig site.
- The stereomicroscope used to describe the shale cuttings for Tanuma and Zubair formations.
- The Scanning Electron-Microscope technique was used to observe shale structure.
- Cation Exchanging Capacity tests have been carried out to categorize the reactivity level of each shale formation.
- The capillary suction timer testing was performed to design the required percent of base additive to inhibit the shale activity.
- Based on the obtained results, appropriate mud chemicals and additives are selected.
- The new mud compositions are verified by Linear Swelling Meter (LSM) and Shale Erosion techniques.

4. Shale-Fluid Interactions

The incompatibility of the used drilling mud with shale formation is one of the root causes of shale instability. The goal of testing the shale with various mud chemicals is to select the appropriate mud chemistry. There are many tests, and each test technique is initiated to target or evaluate a single impute in a shale-chemical reaction. Some of these tests are quantitative and some of them are qualitative. Shale-fluid testing requires many tests to understand the complexity of shale instability through holistic approaches and a full understanding of the shale type and condition (Al-Mimar et al., 2018). It will allow for a screening process to develop new mud or properties to utilize the shale instability issue (Friedheim et al., 2011).

4.1. Shale Characterization

The cutting samples from both formations, Tanuma and Zubair shales, are collected, washed, and the shale characterizations are observed. That includes the bedding structure, sedimentary structures,
color, fractures, and consolidation, which are helping to indicate the initial shale type and to understand the potential instability mechanisms. The check was done by using the transmitted light microscope and visual test to describe the color, hardness, fissility, and shape of the shale samples. The cementation (shale calcareous and siliceous) of the shale samples is detected by putting the samples in a solution containing 10% of HCL and observing. The descriptive information considers qualitative instead of quantitative and the results are as follows:

4.1.1. Tanuma Shale

A very huge quantity of Shale has been identified in the Tanuma Formation (Boschetti et al., 2020). Tanuma shale is 100% shale, greenish gray, olive-gray, brittle to slightly hard, sub- fissile and weak fissile, sub blocky, splintery, occasionally tabular, and calcareous, as shown in Fig.4.

![Fig.4. Tanuma’s shale samples under the stereomicroscope](image)

4.1.2. Zubair Shale

The facies of the Zubair clasts show well-sorted quartz arenite sandstone, poorly sorted quartz arenite sandstone, clayey sandstone that has not been properly sorted, sandy shale, and shale lithofacies (Awadh et al., 2014; Alsultan et al., 2021). As shown in Fig.5, It consists of shale from 90 to 100% shale and siltstone from 0 to 10%, dark and light grey, brittle, occasionally firm, blocky to sub-blocky, fissile, occasionally sub-fissile, splintery, non-calcareous.

![Fig.5. Zubair’s shale samples under the stereomicroscope](image)
4.2. Shale Structure

The presence of micro-pores, cracks, and fractures is providing channeling across the wellbore. That allows the fluid for moving through and inside the shale rock which causes the shale to swell. Because of that, pore pressure is increased and leads to breaking of the cementation bonds between particles. The micro crakes and pores are considered a significant contributing factor in wellbore failures and shale stability (Gomez and He, 2006). The SEM was performed to observe the shale structure (micro-fractures, micro-crakes, and micro-pores) for both of Tanuma and Zubair formations. The SEM showed many micro-fractures and pores in both of Tanuma and Zubair formations (Fig.6). It is observed that the presence of micro-fractures and pores in the Tanuma Formation are significantly larger and higher than that in the Zubair shale. Tanuma’s shale contains micro-cracks and microfractures lengths ranging between 16-10 μm and widths ranging between 1-3 μm. Zubair’s shale micro-cracks and pores ranged between 0.5 and 1.5 μm in width and lengths between 2 and 7 μm.

Fig.6. Scanning electron image of Zubair and Tanuma shale specimens: (a) SEM result of Tanuma shale Formation; (b) SEM result of Zubair shale Formation.

4.3. Cation Exchange Capacity (CEC)

The CEC technique is a practical testing method for identifying and categorizing shale reactivity level (Babajide et al., 2016). The methylene blue solution is used to measure the shale reactivity by measuring the CEC (Stephens et al., 2009). However, the active shale is higher than 20 (meq/100g) and the moderately reactive shale is ranged between 10 to 20 (meq/100g). While the low CEC (< 10 meq/100g) can still be a problem if there are small amounts of active clays for swelling which lead to breaking down the shale apart (Garcia et al., 2013; Alshamy and Almahdawi, 2021). The cation exchange capacity test was carried out per the American Petroleum Institute (API) (2004) testing procedure for Tanuma and Zubair formations. The test shows that Zubair shale has low values of CEC which is exhibiting values of 6 milliequivalents per 100 grams (meq/100gm). And as it can be seen that Zubair’s shales results are fallen in the low reactivity category. While Tanuma formation’s sample has
shown a higher reactivity behavior than the Zubair Formation. Tanuma’s shale is moderate to high reactive shale, and it has a value of CEC as 12.5 milliequivalents per gram.

