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The Performance of Iraqi Palygorskite in Salt Drilling Fluid

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Abstract— In drilling fluid program, selecting the drilling fluid that will reduce the lost time is the first objective, and will be economical regardless of its cost. The amount and type of solids in drilling fluid is the primary control of the rheological and filtration properties. Palygorskite clay (attapulgite) is an active solid that has ability to reactive with its environment and form a gel structure within a fluid and due to its stability in the presence of brines and electrolytes this type of clay is preferred for use. The aim of this study is to calculate the yield of clay for both types of local PAL in both fresh and salt water based mud. Determine the effect of aging time. Besides that, the effect of chloride sodium (NaCl) on rheological properties of drilling fluid by preparing salt water based drilling fluid with Bahr Al-Najaf PAL in three different procedures. The palygorskite claystone of Late Cretaceous age is present in the Western Desert within the Digma Formation. In this study, from two areas in Western Desert palygorskite were obtained, Bahr Al-Najaf and Trefawi. The results showed that, the clay yield of Bahr Al-Najaf PAL (49.54 bbl/ton), Trefawi PAL (57 bbl/ton), and commercial PAL (166.8 bbl/ton) in fresh water environment was higher than in salt water environment. As observed in this study, the clay yield of Bahr Al-Najaf PAL, Trefawi PAL, and commercial PAL in salt water environment were 37.9, 50.7, and 135.6 bbl/ ton respectively. Poor yield of clay was obtained with Trefawi PAL (Grinding) so it was not used to prepare samples in this study. This experimental investigation, 16 hours aging time after preparation drilling fluids was applied.

Keywords— palygorskite, salt water based drilling fluid, clay yield, aging time.

1.Introduction

Drilling fluid is one of an important factor to success rotary drilling operation which consists of liquids and different active solids, inert solids, and chemicals additives to enhance properties of drilling fluid. The principle functions of a drilling fluid are removing cuttings from beneath the bit and carry out from the bore hole, lubricate and cooling the bit, and maintain the stability of borehole by controlling the hydrostatic pressure to prevent blowouts and formation damage [4].

Clay type is classified to high, intermediate, and low yield drilling clay. Clay yield is defined as the number of barrels of 15 cP drilling fluid that can be obtained using ton of dry clay.

Palygorskite (PAL) is one of the most important gel forming clays where it gives stable suspensions of high viscosity at relatively low concentrations compared to other clays. Palygorskite suspensions are thixotropic and non-Newtonian at all concentrations. During dispersion the bundles of palygorskite needle-shaped crystals disassociated to form a random lattice that can traps liquid to increase the viscosity of the system [9]. In other words, the particles are cross-linked and water (liquid) is trapped [11].

The palygorskite claystone of Late Cretaceous age is present in the Western Desert within the Digma Formation. Palygorskite claystones is originally black shales, rich in the carbonaceous matter and was oxidized to yellow and green claystone in surface and near-surface sections [13].

"Al-Baidari in [2]", studied the effect of aging time, chemicals, polymers on rheological properties of that was prepared with Iraqi claystones from Injana formation/ Najaf-Karbala region and showed that when added Iraqi bentonite to palygorskite reach to viscosity at API specification. Eliminate Zeolitic water from channels of structure of palygorskite and part of coordinate water through temperature activation which lead to significant changes in the crystalline structure and increase specific surface area of the clay to some extent, and then to the enhancement of the adsorption properties [6-8]. Palygorskite nanoparticles is added to montmorillonite in order to improve the stability of drilling fluid and get on stable rheology properties, density, filtration properties, and lubricity index at HPHT environment [1]. Aging time has important effect on rheological behavior, where opposite to bentonite drilling fluids, hydration ability of sepiolite drilling fluids increased with increasing aging time, and the aging effect on hydration ability was higher when the salt concentration increased. Minimum 16 hours of aging time should be provided for sepiolite drilling fluids to get satisfactory hydration, and more aging time was required as the salinity increased [3].

In this study is an attempt to illustrate the effect of aging time and to investigate the effect of salt on rheological properties of water based drilling fluid prepared with two type of dispersed phase (palygorskite) were obtained., Bahr Al-Najaf in Al-Najaf governorate and Trefawi in Al-Anbar governorate. Besides that, compute the clay yields of PAL in both fresh and salt mud and compare with clay yield of commercial PAL.

