Egyptian Geophysical Society
EGS Journal, Vol. 21, No. 1, 65-74 (2023)

MITIGATION OF FORMATION DAMAGE CAUSED BY MUD SOLIDS USING NANO MATERIALS IN ABO ROASH "C" SANDSTONE, BADR EL-DIN FIELD- NORTHERN WESTERN DESERT, EGYPT

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التخفيف لاضرار اللاحقة بطبقة الخزان والتي تسببها المواد الصلبة الطينية باستخدام مواد النانو في الحجر الرملي أبو روش " سي" ,حقل بدر الدين – شمال الصحراء الغربية , مصر

الخلاصة: لوحظ انخفاض إنتاجية الآبار على نطاق واسع في الصحراء الغربية بمصر بالنسبة لآبار النفط والغاز . تم تفسير هذه الظاهرة من خلال الرفع والهجرة والانسداد اللاحق للمسام بواسطة الجزيئات الدقيقة ، مما أدى في النهاية إلى انخفاض النفاذية. وقد لوحظ في العديد من اختبارات الفيضانات الأساسية والحالات الميدانية.

تناول هذا البحث الشامل موضوع تلف التكوين بسوائل الحفر. ويناقش تأثير الضرر على إنتاجية البئر،والآليات الرئيسية لتلف الخزان بواسطة سوائل الحفر،وتقييم واختبار الضرر، وتحديد الاعتبارات لاختيار الطين وتحسينه، وإزالة أضرار الطفله.

سيستمرالعمل الجاري في شركات النفط وشركات الخدمات والمؤسسات الأكاديمية في تحسين معرفتنا ، والتي بدورها ستزيد من الكفاءة التي ننتج بها النفط والغاز.

تم استخدام اختبارات الفيضانات المخبرية الأساسية لتحديد أسباب الضرر ودرجته ومدى حدوثه. تم استخدام الفحص المجهري الإلكتروني (SEM) لتحليل عينات الصخور المستخدمة في اختبار الفيضان الأساسي قبل الاختبار وبعده. تم إجراء اختبار الفيضان الأساسي لتقييم تأثير حمض الطفله على عينه الطبقه التالفة. تم تقييم تحفيز الطفله علي عينه الصخور في دراسة حالة من المجال المدروس. في هذا البحث ، سيقترح الباحث بعض الحلول الفريدة للتخفيف من أضرار التكوين باستخدام مواد النانو مع التركيز بشكل خاص على تلف طبقه الخزان الناجم عن سائل الحفر الذي يؤدي إلى مشكلة انسداس مسام الطبقه.

ABSTRACT: *Well productivity decline have been widely observed in Western Desert, Egypt for oil and gas wells producing the reservoir fines. The phenomenon has been explained by the lifting, migration and subsequent plugging of the pores by the fine particles, finally resulting in permeability decrease. It has been observed in numerous core flood tests and field cases.*

This extensive work deals with the subject of formation damage by drilling fluids. It discusses the impact of damage on well productivity, the major mechanisms of formation damage by drilling fluids, assessment and testing of damage, outline considerations for mud selection and optimization, and removal of mud damage.

Work in progress in oil companies, service companies and academic institutions will continue to improve our knowledge, which in turn will increase the efficiency with which we produce oil and gas.

Laboratory core flood tests had been used to determine the causes, degree, and extent of damage. Scanning electron microscopy (SEM) was used to analyze the rock samples used for the core flood test before and after the test. Core flood test had been done to evaluate the effect of acid on damaged cores. Matrix acid stimulation on a case study from the studied field was evaluated. In this work, the authors will suggest some unique solutions to mitigate formation damage using Nano-materials with especial emphasis on formation damage caused by drilling fluid which lead to clay swilling problem.

1. INTRODUCTION

We formation damage as the purposes of this work is define any process that impairs the permeability of reservoir formations such that hydrocarbon production (in production wells) or infectivity (in injector wells) is reduced. While formation damage can occur at all stages of well construction, during remedial treatments and during production, this work is concerned with damage caused by drilling fluids and other reasons.