4.4. Capillary Suction Test (CST)

A capillary suction timer test (CST) is used to identify the shale dispersion and the shale flocculation. It is a proven method for evaluating shale ionic inhibition and estimating the inhibitor weight percentage of a particular salt. In the CST test, the used materials and mixing time are kept constant and only the chemical concentration is changed. This time depends on the type of solids, slurry content, pH, salinity concentration, characteristics, and concentration of deflocculant and polymer (Stephens et al., 2009). The test was conducted on shale samples with different salt concentrations to rectify the shale reactivity. The KCl concentration was increased in steps, by adding 2% of KCl per step and running the test. The CST that was conducted for Tanuma and Zubair Shales samples (Table 1). Tanuma and Zubair formations showed a different reactivity behavior with Deionized water (D.I water) and in each incremental step of salt concentration. The CST results, by using D.I. water, are recorded at a higher time in both formations. However, Tanuma recorded 335 seconds which is higher than the record time in Zubair’s shale which recorded 159 seconds. That is considered as another evidence of Tanuma shale’s potential and behavior to interact with fresh water. Also, Tanuma’s samples are always showing higher CST readings at all stages than Zubair Formation. Zubair Formation has been recorded with the lowest CST time at 4% of the KCl, at 16.3 seconds. While the Tanuma Formation needed 8% of KCl until recording the lowest CST timing which is 24 seconds. Tanuma Formation was showing a significant increase in the CST time when continue adding KCl above the optimal point. Whilst the Zubair Formation was relatively almost stable at the higher salt concentrations than the optimal KCl.

| KCl (%) | Tanuma (Seconds) | Zubair (Seconds) |
|---------|------------------|------------------|
| 0       | 335.0            | 159              |
| 2       | 39.0             | 23.3             |
| 4       | 28.5             | 16.3             |
| 6       | 34.1             | 18.8             |
| 8       | 24.0             | 21.0             |
| 18      | 33.7             | 21.0             |
| 12      | 35.8             | 23.0             |

4.5. Mud Development Plan

To drill a shale formation, it is necessarily required to test the shale hydration or dehydration (swelling) with the designed mud by showing the percent of clay swelling versus time, to demonstrate the effectiveness of the selected inhibitors on shale swelling (Baroid, 1998). Based on the outcome of the capillary suction time (CST) test and the shale characteristics, the decision was made to design two formulations of water-based muds (WBM) with different shale inhibitors agents to rectify the shale swelling issue in Tanuma and Zubair formations. The linear swelling meter (LWM) tests were used to test the formulated muds with shale. Then, the shale erosion (Hot rolling) test was performed to confirm the effectiveness of the mud with shale via the hot rolling technique.

The first polymer mud (1st WBM) was formulated with the additives (polyglycol, PHPA, and asphaltite) and the second polymer mud (2nd WBM) was formulated with Dispersion and Hydration suppressant (which is basically Poly amino acid hydration suppressant). The KCl percent, in both formulated muds, were selected based on the lowest records of CST value (Table 1) which is 8% for Tanuma shale and 4% for Zubair Formation. The filtration controls and the asphaltite are selected based
on the SEM results to plug the micro-fractures and pores present in the shale rocks and the polymers added to the system to reduce the shale disintegration.

4.5.1. Linear swelling test

The swelling test is carried out by using the LSM technique. This technique is measuring the free swelling, of, a reconstituted, pellet of shale after it was in contact with the fluid. The LSM measures the tendency of shale samples to hydration or dehydration when they expose to mud. It is considered a proper technique for testing shale reactivity. The swelling measurement, that the shale uptake, represents the shale reactivity to the used mud (Abbas et al., 2018). The LSM consists of a reservoir for fluid, a chamber for shale pellet, a linear, variable, differential transformer, a diverter, and a computer. The test is required to be done by placing the pellet of shales into the chamber which confines the pellet, between two screens, and pressing the swell in the vertical, direction. The result shows the swelling percent when the sample exposed to fluid. (Wysocki et al., 2015; Stephens et al., 2009).

The LST conducted to approve the selected shale inhibitors and the other additives due to the low swelling percent of shales in both muds. All results show a positive slope which confirms an immediate and constant interaction between the shale and the used fluid. Also, the WBM1 showed a higher rate of shale swelling than the 2nd mud in both Tanuma and Zubair shales. As shown in Fig.7 for Tanuma shale, both muds needed around 20 hours before the relatively positive stabilization. Whereas the shale expanded by about 2.5% with the WBM1 and 1.5 with the WBM2 after the 20 hours. At the end of the test, the shale expansion became a total of 3.2% with the WBM1 and 2% with the WBM2. The shale stabilization rated in Zubair shale, as shown in Fig. 8, showed different behavior in each mud. The immediate reaction expanded the shale up to 1.5% during the first 15 hours. Then, a stable expansion rate was noticed which increased to 0.5% and 2% at the end of the test. Whilst the WBM2 started with a higher reactivity percent (around 0.6%) at the beginning of the test (2 hours). The trend then began to become stable until the end of the test where the expansion became 1%.