2. Experimental Work

2.1 *Materials*

The materials that have been used in this study to prepare different samples of water based drilling fluids are:

2.1.1 *Palygorskite*

Two types of local Palygorskite (PAL) were used that have been supplied by Iraq Geological Survey (GEOSURV- IRAQ) from Bahr Al-Najaf in Al-Najaf governorate and the second from Trefawi quarry in Al-Anbar governorate. These two types were compared with commercial Palygorskite which was supplied from Basrah Oil Company (BOC).

2.1.2 *Sodium Chloride NaCl*

It used as produced or as prepared brine in completion and workover operations to saturate water before drilling rock salt. The limited range of it was from 10-25 g/350cc.

2.2 *Experiments*

2.2.1 Clay Yield

The five concentration of each type of PAL were used to formulate fresh water based drilling fluid and salt water based drilling fluid in order to determine their clay yield as illustrated in Table 1. As shown in Table 1, comparison was made between Trefawi PAL (grinding and wet processing), Bahr Al-Najaf (wet processing), and commercial PAL. Semi- saturated salt water was prepared by adding 80.25 g Nacl/ 450cc water which is half saturated salt water (125 g NaCl/ 350 cc water) [10]. The concentrations is selected based on percent solid that's not exceed 12% [10].

Table 1: Clay yield of different types of Palygorskite

Weight , g				Water Volume, cc	
Bahr Al-Najaf PAL (Wet processing)	Trefawi PAL (Grinding)	Trefawi PAL (Wet processing)	Commercial PAL	Fresh water	Semi-Saturated Salt Water ★
25.71	25.71	25.71	10	450	450+80.25 g NaCl
35	35	35	20	450	450+80.25 g NaCl
45	45	45	25.71	450	450+80.25 g NaCl
55	55	55	35	450	450+80.25 g NaCl
65	65	65	40	450	450+80.25 g NaCl

★First procedure of preparing salt water based drilling fluid was applied.

2.2.2 *Salt water based drilling fluid*

Three different procedures were tried in salt water based drilling fluid preparation to verify the correct one which gives good dispersion of PAL. It is recommended that minimum of 16 hours of aging should be applied to get better rheological values [3].

***First Procedure**

The steps of this procedure are described below:

1. Part one: add the required quantity of PAL to two thirds of the required distilled water and mix for 20 minutes. Then the mixture is aged for 16 hours to get better rheological values.

2. Part two: add the required quantity of rock salt (NaCl) to one third of the required distilled water and mix it for 5 minutes.

3. Mix above (two parts) for 20 minutes to ensure good salt water based drilling fluid is formed. After that the salt water based drilling fluid is ready to be tested.

- ***This procedure was based for preparing salt drilling fluid for good results obtained.***

Second Procedure

This procedure was prepared as illustrated below:

1. Add the required quantity of rock salt (NaCl) to the distilled water as required and mix for 5 minutes.

2. Add the required quantity of PAL to the salt water solution (above) and mix for 20 minutes to ensure good salt water based drilling fluid is formed.

3. The mixture is aged for 16 hours to get better rheological values. After that the salt water based drilling fluid is ready to be tested.

***Third Procedure**

Salt water based drilling fluid was prepared according to the following steps:

1. Add the required quantity of PAL to the required distilled water and mix for 20 minutes. Then the mixture is aged for 16 hours to get better rheological values.

2. Add the required quantity of rock salt (NaCl) to the above drilling fluid (PAL and distilled water) and mix for 20 minutes to ensure good drilling fluid is formed and ready to be tested.

Note: Hamilton Beach Mixer is used to prepare drilling fluid and mixed for 20 min.

The rheological properties of each sample were analyzed by using Viscometer (Model 900), the apparent viscosity (AV), plastic viscosity (PV), gel strength were measured.

Each experiment was repeated three times to obtain on accuracy results.