A traditional philosophy has been to worry less about formation damage by drilling fluids because stimulation treatments could generally be employed to recover lost productivity. There is now a growing awareness that prevention of damage is better than cure. If muds are designed and used properly, the need for stimulation can be reduced and often removed. An increasing number of wells are completed without casing and perforation, using instead gravel packs, pre-packed screens and slotted liners. In these completions, near-wellbore damage by drilling fluids is not by passed by perforation tunnels. Hence avoidance of shallow mud-induced damage becomes a major issue in non-Perforated wells. These considerations explain the increased importance given to the understanding and control of formation damage. Of the preventable forms of damage, that caused by drilling fluids is generally seen as a major issue. This work will discuss the impact of mud damage on well productivity, the mechanisms by which drilling muds can cause damage and methods of formulating low formation damage (Abdo and Haneef, 2013).

Badr El-Din wells started producing with high productivity indexes and low skin values; initial measured productivity indexes for Bed 15-1 & Bed 15-4A is about 2 bpd/psi. The wells started producing with oil rates from 1500-3000 bopd, after 2-4 years the oil rates had dropped to 250-500 bopd. This early rate decline is largely related to the pressure depletion by +/- 3000 psi (Amanullah and Al-Tahini, 2009).

During the history match process of Bed 15 AR/C models it was found that Bed 15-1 (after put-back on production in 1997) and Bed 15-4A (after 1999) had to be given a high skin to match the production behaviour under the measured tubing head pressure (Fig.1).

The skin describes any anomaly around the bore hole that causes a distortion of the fluid inflow. A positive skin value is used if this deviation from normal flow behaviour around the well causes an additional pressure drop (Aftab et el., 2016).

The range of skin applied was 20 –50 for Bed 15-1, and 70-100 for Bed 15-4A (ranges depend on whether the low or base case subsurface model was used). A skin of this range means a significant reduction in well productivity and may indicate severe well damage. Therefore, further investigations will be carried out to clarify the cause of this high skin. We will be selecting for a Badr El –Din field was selected to complete studying of formation damage caused by mud and productivity loss problem through this work (Aramendiz and Imqam, 2019).

The aim of the study is mitigate formation damage by mud solids and the impact of drilling fluid inside the Abu Roach "C " Member sandstone and Improve of drilling fluids characteristics using Nano-Technology.

Expected outcomes nano-materials could be the solution of fine migration problem and the recommended treatment for fines is a combination of Nanomaterials with acidizing to dissolve fines, enlarge pore-throat size to diminish near wellbore particle bridging and consolidation of the formation to lock in place those fines that are not removed by the treatment and prevent future fines re-invasion. Also trial in made with polarity techniques.

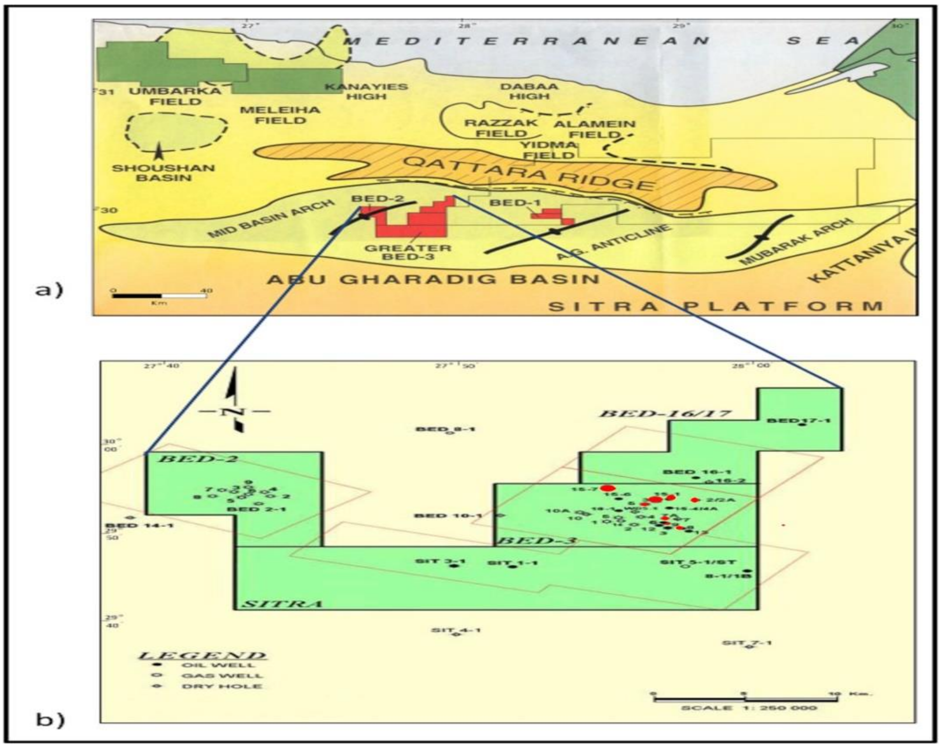

Fig. 1: Location map of study area (After Bapetco, 2004).

