Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol.23 No.3 (September 2022) 35 – 41
EISSN: 2618-0707, PISSN: 1997-4884

Laboratory Testing and Evaluating of Shale Interaction with Mud for Tanuma Shale formation in Southern Iraq

Fadhil Hameed Alshibli and Ayad A. Alhaleem A. Alrazzaq

Petroleum Department, College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract

Rock failure during drilling is an important problem to be solved in petroleum technology. one of the most causes of rock failure is shale chemical interaction with drilling fluids. This interaction is changing the shale strength as well as its pore pressure relatively near the wellbore wall. In several oilfields in southern Iraq, drilling through the Tanuma formation is known as the most challenging operation due to its unstable behavior. Understanding the chemical reactions between shale and drilling fluid is determined by examining the features of shale and its behavior with drilling mud. Chemical interactions must be mitigated by the selection of suitable drilling mud with effective chemical additives. This study is describing the laboratory methods that concern testing and evaluating the shale instability encountered while drilling operations. The cutting samples are collected from the targeted formation and used to categorize shale reactivity levels and the required additives to inhibit the clay instability. These tests include the descriptive method with the various analytical technique of standard laboratory equipment. The shale testing techniques are the Scanning Electron Microscope (SEM), X-ray Diffraction, X-ray Fluorescence, Cation-Exchange, Capacity (CEC), and Capillary Suction Timer test (CST). Also, Linear swelling meter test (LSM) was performed to enhance the development plan. Tanuma formation contains moderately active clay with the presence of microfractures and micropores in its morphology. And it is controllable by using polymer muds with 8 % of inorganic inhibitor (e.g., KCL), filtration controls additives, and poly amino acid hydration suppressant which showed minimum swelling percentage.

Keywords: Shale rock, Tanuma shale, shale failure, shale swelling, shale-mud interaction

Received on 06/04/2022, Accepted on 25/05/2022, published on 30/09/2022

https://doi.org/10.31699/IJCPE.2022.3.5

1- Introduction

The shale rocks represent around 75% of the drilled formations and 70% of the downhole problems encountered while drilling to the targeted pay zones. It is still early to say that the shale issue is controlled as the oil and gas industry is still making efforts to control the shale instability issues. The drilling costs are still carrying a vast involvement in the shale instability issues due to many downhole problems, such as tight holes, hole collapse, poor hole cleaning, and stuck pipe. These issues are mainly created and developed due to the nonexistence of knowledge about the drilled formation [1].

Shale instability is a serious issue that appears when it is exposed to drilling muds. it might be encountered due to chemical interaction between the drilling fluid and shale rock or due to mechanical effects resulting from unbalanced stresses between the wellbore and formation being drilled.

However, it is necessary to predict wellbore instability before drilling any well for reducing or eliminating the risk of downhole problems. And the result of stable drilling is leading to minimizing the overall well costs which might be major [2].

Analyzing the shale instability, based only on the mechanical mechanisms, is an incorrect workflow, which is beyond the scope of this research. It is required to be analyzed aside from the mechanism of shale-drilling fluids interaction [3].

Chemical interactions must be mitigated by selecting suitable drilling muds with effective chemical additives. An effort must be made to understand the chemical reactions between shale and drilling fluid by examining the features of shale when drilling mud is present.

Then, using effective laboratory tests, that are indicative of the shale compositions and concentrations of the chemical in the drilling fluids, will lead to a significant improvement in mitigating and reducing the risk of interaction between shale and fluids [4].

This study is evaluating the shale reactivity and rectifies the failure by using mud additives that suit the Tanuma structure and properties. The cutting samples are collected from the targeted formations and used to categorize shale reactivity levels and the required additives to inhibit the clay instability. These tests include the descriptive with the various analytical technique of standard laboratory equipment.