3. Results and discussion

3.1 *Clay Yield*

The data that were used to determine clay yield of Palygorskite of Bahr Al-Najaf (PAL1), Trefawi wet processin and grinding (PAL2 and PAL3) respectively, and commercial PAL (PAL4) are illustrated in **Table 2** and **Table 3** and shown in **Figure. 1** to **Figure. 3**

Table 2: Data of clay yield for all PAL types in fresh water

PAL1		PAL2		PAL3		PAL4	
wt. %	AV, cP	wt. %	AV, cP	wt. %	AV, cP	wt. %	AV, cP
5.4	3.95	5.4	5.37	5.4	3.12	2.17	7.0
7.2	6.35	7.2	11.42	7.2	5.0	4.26	20.5
9.1	8.5	9.1	13.79	9.1	8.25	5.4	33.0
10.9	14.5	10.9	18.59	10.9	12.67	7.22	63.5
12.6	19.45	12.6	23.4	12.6	18.34	8.16	86.0

Table 3: Data of clay yield for all PAL types in salt water

PAL1		PAL2		PAL3		PAL4	
wt. %	AV, cP	wt. %	AV, cP	wt. %	AV, cP	wt. %	AV, cP
8.19	8	6.49	8.25	4.33	3.25	2.89	9.25
10	12.65	8.69	12.34	5.62	4.0	4.85	22.5
11.42	13.5	9.84	16.5	9.03	5.5	6.49	42.67
12.95	15.67	12.19	23.5	10.64	7.75	7.35	55.5
……	……	……	……	12.19	12.0	……	……
……	……	……	……	13.69	17	……	……

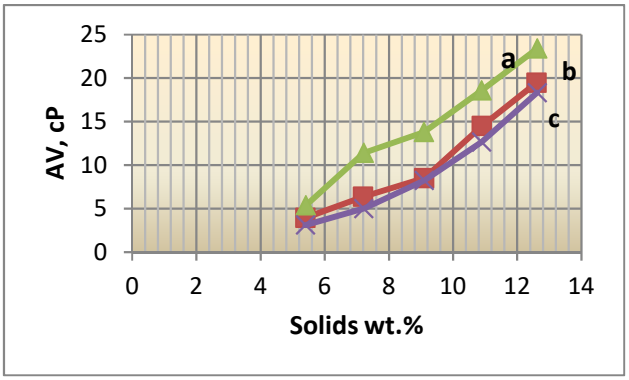

Figure 1: Yield of clay in fresh water for a-Trefawi PAL (PAL2) b-Bahr Al-Najaf PAL (PAL1) c-Trefawi (PAL3)

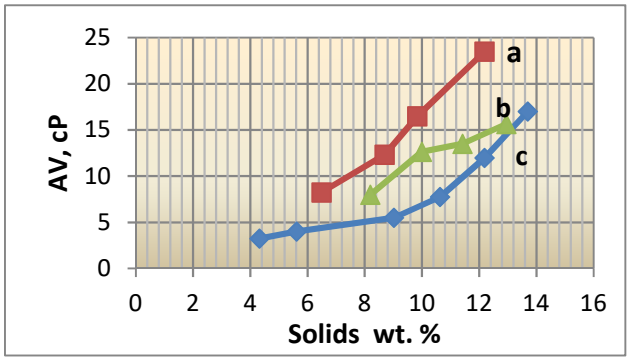

Figure 2: Yield of clay in salt water for a-Trefawi PAL (PAL2) b-Bahr Al-Najaf PAL (PAL1) c-Trefawi (PAL3)

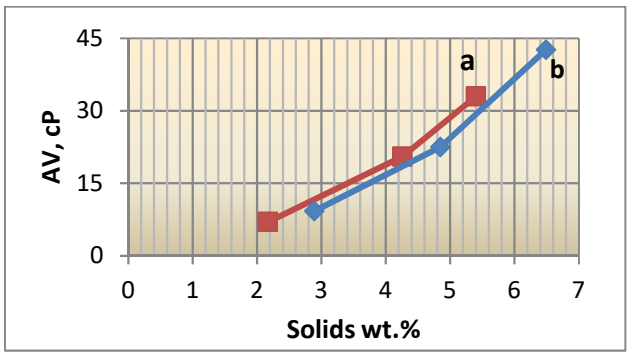

Figure 3: Yield of clay for commercial PAL (PAL4) in a- fresh water b- salt water

