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Chemical and Thermal Investigation on Stability of Tanuma Formation Using Different Additives with Drilling Fluids

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ABSTRACT

Wellbore stability is considered as one of the most challenges during drilling wells due to the reactivity of shale with drilling fluids. During drilling wells in North Rumaila, Tanuma shale is represented as one of the most abnormal formations. Sloughing, caving, and cementing problems as a result of the drilling fluid interaction with the formation are considered as the most important problem during drilling wells. In this study, an attempt to solve this problem was done, by improving the shale stability by adding additives to the drilling fluid. Water-based mud (WBM) and polymer mud were used with different additives. Three concentrations 0.5, 1, 5 and 10 wt. % for five types of additives ($CaCl_2$, NaCl, Na_2SiO_3, KCl, and Flodrill PAM 1040) was used. Different periods of immersion (1, 24 and 72 hours) were applied. The results of the immersion test showed that using 10 wt. % of Na_2SiO_3 for WBM gives a high recovery percentage (77.99 %) after 72 hr, while the result of the dispersion test (roller oven) of 10 wt % of sodium silicate with WBM was (80.97 %) after 16 hr. Also, the immersion test result of 10 wt% of sodium silicate with polymer mud was (79.76 %) after 72 hr and the results of dispersion test (roller oven) of 10 wt. % of sodium silicate with polymer mud was (84.51 %) after 16 hr.

Keywords: Tanuma formation, Shale stability, drilling fluid.

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الدراسة الكيميائية والحرارية لأستقرارية الصخور الطينية لطبقة التنومة بأستخدام أضافات مختلفة لموائع الحفر

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الخلاصة

استقرارية البئر تعتبر واحدة من اكثر التحديات خلال عملية حفر الابار نتيجة لفعالية الصخور الطينية مع موائع الحفر.طبقة التنومة في حقل الرميلة الشمالية تعتبر واحدة من اكثر الطبقات المسببة للمشكلات خلال عملية الحفر. الانسلاخ و التهدم بالاضافة الى مشكلات في عملية التصلب نتيجة لفعالية الصخور الطينية مع موائع الحفر تعتبر من اهم المشكلات اثناء الحفر. الهدف من البحث هو ايجاد حل لمشاكل الصخور الطينية من خلال استخدام اضافات لها القابلية على تقليل التفاعل بين الموائع والصخور الطينية. نوعين من موائع الحفر تم استخدامها وهي اطيان حفر ذو اساس مائي واطيان البوليمر مع اضافات ملحية مختلفة. خمسة انواع من الاضافات الملحية تم استخدامها (KCl, NaCl, $CaCl_2$, Na_2SiO_3, and Flodrill PAM 1040) بتراكيز مختلفة (0.5, 1, 5, 10) % مع فترات غمر مختلفة (1, 24, 72) ساعة. نتائج عملية الغمر تبين ان اضافة 10 % من سليكات الصوديوم الى طين الحفر ذو الاساس المائي تعطي نتيجة بنسبة (77.99%) بعد 72 ساعة من الغمر بينما نتيجة (roller oven) بعد غمر لمدة 16 ساعة تعطي نتيجة بنسبة (80.97%). كذلك عملية الغمر تبين ان اضافة 10 % من سليكات الصوديوم الى اطيان البوليمر تعطي نتيجة بنسبة (79.76%) بعد 72 ساعة من الغمر بينما نتيجة (roller oven) بعد غمر لمدة 16 ساعة تغطي نتيجة بنسبة (84.51%).

الكلمات الرئيسية: طبقة التنومة, استقرارية الصخور الطينية, موائع الحفر

1. INTRODUCTION

Managing wellbore stability is represented as one of the important parameters during drilling for petroleum production. The amount of distribution water around the shale is significantly influenced the borehole stability and shale deterioration. Prior research has studied the effect of transportation of fluid as a result of chemical activity and hydraulic pressure gradient **(Mody and Hale, 1993), (Onaisi, et al., 1993), (Sherwood and Bailey, 1994), (Van Oort, et al., 1996), (Sharma, et al., 1998)** and **(Ghassemi, et al., 1998).** When shale in contact with drilling fluids, water will adsorb on the clay minerals. The absorption of water is led to increasing the interlayer spacing between clay surfaces. The chemical composition of drilling fluid, amount and distribution of water with the shale itself is influenced the shale stability. Prior researchers have studied shale stability problems for investigating a suitable solution to solve this problem by using different types of additives such as; oil-based mud, $CaCl_2$, NaCl/KCL, NaCl/KCL/Amine, K Acetate/Polymer Fluid, Polymer system, Potassium chloride (KCl)/Polymer, and series of different Nano-silicate substances with water-based mud **(Sandra Gomez and Wenwu, 2012), (Simpson and Dearing, 2000),** (**Nediljka, et al., 2004), (Friedheim, et al., 2011), (Brady and Michael, 2012), (Wenwu, et al., 2014)** and **(Peter, et al., 2016)**. Drilling fluid interaction with shale formation or movement toward the shale may be led to huge problems within few hours (**Farrokhrouz and Asef, 2013**) such as bit balling, caving, stuck pipe and increase in torque and drag. During drilling wells in North Rumaila, Tanuma shale is represented as one of the most abnormal formations in North Rumaila and it is located at a depth from (2102 -2126 m MD). The main goal of this study is to overcome such problems by improving the drilling fluid properties through different additives types and concentrations. To understand the effect of these additives, the chemical and thermal drilling fluids interaction with shale samples were studied as well as shale properties.