Corresponding Authors: Name: Fadhil Hameed Alshibli , Email: Fadhil.ALI2008M@coeng.uobaghdad.edu.iq, Name: Ayad A. Alhaleem A. Alrazzaq, Email: Dr.ayad.a.h@coeng.uobaghdad.edu.iq

The shales minerals are categorized by the X-ray Diffraction (XRD) technique, the shale geochemical are analyzed by the X-ray Fluorescence (XRF) method and then the Scanning Electron Microscope (SEM) was then involved to enhance the decision of the shale reactivity analysis and to help for understanding the instability mechanisms which might be encountered due to microfractures and pores. The capacity of exchanging the cations (CEC test), which are present on the clay of the shale, was also performed to indicate the reactivity potential of shale samples. The XRD and the CEC methods combined to anticipate the need for inhibitions in drilling fluids. Additionally, the capillary suction time (CST) test was implemented on the shale to optimize the required inhibitor to stop shale dispersion into the fluid. By combining the obtained results from the analysis of the shale samples methods (SEM, XRD and XRF) and the method of evaluating the direct interaction of the rock samples with the fluids (CEC and CST), the shale reactivity levels are assessed for Tanuma shales. Based on that, a development plan was formulated and tested the shale stability with the new muds by Linear swelling meter test (LSM) [5], [6].

1.1. Shale Failure

Shale failure starts to occur when an insufficient type of mud is used to drill shale intervals where it depends on the properties of both shale rocks (e.g., mineralogy, porosity) and the drilling muds used to drill the shale (e.g., salinity, ionic exchange). It is also encountered if the effective stress in the drilled wellbore exceeds the strength of the hole. The shale is already in equilibrium (stresses and pore pressure) which is naturally established between the stress and the strength. When the native shale is exposed to a sudden alter in its environment and foreign chemicals from mud, it will disperse into mud. The reaction between drilling fluid and shale changed its strength as well as pore pressure relatively to the hole wall. Shale rock strength usually decreases, and pore pressure increases when fluid penetrates shale [6].

1.2. Chemical Effect

Chemical Effect is the interaction process between shale minerals (clay) and drilling fluids when shales expose to drilling operations. It is an important phenomenon in borehole stability. The fundamental of this interaction is the driving force for the water movement into or out of the shale formation [3], [8]. Chemical interactions, that occur between drilling fluids and shale rocks (clay-rich shale), are leading to affect rock strength and wellbore (local) formation pore pressure, thus, causing borehole failure.

In the context of the theory described by Mody and Hale (1993). The three influential factors, that lead to well instability issues, when chemical effects may encounter are: The **first factor** is, relatively, the salinity of drilling fluid relevant to the fluid in shale pores.

That is identified as the water activity (Am) and it is inversely proportional to the salinity. If the mud reactivity is above the reactivity of the fluid in a formation (Ap), the osmosis phenomena will occur which raises the shale pore pressure and cause the instability issue. Simply, osmotic pressure means the movement of the fluid from the less saline side toward the more saline side. The osmotic pressure concept, which is greatly impacting borehole stability, is easier to be understood while using water-based drilling fluids. **Second**, the changes in shale pore pressures are eliminated to the membrane efficiency, which is defined by how easily ions will move from drilling fluids into the shale formation. **Third**, the exchange capacity of ions in the shales is crucial because the changing of cations like Mg^{++} by Ca^{++} and Na^{+} by K^{+} will weaken the shale rock [3].

2- Experimental Work

Laboratory tests are conducted to describe and evaluate the shale reactivity of the Tanuma formation and to estimate the shale-mud interaction as follows:

2.1. Tanuma shale description

Tanuma Shale Formation is 100% shale. The cutting samples are checked visually and by using a microscope. It was described as Dark gray, olive-gray, slightly hard, fissile to sub fissile, sub blocky, splintery, occasionally tabular, and non-calcareous, as shown in Fig.1.

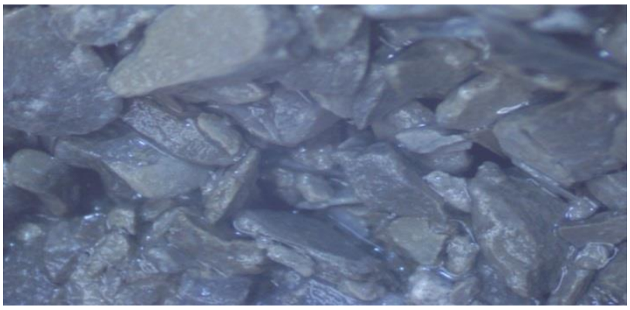

Fig. 1. Tanuma Shale sample under the microscope

2.2. Tanuma shale structure

The Scanning Electron Microscope test (SEM) was carried out to investigate The Tanuma shale structure and to observe the substructure morphology of the shale (micro-pores, micro-crakes, and micro-fractures). As shown in Fig. **2**, there is a significant presence of micropores and microfractures in Tanuma shale.