Table 4: Values of clay yield for different types of PAL

Type of Based Mud	Type of PAL	Value of Clay Yield	Clay Quality
	Commercial PAL (PAL4)	166.89	Good
Fresh Water Based Mud	Bahr Al-Najaf PAL (PAL1)	49.54	Poor
	Trefawi PAL(PAL2)	57	Poor
	Trefawi PAL (PAL3)	47.1	Poor
Salt Water Based Mud	Commercial PAL (PAL4)	135.68	Good
	Bahr Al-Najaf PAL (PAL1)	37.9	Poor
	Trefawi PAL (PAL2)	50.72	Poor
	Trefawi PAL (PAL3)	36.82	Poor

The procedure of clay yield value determination of different PAL types, the equations, and their derivation are presented in Appendix.

There are three categories of drilling clay that determine its quality, high, moderate, and low. According to API specifications [12], the yield of Palygorskite is 100-115 bbl/ton. So the qualities of Palygorskite types in this study are poor in fresh and salt water as shown in Table4.

Unlike the swelling clay minerals such as montmorillonite (MMT), palygorskite as a fibrous non swelling clay mineral, the fiber length and number of silanol (SiH4O) groups on the surface of the fiber play an important role in aggregating fiber together and forming a random network that entraps water and increases viscosity. Palygorskite particles could be considered as charged particles with zones of + and - charges. It was the bonding of these alternating charges that allowed them to form gel suspensions in salt and fresh water [15]. As shown in Figure.1 to Figure.3, the percent solids by weight of PAL1, PAL2, PAL3, and PAL4 in fresh water based drilling that have an apparent viscosity of 15 cP are 11.0%, 9.6%, 11.5% and 3.4% respectively. While in salt water drilling fluid, the percent solid by weight of PAL1, PAL2, PAL3, and PAL4 are 12.70 %, 9.60%, 13.0% and 3.7% respectively. The percent solids by weight of Trefawi PAL (PAL2) are lower than Trefawi PAL (PAL3) due to the processing method effect. Where, grinding is not suitable for the disaggregation of palygorskite (PAL) crystal bundles because it breaks the rod crystals, reduce the length of rods, and damage the crystal structure of palygorskite (PAL) [14]. Also grinding method does not remove the impurities and compounds that adversely effect on PAL performance in drilling fluid.

Clay yield of PAL2 is higher than PAL1 due to the high percent of K2O in PAL1 as shown in XRF test, Where

K+ reduces the negative charges of PAL and thus reduces the attractive forces between PAL particles in the drilling fluid and reduces apparent viscosity [2].

3.2 *Effect of Aging Time*

The effect of aging time on drilling fluids prepared with Palygorskite (PAL1 and PAL2) properties is shown in **Table 5** and **Table 6**. In general, aging time refers to the period of time when the prepared drilling fluids aged in order to allow the colloids time to hydrate and any chemical reactions to proceed to completion [5]. It is recommended that 16 hours of aging should be applied to get better rheological and filtration properties [15]. This study is applied on local palygorskite but the study in source three that's mentioned in references was done on sepiolite and get on approximately the same result whichs explained the aging period of muds has significant effect on rheological properties and slightly effect on water loss properties. Even though aging effect is not recognized by API standard for clay sepiolite, it is recommended that minimum of 16 hours of aging should be applied to get better rheological values.

Table 5: Effect of aging time on the apparent viscosity of Bahr Al-Najaf Palygorskite (PAL1) drilling fluids

AV, cP					
Fresh Water			Salt Water		
10 min	16 hrs	48 hrs	10 min	16 hrs	48 hrs
11.0	15.17	15.25	9.33	12.65	12.65

Table 6: Effect of aging time on the apparent viscosity of Trefawi Palygorskite (PAL2) drilling fluids

AV, cP					
Fresh Water			Salt Water		
10 min	16 hrs	48 hrs	10 min	16 hrs	48 hrs
10.0	15.34	15. 5	9.25	12.34	12.36

As shown in **Table 5** and **Table 6**, aging time has significant effect up to 16 hours, where apparent viscosity increases with increasing aging period. The apparent viscosity value did not affect after 16 hours aging time. So in this experimental investigation, 16 hours aging time after preparation drilling fluids was applied.