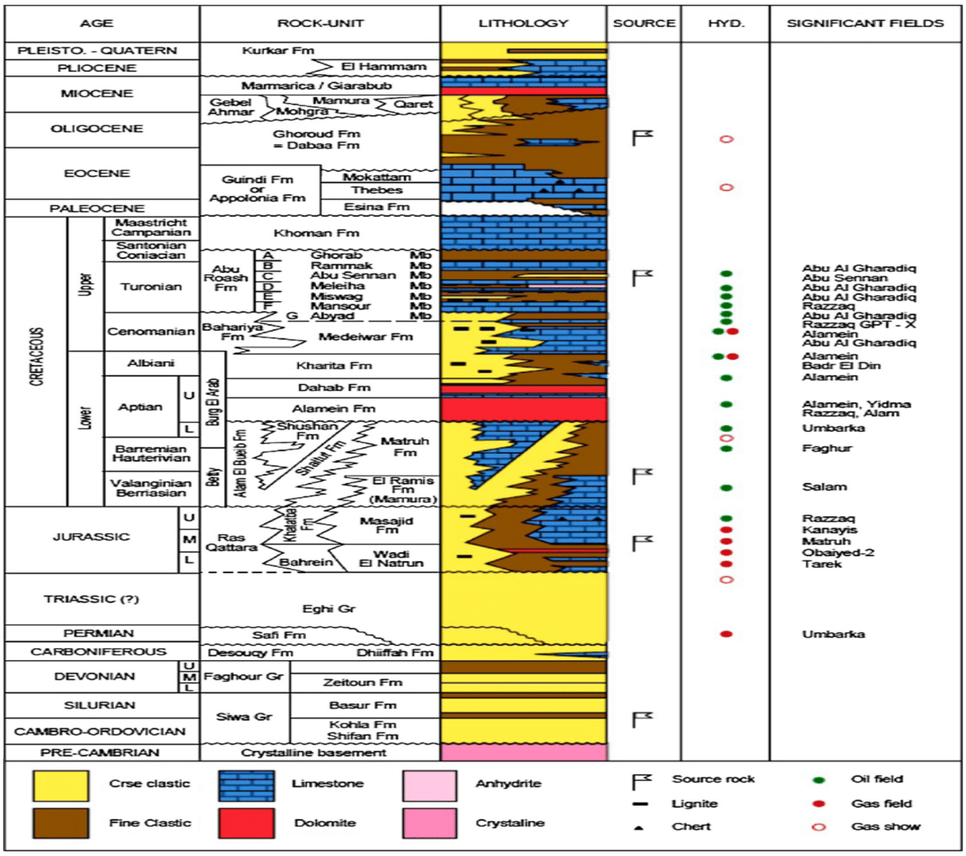

Fig. 2: Generalized litho-stratigraphic column of the western desert (Schlumberger, 1995).

Methodology

The experimental work was run in several locations as: The British University in Cairo, Corex and FMI labs, Egyptian Drilling Fluid Drilling Fluid Company and Egyptian Petroleum Research Institute according to the proposed plane as follow:

1- Core Sample preparation with Corex Company and Data log companies During this study, we will be used for core samples (for Abu Roach C member) and available facilities and applying for reservoir conditions about it. (1.5 inch)

2- Prepare Drilling fluid sample at EMEC drilling fluid company at Alexandria branch to measure mud Rheology and drilling fluid properties.

3- Nano material preparation at EPRI LABS.

4- Core flood with drilling fluid (using Formation damage rig at Corex and Datalog companies. The core sample (prepared), was loaded into a core holder to reservoir conditions.

a- A base specific permeability measurement to humidified nitrogen gas will be undertaken in the formation to wellbore direction at a low flow rate to avoid fines migration,

b- Under reservoir conditions, the humidified nitrogen gas was flowed into the core sample, in the formation to wellbore direction at 5 different flow rates. During each separate flow rate effluent was collected and the weight of eluted material measured,

c- Once adequate pore volumes of humidified nitrogen gas was allowed to flow at each different rate, a specific permeability to humidified nitrogen gas will undertake at the same flow rate as used to determine the base specific permeability alteration, and

d- On offloading the core sample, photography and visual observations was made.