The length of the microfractures is ranged between 10 to 16 μm and their widths are ranged from 1 to 3 μm. The presence of micro-pores, cracks, and fractures becomes channels when the drilling fluid become in contact with shale, and these channels act to provide a path across the wellbore for the drilling mud and fluids and to inside the shale rock.

The penetration of fluid will cause the shale-swelling, which leads to an increase in the pore pressure and affects the base fluid saturations.

These activities and the nature of the shale structure are considered critical factors and play a vital role in shale failures and wellbore instability [9].

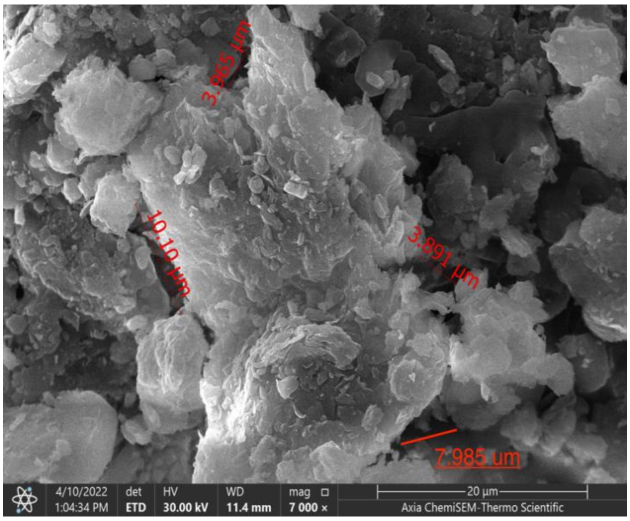

Fig. 2. Tanuma shale structure observed by Scanning Electron Microscope test

2.3. Tanuma shale mineralogy

The X-ray diffraction detector (XRD) was used to analyze the shale mineralogy and the presence of deferent minerals, which are the clay and non-clay mineral in shale. Tanuma cutting samples were collected from a drilling rig, cleaned, and washed on-site to remove the residual of the drilling mud.

The cuttings were dried in the electrical oven less than 105 °C for 2.5 hours to remove clear the shale from the water. The samples are ground and milled to a fine powder for the purpose of the accuracy of the results.

The test was performed with shale powder and results are shown in Fig. **3**, Tanuma formation mainly consists of clay minerals with non-clay minerals. It is also noticeable; that clay minerals represent a higher percentage than non-clay minerals. Tanuma formation mainly consists of Kaolinite, chlorite, Illite, and Palygorskite, as the clay minerals, Quartz, Dolomite, as the non-clay minerals.

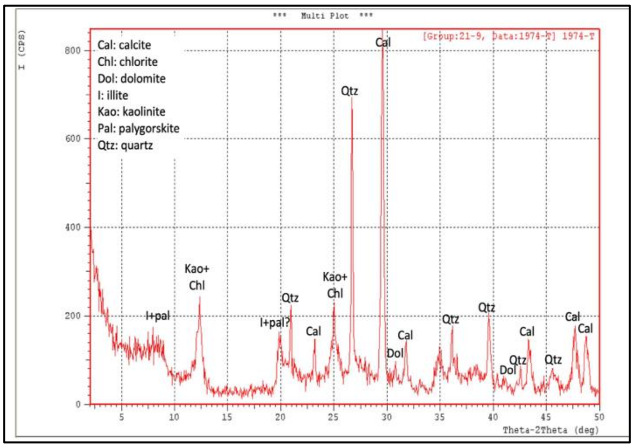

Fig. 3. Tanuma shale mineralogy obtained by the X-ray diffraction

2.4. Shale chemical

The X-ray fluorescence instrument (XRF) test was carried out for the purpose of analyzing the shale geochemical. The cuttings were prepared by washing the cuttings samples with water and drying them with electrical over 105 °C for up to 2.5 hours.