3.3 *Rock Salt (NaCl)*

Bahr Al-Najaf PAL (PAL1) with11.0 wt. % (56 g/ 450cc distilled water) was used to investigate the effect of salt on the rheological properties, density, and pH value. Three different procedures were applied to prepare salt water based drilling fluid with PAL are illustrated in **Table 7** and shown in **Figure 4**

As shown in **Figure 4**, the first procedure is the best choice to prepare salt water based drilling fluid with PAL due to the better results compared with other two procedures. The lower rheological properties in the second procedure are due to forming foam during preparation of this sample. The rheological properties of sample three (third procedure) is close to sample one.

The PAL drilling fluid prepared with fresh water has high rheological properties with respect to PAL salt water drilling fluid due to the composition of Bahr Al-Najaf PAL, as shown in Appendix A. Bahr Al-Najaf PAL has more montmorillonite (MMT) than Palygorskite and kaolinite. So, adding salt caused a decrease in rheological properties due to the aggregation of clay particles. Palygorskite particles could be considered as charged particles with zones of + and - charges. It was the bonding of these alternating charges that allowed them to *form gel suspensions in salt and fresh water* [15]. Unlike bentonite, Palygorskite would be formed gel structures in salt water and was used in brine drilling fluids while drilling formations contaminated with salt [5], but in this study revealed the opposite as shown in **Figure 4**.

The value of pH in all methods preparation is low. When NaCl (a neutral salt formed by the combination of a strong acid and a strong base) is dissolved in water, the solution remains neutral [10]. So, caustic soda (NaOH) and soda ash (Na_2CO_3) which is strong and weak base respectively can be added to enhance pH value to increase the ability of PAL dispersion in drilling fluid.

Table 7: Rheological Properties for different samples Bahr Al-Najaf PAL

Drilling Fluid	AV, (cP)	PV, (cP)	YP, (lb/ 100ft²)	YP/PV, (lb/100 ft²/cP)	pH	ρ, (lb/gal)	Gel Strength (lb/100 ft²)	
							10 sec	10 min
Reference (F.W+56g PAL) Sample 1	15.17	4.33	21.67	5	7.5	8.5	17.5	18.5
Sample 2 *	12.65	5	15.3	3.1	6.6	9.5	9	11
Sample 3 *	8.4	3.5	9.83	2.81	6.6	9.5	5	6
Sample 4 *	11.5	4.67	13.66	2.93	6.6	9.5	8	9.5

* Sample 2,3 and 4 were prepared by procedures one, two, and three respectively as discussed in section 2.2.2