2. Experimental work

Experimental works include shale-drilling fluid interaction tests, which provide information about the recovery for shale samples.

2.1 Preparation of Samples

Tanuma Samples collected from the North Rumaila oil field at a depth of 2120 m. Its description is illustrated in **Table 1**. Two techniques were used for cleaning samples from drilling additives and hydrocarbons. First, the hydrodynamic compounds were removed by using the soxhlet method with the addition of three materials (benzene, methanol, and toluene) after that, the samples were kept for three hours inside the soxhlet device. Second, wet sieving was used to clean samples from salt additives as shown in **Figure 1**.

Figure 1. Tanuma shale samples.

Table 1. Characterization of Tanuma formation (**Halliburton, 2015)**.

Depth	Description of Tanuma formation
2102-2104 m	Shale (50%): Medium-dark grey, olive-grey, slightly hard, commonly fissile and slightly calcareous in place, occasionally thinly laminated.
	Limestone (50%): Mudstone to Wackestone, very light grey, yellowish-grey, light olive-grey, soft, firm in place, fine crystalline, earthy luster, argillaceous, no visible porosity, no oil show.
2104-2110 m	Shale (70%)
	Limestone (30%)
2110-2120 m	Shale (100%)
2120-2126 m	Shale (60%)
	Limestone (40%)

2.2 Drilling Fluid Preparation

Water base mud according to API-specification and Polymer mud were used in this study. Hamilton Beach mixer was used for mixing of 350ml of water with 22.5g of bentonite for preparing WBM and mixing it for 20 min in the mixer (**Assi, et al., 2018)**. For ensuring good hydration of bentonite, the mixture was aged in a sealed container for 24 hr. After that, different concentrations (0.5, 1, 5, and 10 wt. %) of salts were added to WBM and mixed for 10 min. Preparing polymer mud was done by adding fixed quantities of PAC Polymer, KOH, KCl, and XC polymer to the hydrated mixture of bentonite. The mixture should be mixed for 2 min after adding each additive to ensure the distribution of materials into the matrix of drilling fluids. Finally, the solution of polymer mud should be mixed for 10 minutes before adding (0.5, 1, 5 and 10) wt % of salts concentrations and mixed for 10 min (**Salam, et al., 2019)**.

2.3 Experimental procedure

Tanuma samples were soaked in (WBM and polymer mud) of drilling fluids with different additives. Five types of salts additives (Potassium chloride, sodium chloride, calcium chloride, sodium silicate, and Flodrill) with different concentrations (0.5, 1, 5 and 10 wt %) and at (1, 24 and 72) hrs soaking period time were applied.

Flodrill PAM 1040 is used as an inhibitor for shale formation. The flodrill pam 1040 is a mixture with a granular solid and white appearance. The range of its pH is 5 to 9 at 5 g/l and relative density is 0.6 to 0.9 as well as it is considered as a soluble in water. The flodrill pam 1040 is supplied from SNF SA Company/France. In this study, flodrill additive with 2 to 4 Ib/bbl concentration was used. Immersion and dispersion tests were applied to get the recovery percentages for the Tanuma shale. The dispersion test was conducted by a rolling oven in order to measure the recovery percentage at 100 C^o. The immersion test means the recovery percentage at room temperature and static condition. The recovery percentage is the weight of samples after immersion divided by the weight of samples before immersion and it can be described in the equation below for immersion and dispersion test.

$$\text{Recovery (Wt. \%)} = \frac{W_{af}}{W_b} * 100 \qquad (1)$$

The initial moisture content had been determined by weighting shale samples before and after drying in an oven with 100 C^o for 24 hours as below

$$MC\ (Wt.\ \%) = \frac{W_w}{W_s} * 100 \qquad (2)$$

Cation exchange capacity (CEC) is represented as a practical method to measure the reactivity of shale. The CEC of dry clay can be measured with methylene blue titration. The methylene blue solution was prepared by adding 2.5 gm of methylene blue to 500 ml of water and mixing by a stirrer for 15 min. Shale sample 0.5 was added to 30 ml of distilling water and mixed by a stirrer for 30 min, then the shale sample was titrated with methylene blue until the light color appeared (**Adesoye, 2009)**. The CEC value was calculated according to the following Eq. (3)

$$CEC = MB\ added\ cc * \frac{MB\ dry\ (wt)gm}{319.87} * \frac{1000}{vol.\ of\ MB\ solution\ cc} * \frac{100}{clay\ dry\ wt\ (gm)} \qquad (3)$$

CEC = Burette reading *3.1262 meq/100 gm

2.4 Equipment

- Reflected and transmitted microscope
- Roller oven
- Oven
- Balance
- Magnetic stirrer
- Burette