The cuttings were crushed and milled to a fine powder for the accuracy of the results. The power was pressed to pellets by applying 5 tons with the piston. The pellets were then analyzed and evaluated for each formation. The chemical compositions of Tanuma shale are mainly containing Silicon dioxide (SiO_2) 34.28 %, Calcium oxide (CaO) 17.1 %, Aluminum oxide (Al_2O_3) 13.26 %, Iron (III) oxide (Fe_2O_3) 6.831 %, Potassium oxide (K_2O) 2.229 % and 1.973 % and 1.433 % of Sodium oxide (Na_2O) and Magnesium oxide (MgO) respectively.

2.5. Cation Exchange Capacity Test

The compensating cation(s) which adsorbed on the surface of a unit layer might be exchanged with other cations. This process is referred to as the clay exchangeable cations.

The cations are exchanging with the other cations because of the interaction with the ions in aqueous fluids and it could also be intricate with non-aqueous solutions. The cation exchange capacity (CEC) method is a specific method to investigate shale reactivity with mud [10]. Ideally, the oil and gas industry accept the methylene blue test (MBT) to measure the CEC. API recommendation is about using one gram of finely ground dried shale for the assessment of shale reactivity level [11].

The sample is placed in deionized water with the dispersant, the sulfuric, and the hydrogen peroxide.

The sample solution is then heated up gently until a few minutes, cooled down to room temperature, then added to methylene blue fluid.

The MBT stops if a drop from the solution of the sample suspension is placed on the filter paper which results in a faint blue halo surrounding the dyed solids. The shale is considered reactive when the CEC is high and vis vera while the sandstone and limestone ideally are non-active rocks [5].

However, the active shale is higher than 20 meg/ 100 g and the moderately reactive shale is ranged between 10 to 20 meg/100 g while the low CEC can still be a problematic rock if there are small amounts of active clays for swelling which lead for breaking down the shale apart.

The results from the cation exchange capacity (CEC) tests, for Tanuma formation, are 12.5 milliequivalents per gram, as shown in Fig.4. Based on that, Tanuma is classified as moderate to moderately high reactive clay [12].

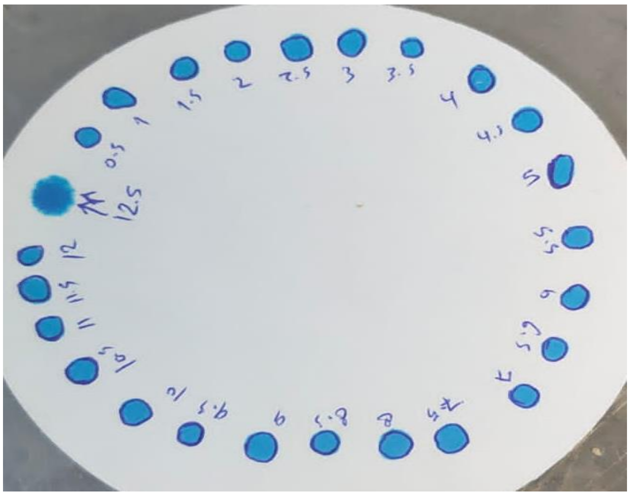
Fig. 4. Cation Exchange Capacity test for Tanuma Formation

2.6. Capillary Suction Timer Test

The CST technique measures the required time for the slurry to move through a known space on a thick-porous filter paper. The test was acclimatized to measure capillary, suction time, for clay or shale, slurries. The experimental can be done on cuttings, caving, and core to estimate clay reactivity [13]. The CST test requires 3 grams of ground and dry shale cuttings mixed, with the water, brine, mud, or any, designed mud filtration in a small blender cup to create the colloidal suspension.

The test is studying the filtration characteristics of the slurry by utilizing the pressure of capillary suction of the filtrate porous paper. The filtration rate, which is spreading away from suspension, will be mainly controlled by suspension filterability. Ideally, several tests can be run with different concentrations of salt, and it is well known to repeat the tests to compare the outputs of the numerical, results in seconds [14].

Usually, the flocculation concentration of salt can be measured which is dramatically lower than the CST. Additionally, the low salt concentration in the fluid will cause the shale particles to disperse into the fluid because of the higher flocculation concentration [5].