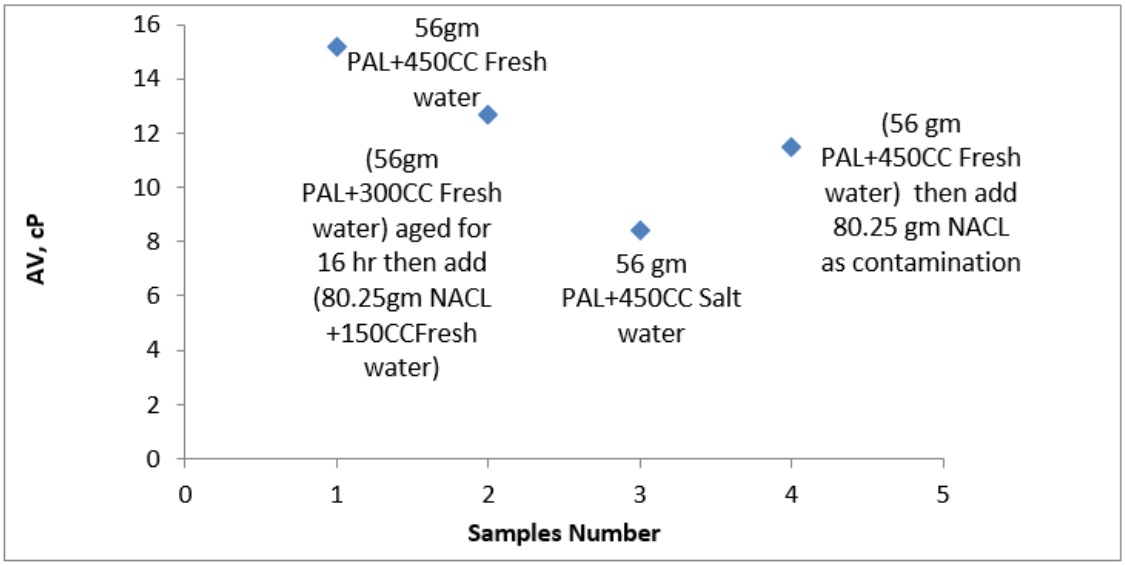

Figure 4: Apparent viscosity versus different drilling fluids with Bahr-Al-Najaf PAL

4. Conclusions

- The percent solids by weight of Bahr Al-Najaf palygorskite, Trefawi palygorskite (wet processing), Trefawi palygorskite (grinding processing), and commercial Palygorskite in fresh water based drilling that have an apparent viscosity of 15 cP are 11.0%, 9.6%, 11.5% and 3.4% respectively. While in salt water drilling fluid, the percent solid by weight of Bahr Al-Najaf palygorskite, Trefawi palygorskite (wet processing), Trefawi palygorskite (grinding processing), and commercial Palygorskite are 12.70 %, 9.60%, 13.0% and 3.7% respectively. So the yield of Trefawi palygorskite (wet processing) is higher than Bahr Al-Najaf palygorskite in both fresh and salt water.
- The yield of Trefawi palygorskite (wet processing) is greater than Trefawi palygorskite (grinding) due to the processing method effect. Where, grinding is not suitable for the disaggregation of palygorskite crystal bundles because it breaks the rod crystals, reduce the length of rods, and damage the crystal structure of palygorskite. Also, it does not remove the impurities and compounds that adversely effect on palygorskite performance in drilling fluid.
- Sixteen hours of aging should be applied to get better rheological and filtration properties.

Where the prepared drilling fluids aged in order to allow the colloids time to hydrate and any chemical reactions to proceed to completion.

Appendix A

The derivation of clay yield (bbl/ton) of any clay in drilling fluid is illustrated as below:

The general equation of clay yield is

$$Y = \frac{2000}{x}\left\{\frac{x}{\rho_{solids}\times 42} + \frac{100-x}{\rho_{water}\times 42}\right\} \qquad A-1$$

where, Y is the clay yield (bbl/ton), x is the solids weight percent of clay to obtain 15 cP, $\rho_{solids}$and $\rho_{water}$are the densities of solids and water respectively (lb_m/gal), and 42 is the conversion factor (1 bbl=42 gal).

- Drilling fluid prepared with Bahr Al-Najaf PAL and fresh water:

The density of distilled water = 0.99 g/cc (0.99 SG)

The density of Bahr al-Najaf PAL = 2.03 g/cc (2.03 SG)
So the clay yield equation becomes:

$$Y = \frac{2000}{x}\left\{\frac{x}{2.03\times 8.33\times 42} + \frac{100-x}{0.99\times 8.33\times 42}\right\} \qquad A-2$$

$$Y = \frac{577.432}{x} - 2.958 \qquad A-3$$

- Drilling fluid prepared with Bahr Al-Najaf PAL and salt water:

The density of salt water = 1.12 g/cc (1.12 SG)

The density of Bahr al-Najaf PAL = 2.03 g/cc (2.03 SG)

So the clay yield equation becomes

$$Y = \frac{2000}{x}\left\{\frac{x}{2.03\times 8.33\times 42} + \frac{100-x}{1.12\times 8.33\times 42}\right\} \qquad A-4$$

$$Y = \frac{510.408}{x} - 2.288 \qquad A-5$$

- Drilling fluid prepared with Trefawi PAL and fresh water:

The density of distilled water = 0.99 g/cc (0.99 SG)

The density of Trefawi PAL = 2.15 g/cc (2.15 SG)