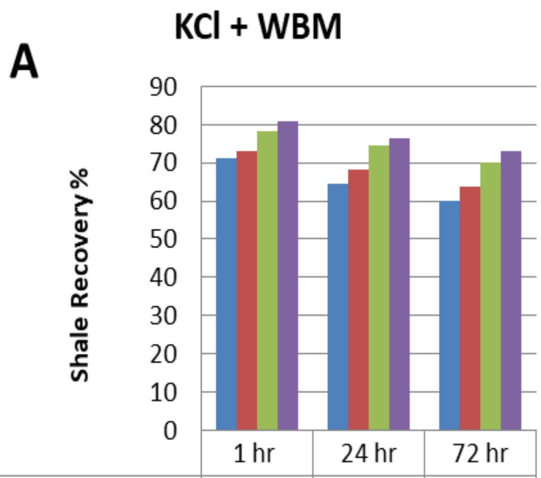
3. Results and Discussion

3.1 Drilling fluids impact on the shale samples

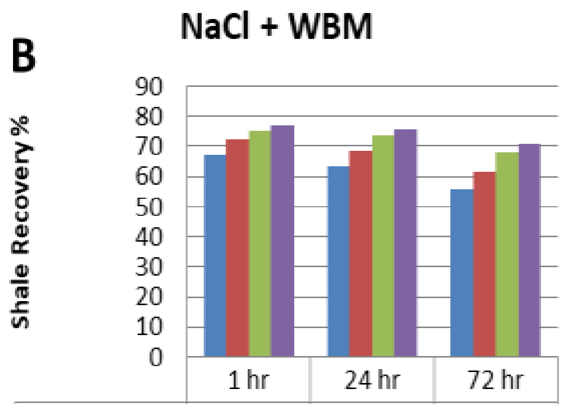
3.1.1 Immersion test

The activity between the additives and shale samples has a direct effect on the values of shale recovery (**Gomez, 2006)**. The recovery percentage of 0.5% of KCl salt with WBM was 71.3 % after 1 hour, while 1% of KCl with WBM gave 73.2 %, 5 % of KCl with WBM gave the recovery after 1 hr with a recovery of 78.4 % and 10 % of KCl with WBM resulted in 80.7 %, the results show the concentration of salts has a direct effect on the recovery percentage of samples (**Mohammed, et al., 2019)**. WBM with 0.5 % KCl resulted in recovery percentage 60.2 % after 72 hr, the recovery percentage of adding 1 % KCl with WBM after 72 hr was 63.9%, 5 % KCl with WBM the recovery was 70.1 %, and 10 % of KCl with WBM after 72 hr with a percentage of recovery of 73.1% as shown in **Table 2 A**. The recovery percentages of shale samples increased when the concentration of salts increased and reduced when immersion time increased as shown in **Table 2**. Shale has the ability to adsorb the positive ions because of the negative ions found on the shale surface and react with the positive ions. So, the ions such as Si^{+4}, K^{+}, Na^{+}, and Ca^{2+} adsorbed on the surface of the sheet (**M-I Swaco, 1998)**. The recovery of 0.5 % NaCl with WBM was 67.1 % while the value reduced to 55.7 % after 72 hr. The values of recovery of shale increased to 72.4 %, 75.2 %, and 76.9 % after one hour when increasing the concentration of NaCl to 1, 5, and 10 % respectively as shown in **Table 2 B**. WBM with 0.5 % $CaCl_2$ resulted in recovery percentage 67.2 after 1 hr and 54.3 % after 72 hr. 1% $CaCl_2$ with WBM the recovery after 1 hr was 72 % and 60.8% after 72 hr. Increasing the concentration of $CaCl_2$ to 5 % and 10 % led to an increase in the recovery percentage to 74.8 % and 76.4 % respectively after 1 hr **Table 2 C**. WBM with 0.5 % sodium silicate gave 64.28 % recovery percentage after 1 hr and 52.86 % after 72 hr. WBM with 1% Na_2SiO_3 gave 65.55 % recovery after 1 hr and 54.13 % after 72 hr. The recovery of 5 % of Na_2SiO_3 with WBM was 77.46 % after 1 hr and 73.11 % after 72 hr. WBM with 10 % of Na_2Sio_3 gave 82.19 % recovery after 1 hr and 77.99 % after 72 hr **Table 2 D**. The sodium silicate salt gave a better recovery percentage at 5 and 10 % concentration while the recovery was low at 0.5 and 1 % concentration (**Mohammed, et al., 2019)**. The recovery results of polymer mud with salts additives are better than WBM with the salts as shown in **Table 3 A**, **Table 3 B**, **Table 3 C,** and **Table 3 D**.