As shown Fig. **5**, the results of the capillary suction time (CST) that was conducted for Tanuma samples. The tests were carried out to measure the effect of the nominated test fluids, with different salt concentrations, on both formations.

To estimate the reactivity nature of Tanuma and Zubair shale formations, Tanuma formation needed 8 % of KCL until recording the lowest CST timing which is 24 seconds.

The same sample of shale was recorded for 335 seconds when it was in contact with deionized water. Thus, the shale reactivity can be rectified by adding 8 % of KCL inhibitor into the drilling mud. This KCL concentration is considered the optimal point. Otherwise, the timing will be higher if the KCL is below or above the optimal point.

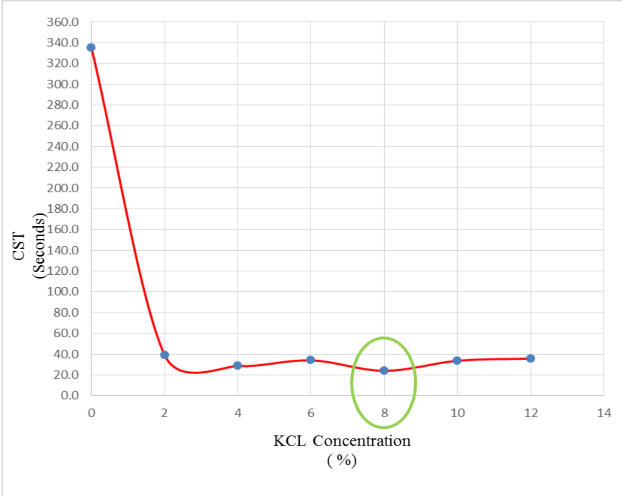

Fig. 5. Capillary suction time for Tanuma Shale formation

2.7. Shale Swelling Test

The swelling test is carried out by using the linear swelling meter (LSM) technique. This technique is measuring the free swelling, of, a reconstituted, pellet of shale after it was in contact with the fluid which shows the tendency of shale rock sample to hydration or dehydration. It is considered a proper technique for testing the shale reactivity checks. The swelling measurement, which is the shale uptake, represents the shale reactivity to the mud used in the test [15].

The swelling test is considered a good indication of the shale reactivity to the fluids being tested. If more, of shale swelling is observed, in the water that means it has a high sensitivity to water. The result of this test is generally associated with chemical reactivity and some of the physical effects, e.g., fractures or cracks [5], [16].

Based on the outcome of the capillary suction time (CST) test, as well as the other tests, the decision was made to design two formulations of water-based muds (WBM) with different shale inhibitor agents to rectify the shale swelling issue in Tanuma shale. The formulations of the water-based mud for the first mud (1st mud) were formulated with the additives (polyglycol, PHPA, and asphaltite) and the second mud (2nd mud) was formulated with Dispersion and Hydration suppressant (which is basically Poly amino acid hydration suppressant).

The KCL percent, in both formulated muds, is 8 % for Tanuma shale.

The filtration controls and the asphaltite are selected based on the SEM results to plug the micro-fractures and poses present in the shale rocks.

As shown in Fig. **6** for Tanuma shale, both muds needed around 20 hours before the relatively positive stabilization where the shale expanded by about 2.5 % with the first mud and 1.5 with the 2nd mud after the 20 hours. At the end of the test, the shale expansion became 3.2 % with the 1st mud and 2 % with the 2nd mud.