So the clay yield equation becomes:

$$Y = \frac{2000}{x}\left\{\frac{x}{2.15\times 8.33\times 42} + \frac{100-x}{0.99\times 8.33\times 42}\right\} \qquad A-6$$

$$Y = \frac{577.432}{x} - 3.115 \qquad A-7$$

- Drilling fluid prepared with Trefawi PAL and salt water:

The density of salt water = 1.12 g/cc (1.12 SG)

The density of Trefawi PAL = 2.15 g/cc (2.15 SG)

So the clay yield equation becomes:

$$Y = \frac{2000}{x}\left\{\frac{x}{2.15\times 8.33\times 42} + \frac{100-x}{1.12\times 8.33\times 42}\right\} \qquad A-8$$

$$Y = \frac{510.408}{x} - 2.445 \qquad A-9$$

- Drilling fluid prepared with Commercial PAL and fresh water

The density of distilled water = 0.99 g/cc (0.99 SG)

The density of Commercial PAL = 2.02 g/cc (2.03 SG)

So the clay yield equation becomes:

$$Y = \frac{2000}{x}\left\{\frac{x}{2.02\times 8.33\times 42} + \frac{100-x}{0.99\times 8.33\times 42}\right\} \qquad A-10$$

$$Y = \frac{577.434}{x} - 2.944 \qquad A-11$$

- Drilling fluid prepared with Commercial PAL and salt water

The density of distilled water = 1.12 g/cc (1.12 SG)

The density of Commercial PAL = 2.02 g/cc (2.03 SG)

So the clay yield equation becomes:

$$Y = \frac{2000}{x}\left\{\frac{x}{2.02\times 8.33\times 42} + \frac{100-x}{1.12\times 8.33\times 42}\right\} \qquad A-12$$

$$Y = \frac{510.41}{x} - 2.27 \qquad A-13$$

Nomenclature

Symbol	Description	Unit
ρ	Density	lb/gal

Abbreviations

API	American Petroleum Institute
AV	Apparent Viscosity
PAL	Palygorskite
PV	Plastic Viscosity
YP	Yield Point

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أدائية البالكورسكايت العراقي في سوائل حفر الملحية

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الخلاصة – اختيار مائع الحفر الذي يقلل من الوقت الضائع في عمليات الحفر، هو الهدف الاول في تصميم برنامج مائع الحفر. كمية ونوع المواد الصلبة في مائع الحفر هي السيطرة الاولية للخواص الريولوجية والترشيح. تعتبر أطيان البالكورسكايت من المواد الصلبة الفعالة والتي لها القابلية على التفاعل مع المحيط وتكون تركيب هلامي داخل المائع ونتيجة الى استقطابها بوجود الاملاح يفضل استخدام هذا النوع من الاطيان. الهدف من هذه الدراسة، تحديد دليل الانتاجية لكلا النوعين من البالكورسكايت المحلي في كلا من الماء العذب والمالح. تحديد تاثير عامل الزمن. بالاضافة الى ذلك، تاثير ملح كلوريد الصوديوم على الخواص الريولوجية للسائل الحفر عن طريق تحضير سائل حفر ملحي باستخدام بالكورسكايت/بحر النجف بثلاث طرق مختلفة. البالكورسكايت يعد من العصر الطباشيري المتاخر موجود في الصحراء الغربية داخل تكوين دكما. في هذا الدراسة، يتم استخدام البالكورسكايت العراقي المتواجد في بحر النجف وطريفاوي في الصحراء الغربية في العراق. واضح من النتائج بانه دليل الانتاجية للبالكورسكايت/بحر النجف 49.54برميل/طن، البالكورسكايت /طريفاوي 57برميل/طن وبالكورسكايت التجاري 150برميل/طن في بيئة مائية عذبة اعلى مما عليه في بيئة مائية مالحة. كما لاحظ في هذا العمل، بانه دليل الانتاجية للبالكورسكايت/ بحر النجف، الطريفاوي، والتجاري يساوي (37.9، 50.7، 120) برميل/طن بالتتالي. استكشف من تجريه عامل الوقت بانه 16 ساعة هو الذي يعتمد بعد تحضير سائل الحفر.

الكلمات الرئيسية – البالكورسكايت، سائل حفر ذات اساس مائي ملحي، دليل الانتاجية و تاثير عامل الزمن.