5- Adding nanofuid to the drilling fluid then run the tests again to observe the effect of nanomaterials on formation damage discussing the results and study the effect of nanomaterials on formation damage.

Experimental work:

1. Core sample preparation:

The materials used in the experiment were core samples from a sandstone reservoir (Fig.3) obtained from a well producing in the Western Desert (Abu Roach C).

Core plugging was done to the sample rock using the plugging machine in Datalog Lab.

Fig. 3: Core sample for Abu Roach (C) Member.

Cores sample were cut off from the sample rock where four core plates samples sandstone formation had average diameter 38.10 mm, lengths ranging from 28.30 to 38.12 mm. The heavy diamond-tooled drill press is specially designed to deliver various core sample sizes. **(Kazemi and Hajiabadi, 2018).**

The standard machine comes with a floor standing drill press, a rotary union, a coolant feeding system, a coolant recovery pan with splash guard and a core clamping vise.

The heavy duty fluid swivel connects the coring bits to the drill press while circulating coolant to the bit. The vise assembly is mounted on the pan table and allows the core sample to be positioned. Various sizes of coring bits as well as a recirculating coolant system are available.

2. **Measuring the following parameter porosity, permeability and oil saturation**

1. Helium Porosimeter the Helium gas expansion Porosimeter enables the determination of a sample's (1" or 1.5" diameter) grain and pore volume via an isothermal helium expansion and the application of Boyle's law and Charles' law. Subsequently, porosity and grain density can be calculated. A data acquisition system performs calibration, data logging and parameter calculation. Optionally, a full diameter matrix cup can be provided for porosity studies on whole diameter core samples. Each sample matrix cup is interchangeable and is supplied with stainless steel calibration check plugs. Pore volume can be measured by placing the core sample in an optional Hassler type core holder, connected to the Porosimeter. Then, the core samples were put into the oven to be dried and it was heated at 64˚C as above this temperature the clays in the samples might break down affecting porosity (Ragaband and Noah, 2014).

2. Measurement of the Permeability The second stage is the measurement of the permeability of the sandstone core after the passing of the blank mud fluid. The permeability has already been at the Datalog Core Laboratory.

By reducing the viscosity of the mud fluid through not entering the amount of EMEC CARB XF, and indeed, the viscosity has decreased very close to the viscosity of the water, and this is inconsistent with the reality of the original mud fluid used in the drilling, so the mud fluid was implemented as it was.

The final stages include placing nanomaterials (nano Graphite) with their different concentrations (0.75 gm. - 1 gm. - 1.5 gm. -2 gm) into the blank mud fluid and make measurements for each of them and pass them on the sandstone core, as happened with the blank mud fluid and measure the permeability of sandstone core every time and thus the final results have been scheduled. (Zhou and Nasr-El-Din, 2017).

From the last results (Table 1), it was proved the ability of nanomaterials to change the permeability of sandstone and make the ability to produce carbohydrates from reservoir better.

3. The Absolute Permeability Klinkenberg, (1941) postulated on the basis of his laboratory experiments, that liquids had a zero velocity at the sand grain surface, While gases exhibited some finite velocity at the sand grain surface. This resulted in a higher flow rate for the gas at a given pressure differential. The Absolute Permeability values for tight formations like shale and siltstones will be few microdarcies.

Table (2) shows the results of measurement of porosity, absolute permeability and oil saturation and calculated of initial water saturation (table 2).

4. Drilling Fluid Preparation at BUE and EMEC labs It was necessary to learn the components and manufacture of blank mud fluid, and this was done in the laboratory of EMEC company in Alexandria (Table 3).

After the blank mud fluid was done at the EMEC laboratory, a double check was run at drilling mud laboratory at the British University.

5. Preparation of Nano-material A nanomaterial was prepared at Egyptian Petroleum Research institute at the central lab as the need volume and scale using Ball mill instrument (Fig. 4).