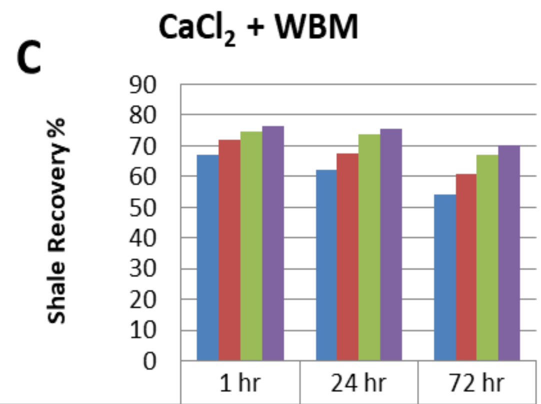
Table 2. Immersion results of WBM for Tanuma A: KCl, B: NaCl, C: $CaCl_2$, D: Na_2SiO_3.



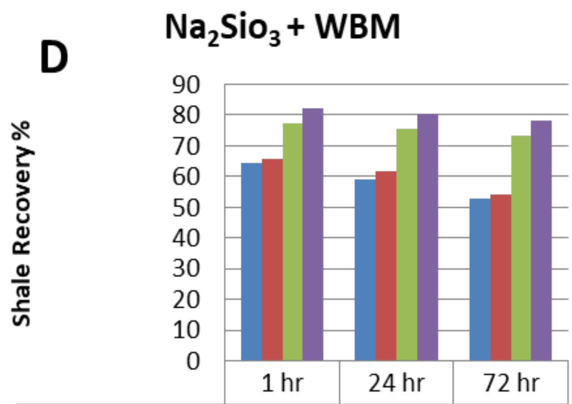
	1 hr	24 hr	72 hr
0.5 % KCl + WBM	71.3	64.6	60.2
1% KCl+WBM	73.2	68.1	63.9
5 % KCl + WBM	78.4	74.4	70.1
10 % KCl + WBM	80.7	76.4	73.1



	1 hr	24 hr	72 hr
0.5 % NaCl + WBM	67.1	63.4	55.7
1 % NaCl + WBM	72.4	68.4	61.3
5 % NaCl + WBM	75.2	73.7	68.1
10 % NaCl + WBM	76.9	75.8	70.7