![Fig.7. Tanuma shale linear swelling test results](image-url)
4.5.2. Shale Erosion

The shale erosion test was performed with a conventional hot rollers oven to simulate circulating shale cuttings up the wellbore annulus (Friedheim et al., 2011). The test was conducted as a screening test to verify the formulated fluids if it exhibits erosion to the shale samples. The mud considers safe if the shale sample shows a high recovery present when it is exposed to that mud (Abbas et al., 2018). The samples are prepared and washed from the mud residuals from Tanuma and Zubair shale. Then the cuttings were crushed, and it passed through 100-mesh (2 mm) sieves and collected 30 gm of shale that is on the 100-mesh sieve. Then the sample was dried at 220 °F for 12 hours to remove the moisture. The designed fluid was poured into the glass rolling jar (350 ml of fluid) and the samples were added to the drilling fluid (the samples were exposed to the drilling fluids WBM1 and WBM2 with the same procedure). The jar was placed in the hot roller oven at 150 °F for 16 hours. After that, the mixture cooled down and poured onto the 100-mesh sieve, washed, and cleaned the samples that collected on the sieve. The samples were placed on absorbent paper and then dried at 220 °F for 12 hours to remove the moisture and weighted the dried samples after rolling. Via percentages principle, the weight loss and the recovered present (%) are calculated for each sample.

The shale erosion test approved the LSM results because the loss in weight, or dispersion, was at a low tendency. WBM2 showed a higher recovery percent in both formations than WBM1, as shown in Fig.9. The WBM2 recovery percentage is 94% in Tanuma Formation and 96% in Zubair shale whilst the WBM1 recorded 91% in Tanuma shale and 93% in Zubair’s shale.
5. Discussion

In the initial assessment of the shale rock, Tanuma’s shale is relatively different from Zubair’s shale. Where the olive-greenish color in Tanuma’s shale indicates the presence of Chlorite and Kaolinite and possible Illite. And the black-gray color indicates the presence of the carbonic environment in Zubair, which is true as it is interbedded with the reservoir layers. Both shales of the formations are having parallel laminae and that is more in the Zubair compared to Tanuma. And Tanuma’s sample showed a lower level of fissility due to the presence of calcareous material, which indicates weaker composition. The other feature, of shale hardness, is indicating the possible existence of Illite and mixed layers of clay in both formations.

The microfractures and pores in the structure of Tanuma and Zubair shales, observed by the SEM, will always present the shale instability issues resulting from the raises in the pore pressure. The size and the amount of the microfractures and pores are significantly bigger and higher in Tanuma shale than in Zubair shale. That means the exposed channels for the fluid to penetrate through are relatively greatly bigger in Tanuma’s shale compared to Zubair Formation. The CEC and CST tests approved the reactivity of shale are matching XRD and XRF results. The low CST and CEC results are all recorded in Zubair shales which is due to the lower content of clay minerals. CST method approved the reactivity and the category of shale reactivity. Testing the shales with DI water shows CST higher than 150 seconds, which means the shales of both formations’ clay particles disperse into the fluid. That’s because of the osmosis pneumonia of the fluid inside the shale pores, as discussed in sections 2-4. However, when continue adding the KCl, the CST readings dramatically decreased until reaching the equilibrium level between the formation fluid and the mud activity. Based on all the above, the shale-chemical interactions are happening in both formations, and it is potential in Tanuma’s shale. The salinity of the water inside the shale pores, the exchanging capacity of the cations, and the membrane efficiency of cations (due to the microfractures and pores) are all occurring and causing the shale instability when it is in contact with drilling the low salinity muds.

6. Conclusions

- The shale rocks are dispersed in freshwater, and they can become stable by using inorganic additives (KCl).
- Each shale can be drilled safely with WBM, and each formation must be treated separately with changes in mud conditions.
- The designed mud for Tanuma shale can be used to drill Zubair shale and the opposite is not correct.
- The safest mud is that formulated with the optimum KCl concentration with Poly amino acid hydration suppressant.
- The Tanuma Formation is only stable with the optimal concentration of KCl (8%) inhibitor where it tends to become at a higher reactivity level when the KCl concentration is above or below the optimum point. On the other hand, the Zubair Formation is only chemically unstable if the concentration of the inhibitor dropped below the optimum point (4%) while adding more percent of KCl above the optimum point did not significantly affect the shale reactivity.

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