6. Preparation of Graphite Nanoparticles In order to prepare Graphite nanoparticles, stock solutions of Zn $(CH_3COO)_2.2H_2O$ (0.2 M) as prepared in 50ml methanol under stirring. To this stock solution 50 ml of NaOH (varying from 0.4M to 0.8M) in methanol was added under constant stirring in order to get the pH value of reactants between 8 and 11. These solutions was transferred into Teflon lined sealed stainless steel autoclaves and continuous at various temperature in the range of 100 - 200^{o}C for 6 and 12 h under autogenously pressure. It was then allowed to cool naturally to room temperature. After the reaction was complete, the resulting white solid products were washed with methanol, filtered and then dried in a laboratory oven at 60^{o}C

Preparation of sample oil base mud from emac company to be used in nanocomposide samples. (Zhou and Nasr-El-Din, 2017)

Table 1: Basic properties of core.

Sample No.	Porosity %	Bulk Volume Cc	Pore Volume Cc	Grain Density g/cc	Air permeability mD
117	17.3	53.37	9.24	2.61	4381.76

Table (2): Brine Permeability Test Results.

Brine Permeability According to flow rate before Mud Blank Flooding.							
	1 cc/min mD	2 cc/min mD	3cc/min mD	4 cc/min mD	6 cc/min mD	8 cc/min mD	10 cc/min mD
117	284.14	385.98	495.48	668.94	781.00	785.15	855.61
Brine Permeability According to flow rate after Mud Blank Flooding.							
	1 cc/min mD	2 cc/min mD	3cc/min mD	4 cc/min mD	6 cc/min mD	8 cc/min mD	10 cc/min mD
117	5.22	9.20	14.97	23.55	27.82	33.04	39.53
Brine Permeability According to flow rate after "Nano-Mud 0.75" Flooding.							
	1 cc/min mD	2 cc/min mD	3cc/min mD	4 cc/min mD	6 cc/min mD	8 cc/min mD	10 cc/min mD
117	32.02	39.73	59.32	76.20	89.06	92.62	103.14
Brine Permeability According to flow rate after "Nano-Mud 1" Flooding.							
	1 cc/min mD	2 cc/min mD	3cc/min mD	4 cc/min mD	6 cc/min mD	8 cc/min mD	10 cc/min mD
117	33.50	50.84	78.91	93.08	107.84	116.24	120.35
Brine Permeability According to flow rate after "Nano-Mud 1.5" Flooding.							
	1 cc/min mD	2 cc/min mD	3cc/min mD	4 cc/min mD	6 cc/min mD	8 cc/min mD	10 cc/min mD
117	40.41	57.75	85.82	102.54	117.30	121.02	125.13
Brine Permeability According to flow rate after "Nano-Mud 2" Flooding.							
	1 cc/min mD	2 cc/min mD	3cc/min mD	4 cc/min mD	6 cc/min mD	8 cc/min mD	10 cc/min mD
117	41.98	59.32	87.39	106.74	121.50	123.21	127.32

Table (3): Drilling fluid additives at EMEC Lab.

Trade Name	Concentration
DIESEL OIL	222.33 ml
EMEC CON	2.24 ml
EMEC WET	0.5 ml
WATER (tap water)	56 ml
Calcium Chloride	22.4 gm
LIME	8 gm
EMEC VIS	8.5 gm
EMEC TONE	6 gm
EMEC CARB XF	130 gm

Fig. (4): Ball mill instrument.

Structure of Graphite Nanoparticles

XRD of Graphite nanoparticles (Fig. 5) prepared by hydrothermal treatment of zinc acetate. The diffraction pattern of the Graphite nanoparticles the data were recorded by using Cu Kα radiation (1.5406 Å). The intensity data were collected over a 2θ range of 10-80^o and all the characteristic peaks of Graphite nanoparticles appear (100) at 2θ=31.8^o, (002) appear at 2θ= 34.4^o, (101) at 2θ= 36^o, (102) at 2θ= 47^o, (110) at 2θ= 56o, (103) appears at 2θ= 62^o and (112) appears at 2θ= 68^o. Also, XRD diffraction pattern established that the synthesized materials were Graphite nanoparticles with wurtzite phase and all the diffraction peaks fixed with the reported JCPDS data15 (and no characteristic peaks were observed other than Graphite Nano.