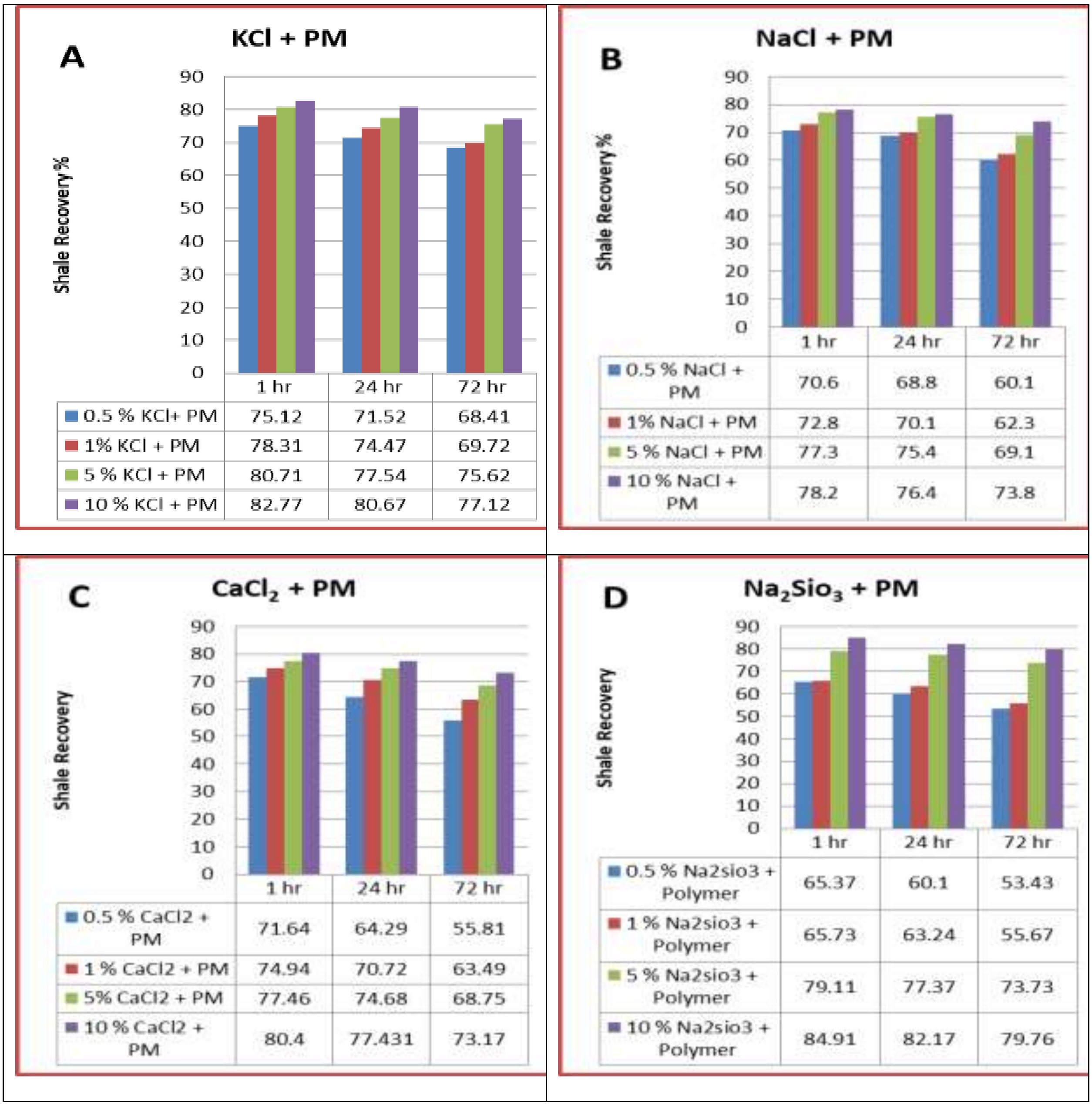


	1 hr	24 hr	72 hr
0.5 % CaCl2 + WBM	67.2	62.3	54.3
1 % CaCl2 + WBM	72	67.4	60.8
5 % CaCl2 + WBM	74.8	73.6	67.2
10 % CaCl2 + WBM	76.4	75.6	70.2



	1 hr	24 hr	72 hr
0.5 % Na2sio3 + WBM	64.28	59.17	52.86
1 % Na2sio3 + WBM	65.55	61.68	54.13
5 % Na2sio3 + WBM	77.46	75.46	73.11
10 % Na2sio3 + WBM	82.19	80.64	77.99

Table 3. Immersion results of PM for Tanuma A: KCl, B: NaCl, C: $CaCl_2$, D: Na_2SiO_3



A	1 hr	24 hr	72 hr
0.5 % KCl+ PM	75.12	71.52	68.41
1% KCl + PM	78.31	74.47	69.72
5 % KCl + PM	80.71	77.54	75.62
10 % KCl + PM	82.77	80.67	77.12

B	1 hr	24 hr	72 hr
0.5 % NaCl + PM	70.6	68.8	60.1
1% NaCl + PM	72.8	70.1	62.3
5 % NaCl + PM	77.3	75.4	69.1
10 % NaCl + PM	78.2	76.4	73.8

C	1 hr	24 hr	72 hr
0.5 % CaCl2 + PM	71.64	64.29	55.81
1 % CaCl2 + PM	74.94	70.72	63.49
5% CaCl2 + PM	77.46	74.68	68.75
10 % CaCl2 + PM	80.4	77.431	73.17

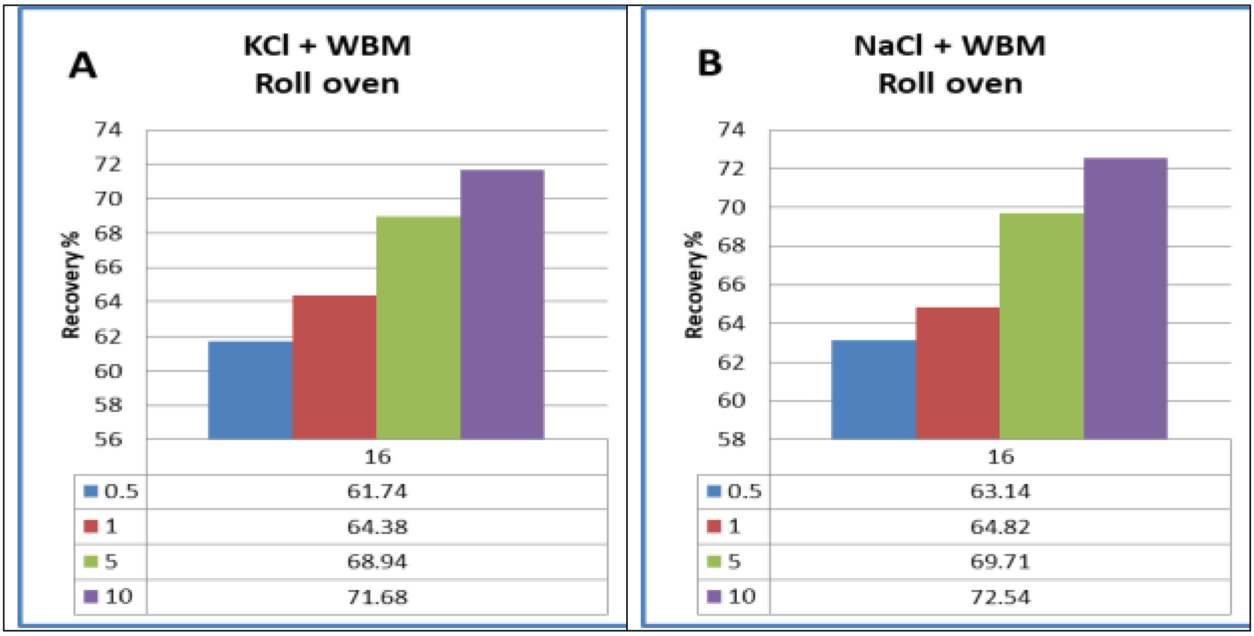
D	1 hr	24 hr	72 hr
0.5 % Na2sio3 + Polymer	65.37	60.1	53.43
1 % Na2sio3 + Polymer	65.73	63.24	55.67
5 % Na2sio3 + Polymer	79.11	77.37	73.73
10 % Na2sio3 + Polymer	84.91	82.17	79.76