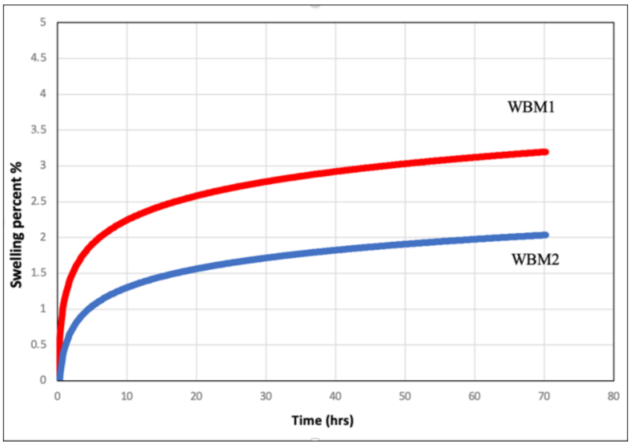

Fig. 6. Linear swelling test of Tanuma shale

3- Discussion

Tanuma shale samples are tested with different laboratory methods to investigate the root causes of its reactivity when it is in contact with drilling mud. The visual inspection indicated the presence of clay minerals the presents of Chlorite and Kaolinite and possible Illite according to its color, laminae, and calcareous features [17]. The geochemical (XRF test) analysis showed a higher percentage and more kinds of chemicals Al, Ca, Fe2O, and K2O which refer to the presence of clay. The XRD confirmed that Tanuma shale contains clay (Illite, Chlorite, Kaolinite, and Palygorskite) which are non-swelling clays in their nature.

But The Illite and Chlorite can slightly swell fluid when they expose to altering from drilling operations and this tendency is occur more in Illite than Chlorite clay. Illite clay contains the weakly-bond interlayer cations and weakly layer charges that lead to swelling and dispersion when in contact with water. It is also worth noting that the presence of the larger amount of Illite and Chlorite clays is causing serious problems of instability.

The Kaolinite clay is a tight layer type that does not exchange unless broken bonds occur which cause minor cations exchange. The microfractures and pores in the structure of Tanuma shale, observed by the SEM, will always present the wellbore instability issues resulting from the raises in the pore pressure.

The size and the amount of the microfractures and pores are significant. The XRD and CEC tests approved the reactivity of shale are matching XRD and XRF results. The capillary suction time (CST) method confirmed the reactivity and the category of shale reactivity. It is observed that in testing the shales with DI water, the level of CST is higher than 150 seconds, which means the shales of Tanuma formation clay particles disperse into the fluid. But, when continue adding the KCL, the CST readings dramatically decreased until reaching to the equilibrium level with the flocculation concentration.

The presence of a large amount of Illite (the weak-bond layer type) and chlorite clay in Tanuma shale has affected the salt consumption until achieving the equilibrium point with the water intake and K+ exchange which is at 8 %.

4- Conclusions

Tanuma formation is moderately active shale, and it tends to disperse in the fluid, especially with fresh water. Tanuma shale failure can be managed by using polymer mud with a combination of 8 % KCL, filtration control additives, and other shale inhibitors. The mud with poly amino acid was the most optimum shale inhibitor for Tanuma formation compared to the glycol and asphaltites inhibitors.

References

[1] M. Lal, "Shale stability: drilling fluid interaction and shale strength." In *SPE Asia Pacific Oil and Gas Conference and Exhibition*. OnePetro, 1999.

[2] B. S. Aadnoy, and R. Looyeh. *Petroleum rock mechanics: drilling operations and well design*. Gulf Professional Publishing, 2019.

[3] F. K. Mody, and H. H. Arthur, "Borehole-stability model to couple the mechanics and chemistry of drilling-fluid/shale interactions." *Journal of Petroleum Technology*45.11 1993, pp. 1093-1101.

[4] S. Gomez, and W. He, "Fighting wellbore instability: customizing drilling fluids based on laboratory studies of shale-fluid interactions." *IADC/SPE Asia Pacific drilling technology conference and exhibition*. OnePetro, 2012.

[5] M. Stephens, S. Gomez, and M. Churan, "Laboratory methods to assess shale reactivity with drilling fluids." *AADE National Technical Conference, New Orleans*, 2009.

[6] A. K. Abbas, R. E. Flori. A. Al-anssari, and M. Alsaba, "Testing and Evaluation of Shale Stability for Zubair Shale Formation." *In SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition*. OnePetro, 2018.

[7] M. Lal, "Shale stability: drilling fluid interaction and shale strength." *SPE Asia Pacific Oil and Gas Conference and Exhibition*. OnePetro, 1999.

[8] M. E. Chenevert, and A. K. Sharma, "Permeability and effective pore pressure of shales." *SPE Drilling & completion*8.01 1993, pp. 28-34.

[9] S. Gomez, and W. He, "Laboratory method to evaluate fracture development in hard shale formations exposed to drilling fluids." Proceedings of AADE Fluid Conference. Houston. 2006.