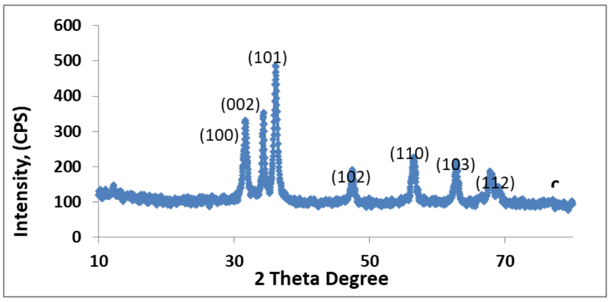

Fig. (5): The XRD of Graphite nanoparticles.

Whereas, the transmission electron microscopy (TEM) displays the formation Graphite nanoparticles with particles size around (6 nm) with very good distribution as shown in (Fig. 6).

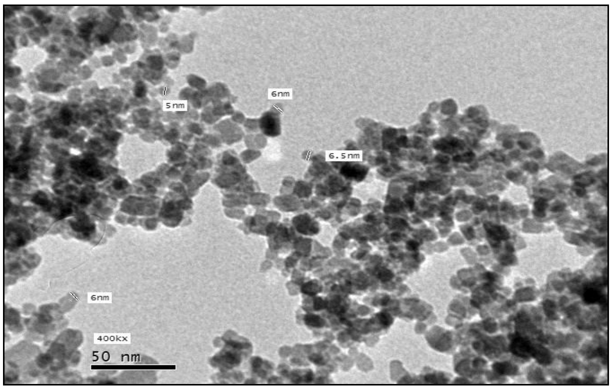

Fig. (6): TEM of Graphite nanoparticles prepared by hydrothermal method.

3. Core Flooding Test

As core samples usually contain water and oil, it is necessary to prepare the core samples for the test. Cores are dried in an oven or extracted by a Soxhlet extractor and then they are subsequently dried. The residual fluids are thus removed and the core samples become 100% saturated with air. In principle measurement at a steady single flow rate permits the "routine" calculation of the permeability from Darcy's law. The core is inserted in a core holder.

A pressure applied on the surface of the core as confining pressure. An appropriate pressure gradient is adjusted across the core sample and the rate of flow of air through the plug is observed. The permeability could be found from either of the below equations. However, there is considerable experimental error in this experiment so the requirement that permeability be determined for conditions of viscous flow is best satisfied by obtaining data at several flow rates and plotting the flow rate versus pressure drop, as shown in (Fig. 7).

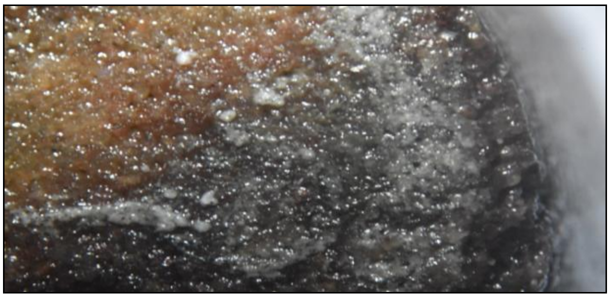

Fig. (7): Core sample after Nano-Mud flooding for Abu Roach C Member.

A straight line is fitted to the data points. According to the Darcy's law, the slope of this line is K / μ, and this line must pass through the origin. But at ultralow flow rates, the flow rate is not proportional to pressure drop. Darcy's law should not be extrapolated to the origin. Deviation from the straight line at high flow rates is an indication of turbulent flow (Fig. 8).

This deviation shows that the pressure drop in turbulent flow is higher than viscous flow. By increasing the pressure drop we can reach to a maximum flow rate capacity of the medium, after that flow rate will not increase by increasing the pressure drop.

Adding nanofuid to the drilling fluid and running the tests again to observe the effect of nanomaterials on formation damage discussing the results and study the effect of nanomaterials on formation damage

RESULTS AND DISCUSSION

The results of routine and the special core analyses study as well as the core flooding test for the selected sample of Abu Roach(C) Member of A/R Formation.

The main objective of this work was to perform the normal brine permeability by Brine 50 g/l conc. then flooding by Mud then measure brine permeability by Brine 50 g/l conc.

Observe the effect of mud solid on the rock permeability for the selected core sample of Abu Roach C Member.