3.1.2 Dispersion test

Dispersion analyzes for shale, were conducted using different drilling fluids at 100 C^o. **Table 4** and **Table 5** show the recovery percentage of shale calculated after the dispersion test. The recovery percentage of 0.5 % KCl with WBM after 16 hr was 61.74 % and the recovery increased to 71.68 % at 10 % of KCl. 0.5 % of $CaCl_2$ with WBM gave a percentage of recovery of 63.14%, while 10 % of $CaCl_2$ gives 72.54 %. 0.5 % of Na_2Sio_3 with WBM gave a percentage of recovery of 66.13%, while 10 % of Na_2SiO_3 gave rise to 80.97 %. The maximum recoveries obtained with polymer mud + 10 wt % Na_2SiO_3 and polymer mud + 10 wt % KCl were 84.51 % and 77.68 %

respectively. The temperature and dynamic motion of the roller oven had a direct effect on the result of shale recovery, as observed in the results of the dispersion test, **Table 4** and **Table 5**. The recovery of the dispersion test after 16 hr is less than the recovery of the immersion test after 24 hr at the same concentration. The temperature of the dispersion test is considered as an influential factor in the weakening of the bonds between the parts of shale due to increasing the vibration of the molecules and this will lead to an increase in the movement of water toward the lattice of shale. Thus more samples of shale were crashed into fines and the percent recovery was decreased. The polymer mud has recovery percentage better than WBM due to the effect of the polymer encapsulation and hydrate ability during exposure which led to increases in its surface area therefore blocked and covered shale surface. This condition is represented as an encapsulation of polymer **(Adesoye, 2009)**.

Table 4. Dispersion results of WBM for Tanuma A: KCl, B: NaCl, C: $CaCl_2$, D: Na_2SiO_3