[10] A. Babajide, O. Adebowale, F. Adesina, A. Churchill, and M. Ifechukwu, "Effects of temperature and pressure on shale cuttings dispersion in water based mud WBM using NACL, CACL2, KCL salts as primary inhibiting agents and polymer XCD xanthan gum as the secondary inhibiting agent." SPE Nigeria Annual International Conference and Exhibition. OnePetro, 2016.

[11] American Petroleum Institute. *Recommended practice for laboratory testing of drilling fluids*. American Petroleum Institute, 2009.

[12] M. N. Garcia, F. Sorenson, J.C. Bonapace, F. Motta, C. Bajuk, and H. Stockman, "Vaca muerta shale reservoir characterization and description: the starting point for development of a shale play with very good possibilities for a successful project." *Unconventional Resources Technology Conference*. Society of Exploration Geophysicists, American Association of Petroleum Geologists, Society of Petroleum Engineers, 2013.

[13] R. D. Wilcox, J. V. Fisk, and G. E. Corbett, "Filtration method characterizes dispersive properties of shales." *SPE Drilling Engineering* 2.02 1987, pp. 149-158.

[14] D. Benoit, G. R. Montenegro-Galindo, K. L. Anderson, and K. W. Hoeman, K. W, "Obtaining Comparable and Relevant Formation Swelling Sensitivity Data from CST: Is this Even Possible?." *SPE International Conference and Exhibition on Formation Damage Control*. OnePetro, 2016.

[15] I. Baroid Drilling Fluids, "Baroid Fluids Handbook." *Houston, USA*, 1998.

[16] S. Wysocki, R. Wisniowski, D. Ryzan, M. Gaczol, "Linear swelling test (LST) of clay formation under the influence of newly developed drilling fluids with the addition of cationic polymers." *AGH Drilling, Oil, Gas* 32.4, 2015.

[17] M. Asef, and M. Farrokhrouz, "Shale engineering: mechanics and mechanisms." *CRC Press*, 2013.

الفحوصات المختبرية التقيميه لتفاعل الصخر الطفل مع الطين لتكوين التنومة في جنوب العراق

فاضل حميد علي و اياد عبدالحليم

جامعة بغداد

الخلاصة

يعد فشل الصخور أثناء الحفر مشكلة مهمة يجب حلها في تكنولوجيا البترول. أحد أكثر أسباب انهيار الصخور هو التفاعل الكيميائي الصخري مع سوائل الحفر. في العديد من حقول النفط في جنوب العراق ، يُعرف الحفر من خلال تكوين تنومة بأنه أكثر العمليات تحديًا نظرًا لسلوكه غير المستقر. فهم التفاعلات الكيميائية بين صخر الطفل و سائل الحفر يتم من خلال فحص خواص التكوين وسلوكه مع طين الحفر. يجب تقليل التفاعلات الكيميائية عن طريق اختيار طين حفر مناسب مع إضافات كيميائية فعالة. يصف هذا البحث الطرق العملية المستخدمة لتقييم واختبار عدم استقرار تكوين الطفل أثناء عمليات الحفر. تم جمع عينات من التكوين المستهدف واستخدم لتصنيف مستويات تفاعل التكوين والإضافات المطلوبة لمنع عدم استقرار الطين. تشمل هذه الاختبارات الطريقة الوصفية مع الأساليب التحليلية المختلفة باستخدام معدات مختبريه قياسيه. هذه الاختبارات هي مجهر المسح الإلكتروني (SEM) ، الأشعة السينية ذات انحراف ، وفلورة الأشعة السينية ، وتبادل الكاتيون (CEC) ، واختبار مؤقت الشفط الشعري (CST). كما تم إجراء اختبار مقياس الانتفاخ الخطي (LSM) لتعزيز خطة التطوير. يحتوي تكوين تنومة على طين نشط بشكل معتدل مع وجود كسور دقيقة ومسام دقيقة في شكله. ويمكن التحكم فيه باستخدام طين بوليمر مع 8٪ من مثبطات غير عضوية (على سبيل المثال KCL) ، ومضافات موانع الترشيح، ومانع ترطيب حمض أميني الذي أظهر أدنى نسبة انتفاخ.

الكلمات الدالة: صخور الطفل، صخور التنومه ، فشل صخور لطفل ، انتفاخ صخور الطفل ، ، تفاعل صخور الطفل