ANALYSIS RESULTS

- Table.1 shows that Porosity value for the selected clean blank core sample was equal 17 % while permeability was 4391 mD which consider as a high value.
- Table.2 shows that, with increases the flow rate of saturated brine from 1 cc/min to 10 cc/min, the permeability value increases from 284 mD to 855 mD and this decided to the gradual increase in the flow rate.
- Table .3 shows that using the drilling fluid as a flooding fluid the permeability values were increases from to 39 mD which was a lower value due to mud solids in the drilling fluid.
- Tables.4, 5, 6 and7 : adding the Nano material of (Graphite nano) (35 nm with 0.75 gm., 1 gm., 1.5 gm. and 2 gms) to the drilling fluid the permeability increases as the flow rate increases and became nearly steady and constant at the 1.5 and 2 grms of Graphite nano, this was related to the Nanomaterial (Graphite nano) which cause the prevention of precipitation of mud solids and then

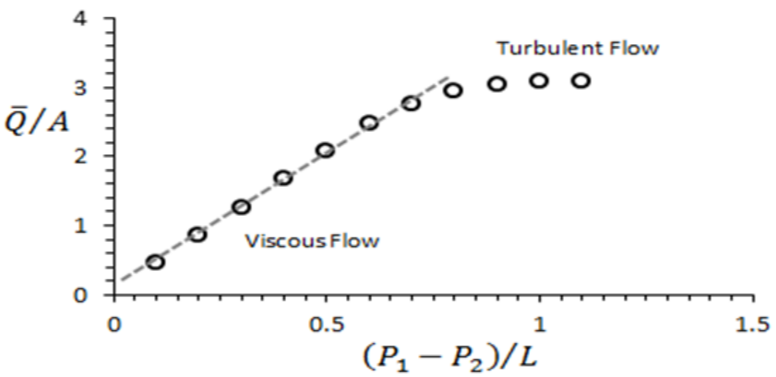

Fig. (8): Experimental Results for Calculation of Permeability.

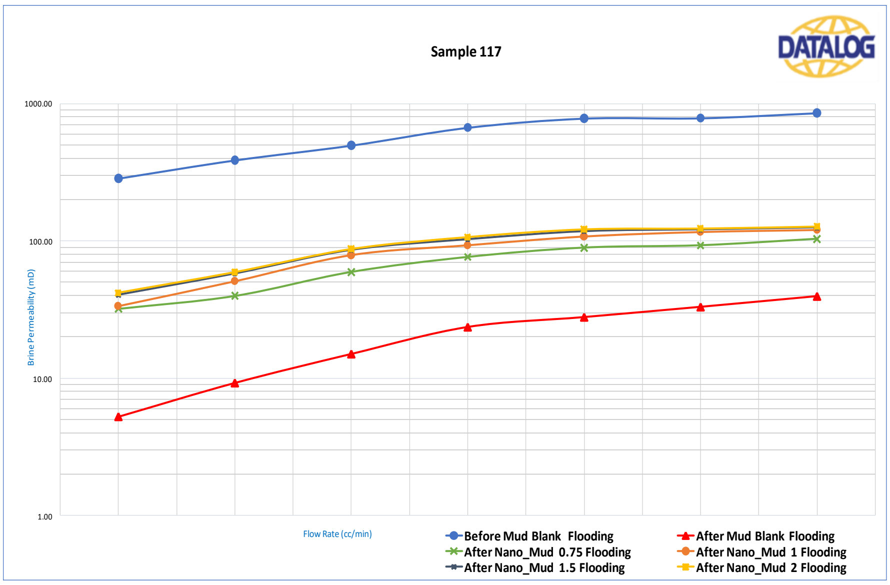

Fig. (9): Routine core analysis results for core plate samples used in this study

stabilized the permeability value as it acts as a bridging agent especially with increasing the nanomaterial concentration.

- This could be achieved by drawing a graph which shows the relation between Permeability and flow rate, from this (fig. 9) we can see that the stabilizing of permeability value at the end of the reaction after adding the drilling fluid with nano material Graphite Nano.

Shows the measured porosity, absolute permeability, oil saturation znd initial water saturation. The following Tables are shown as the results of measurement of porosity, absolute permeability and oil saturation and calculated of initial water saturation. Table (2) routine core analysis results for core plate samples used in this study.

Datalog Oil Services Special Core Analysis Lab has received a total of 1 plug from the researcher for Mitigation of Formation Damage caused by Mud Solids Using Nano materials.

The samples had been cleaned in cold solvent extraction Sechelt. Chloroform was used to remove any residual hydrocarbons and methanol was used to remove water and residual salts. Chemical and visual checks were made to ensure all contaminants had been removed prior to special core analysis testing.