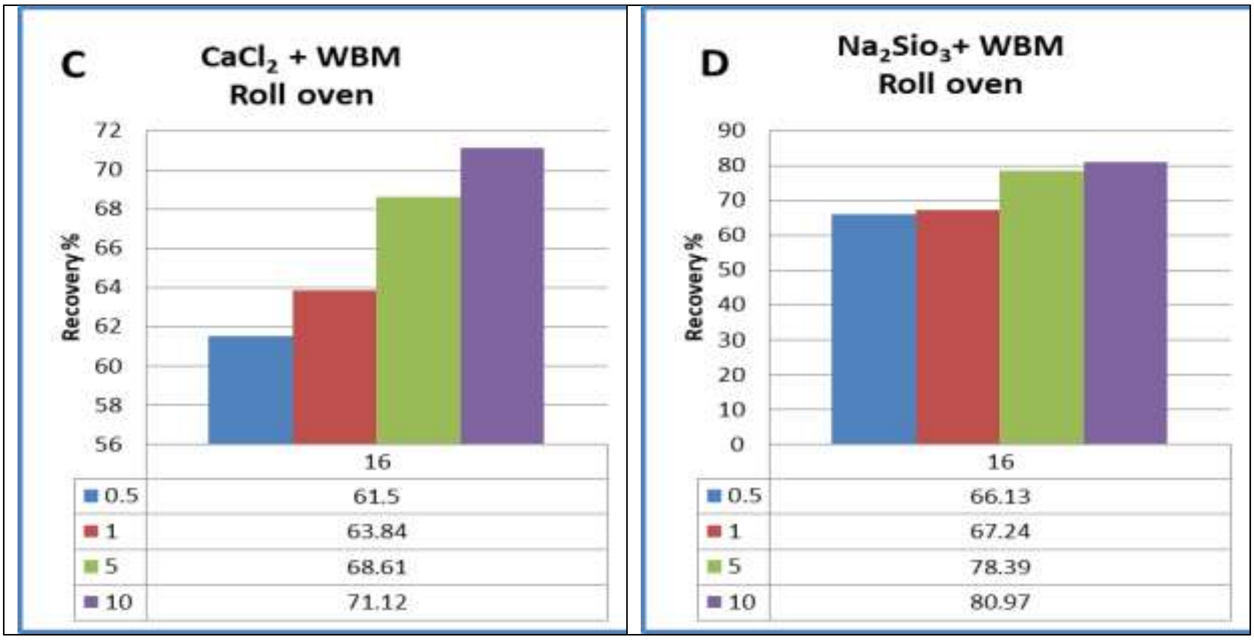
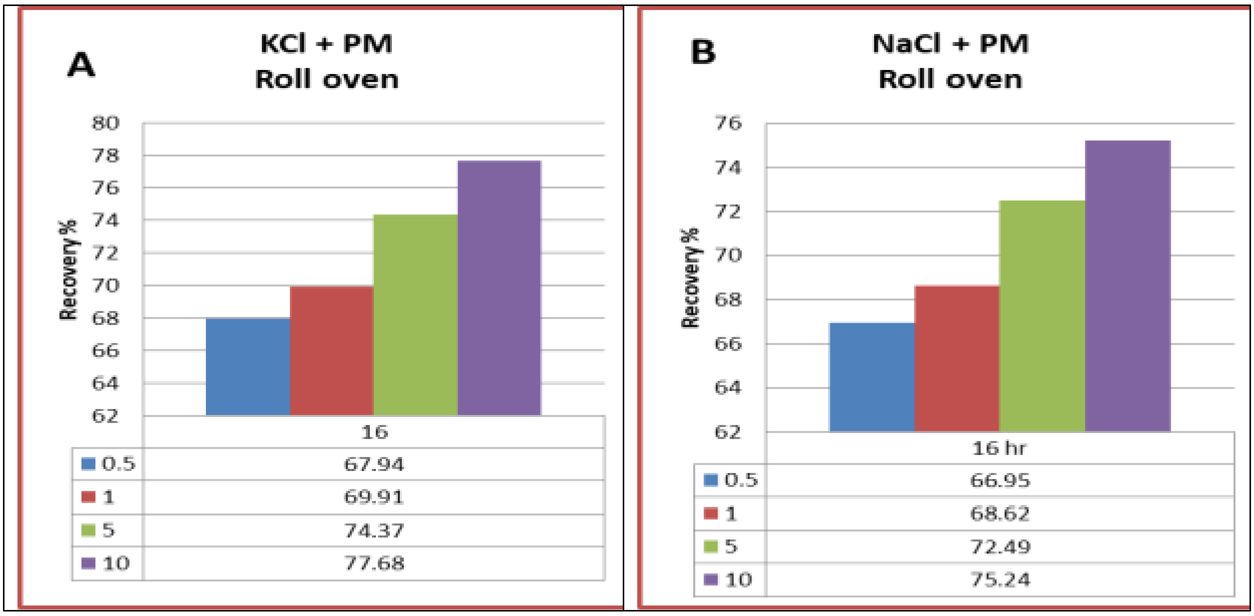
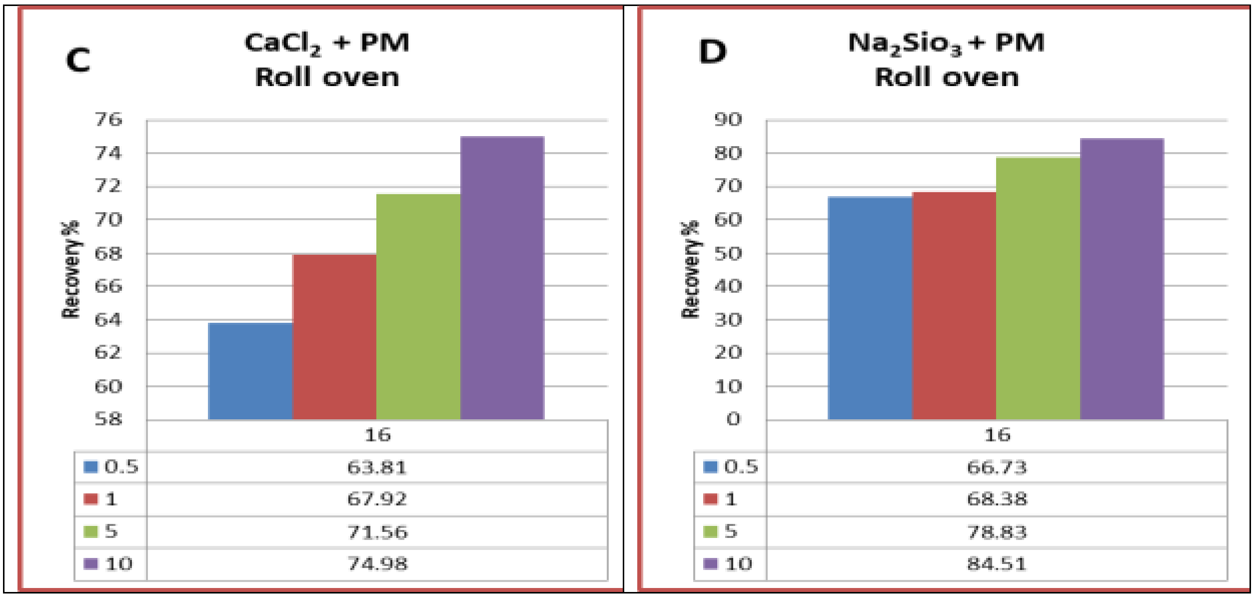


Table 5. Dispersion results of PM for Tanuma A: KCl, B: NaCl, C: $CaCl_2$, D: Na_2SiO_3

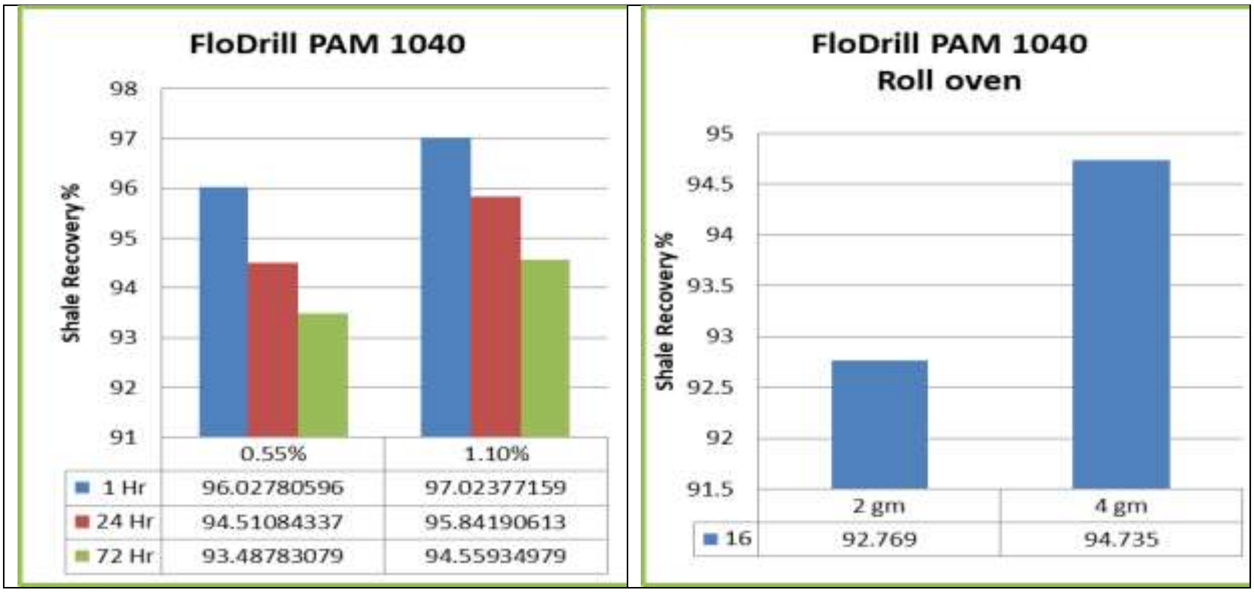




3.2 Fluid Improvement and Special Fluid Formulation

As defined previously, Flodrill PAM 1040 is a special additive used with polymer mud and tested with the Tanuma shale. **Table 6** shows the result of immersion and dispersion tests of Tanuma shale samples. Two concentrations were used 0.55 % and 1.10 % with polymer mud. The recovery percentage of 0.55 % Flodrill was reduced from 96.02 % after 1 hr to 93.48 % after 72 hr, and the recovery result of 1.1 % concentration was reduced from 97.02 % after 1 hr to 94.55 % after 72 hr. The recovery of the dispersion test at 0.55 % concentration was 92.769 % while 1.1 % concentration the recovery was 94.735%. Flodrill PAM 1040 represents a better inhibitor for Tanuma shale because the Flodrill has the ability to form gelatin that's will cover (coat) the shale and prevent the interaction with water.

Table 6. Immersion and dispersion results for Tanuma A: Immersion test, B: Dispersion test.



3.3 Native moisture content

Native moisture content (NMC) represents the total molecules of water inside samples of shale. It's well-known as the percentage of water mass founded in the samples to the total weight of the samples **(Adesoye, 2009)**. The result of NMC is 0.17 for the Tanuma shale sample. The tendency of Tanuma shale to moisture is very low due to the nature of kaolin mineral which has a low activity to the water. The quantity of moisture is considered as a function of various factors with the predominant clay minerals in shale. The content of moisture represents the quantity of clay minerals that has the ability to moisture tendency.

3.4 Cation Exchange Capacity

Clay minerals can adsorb certain cations and anions because of the cation exchangeable state. They are changing with other cations or anions due to interaction with such ions in a water solution. The result of CEC for Tanuma was 10.85 Meq/100 gm, and this result is located within the range of the kaolin group depending on **Table 7 (Adesoye, 2009).**

Table 7. Cation exchange capacity **(Adesoye, 2009)**.

Clay Mineral	CEC (Meq/100g)
Smectite (Montmorillonite)	80-150
Chlorites	10-40
Illites	10-40
Kaolinites	3-15

4. CONCLUSIONS

1. Sodium silicate resulted in a good recovery percentage for Tanuma shale at 5 and 10 % concentration because of the ability of sodium silicate to cover and block the shale samples and reduces the interaction of water with shale.
2. Flodrill PAM 1040 represents a better inhibitor for Tanuma shale due to the Flodrill which can form gelatin that covers (coats) the shale and prevents the interaction with water.
3. Results of the dispersion test after 16 hr were less than immersion test results after 24 hr because of the effect of temperature and dynamic motion.
4. The weakness of bonds between parts of molecules as a result of increasing molecule vibration leads to an increase in water movement into the shale structure.
5. Different additives could be added, such as nano-materials rather than the additives used in the present research to test the stability of shale.

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ABBREVIATIONS

W_{af} = weight after immersion
W_b = weight before immersion
MC = moisture content
W_w = weight of water removed by drying
W_s = Weight of shale samples before drying
CEC = Cation exchange capacity
MB = Methylene blue
NMC = Native moisture content
WBM = Water based mud

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