On completion of the cleaning, the plugs were placed in a humidity oven at 60º C and 40% relative humidity. The plugs were dried until their weights were constant.

The plugs were removed from the oven, placed in a desiccators partially filled with silica gel and allowed to cool to ambient temperature.

When the plugs were in thermal equilibrium the base parameters of gas permeability, porosity and grain density were measured under a confining pressure of 400 psig.

The brine used throughout this study is 50,000 mg/Ltr TDS, as recommended by Researcher discussion.

Porosity and Grain Density

The grain volumes of the samples were measured using a calibrated helium gas volume expansion meter. Prior to each set of data (20 samples maximum) the Porosimeter was checked for potential leaks. This was done by performing a 'dummy' expansion with a steel blank in the matrix cup. The apparatus was then calibrated using seven stainless steel discs of known volumes and the relationship between pressure and volume (which is ideally linear) was calculated. A calibration of 0.99999 (1=linear) or better is acceptable. (Pham and Nguyen (2014)).

The plug samples were weighed and the weight recorded prior to the grain volume measurement. The samples were loaded into the matrix cup. If the cup was not filled a stainless-steel disc of known volume was added in order to minimize the dead volume. Helium was then expanded into the matrix cup and the pressure was allowed to stabilize for a minimum of five minutes per sample before being recorded.

In order to check the repeatability of the results, two stainless steel blanks of known volume were run prior to, and after, each set of results. The results had to fall within 0.02 cc of their known volume for the data produced to be acceptable. The equipment was kept at a constant temperature throughout.

Each plug was loaded into a hydrostatic core holder and an overburden of 400 psig was applied. The samples were then allowed to come to equilibrium under the applied confining stress.

Sample pore volumes were measured directly from helium injection.

Porosity was then calculated from the following:

- (1) Bulk Volume (ccs) = Pore volume (ccs) + Grain Volume (ccs)
- (2) Grain Density (g.cc-1) = Sample Dry Weight (g) / Grain Volume (ccs)

Gas Permeability

Gas permeability was measured using a calibrated steady state permeameter with nitrogen as the flowing medium. The flow was allowed to stabilize before the readings were taken.

To check the performance of the permeameter a full set of check plugs of known permeability was run at the beginning of every day (one check plug for each orifice of the permeameter). After every set of samples analyzed (20 samples maximum), check plugs were again tested - one check plug specific to each orifice used in the analysis.

Gas Permeability measurements were then made on the clean and dry samples in a Hassler core holder with an applied overburden pressure of 400 psig. Nitrogen gas was flowed through each sample and the differential pressure (across the sample) was measured using a transducer. The permeability value was calculated by application of Darcy's law **(Darcy, 1856).**

$$Q_b = \frac{KA}{2\mu L} \times \frac{{P_1}^2 - {P_2}^2}{P_b} \quad (3)$$

Where:

K = Permeability to gas (mD)

L = Length of sample (cm)

A = Cross sectional area of sample (cm2)

μ = Viscosity of gas (cP)

Pb = Atmospheric pressure (atm)

P1 = Corrected upstream pressure (atm)

P2 = Corrected downstream pressure in (atm)

Qb = Flow rate (ccs.sec-1)

When the analysis was complete, 10% of the samples were reanalyzed as a quality control check.

CONCLUSION

This extensive research dealt with the subject of formation damage by drilling fluids especially mud solids. The major mechanisms of formation damage by drilling fluids, assessment and testing of damage, outline considerations for mud selection and optimization, and removal of mud...

Laboratory core flood tests had been used to determine the causes, degree, and extent of damage. Core flood test had been done to evaluate the effect of acid on damaged cores. In this research, the author will suggest some unique solutions to mitigate formation damage using Nano-materials with especial emphasis on formation damage caused by drilling fluid and mud solids and clay swilling problem

Finally, Adding Nano-fluid to the drilling fluid then run the tests again to observe the effect of Nano-materials on formation damage discussing the results and study the effect of Nano-materials on formation damage.

It was found that the Nano-material as Graphite Nano with scale 35 nm with 25 % as a concentration could solve formation damage problem and act as a bridging agent to control the bore whole stability and stabilized the permeability for Abu Roach C member of A/R C formation and also control the precipitation of mud solids.

So it was recommended to use Graphite Nano Nano-material to control and mitigate formation damage which was the main aim for this study.

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