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CONTROL FRACTURE IN SAND FORMATION USING SMART DRILLING FLUID THROUGHOUT EXPERIMENTAL APPROACH

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ABSTRACT: Control losses in geological formations consider as an important issue in drilling operation. Lost of circulation can be one of the more serious problems that can arise during the drilling of an oil well or gas well. Loss of drilling fluid can result in increased cost, loss of time, plugging of potentially productive zones, blowouts from decreased hydrostatic pressure in formations other than the thief zone, excessive inflow of water, and excessive caving of the formation. Lost circulation occurs through existing high-permeability zones such as highly fractured, vuggy, or cavernous structures or induced fractures when the hydrostatic pressure of drilling fluid exceeds the breaking strength of the formation. Carbonates are good examples of the former case. The following preventive measures can be used however in other cases:1 a) set casing, b) maintain drilling fluid density, c) avoid excessive downhole pressures. d) using high energy ball milling to oil based mud to observe the reduction in fluid loss as a result of the nano-additive, the results were positive indicating up to 27.7% fluid loss reduction due to the ability of the suspended nano-material to form compact impermeable mud cake as a result of its physical properties and increased surface area and interaction potential. Core plugs with pre-determined properties were re-tested after the saturation test and showed encouraging results with up to 15% permeability reduction and 8% porosity reduction.

Keywords: formation, Fracture, Nano-materials, Porosity, Permeability, losses, core plug.

1. INTRODUCTION

Nanotechnology is an essentially modern scientific field that is constantly evolving as commercial and academic interest continues to increase and as new research is presented to the scientific community. The field's simplest roots can be traced, albeit arguably, to 1959 but its primary development occurred in both the eighties and the early nineties. In addition to specific scientific achievements such as the invention of the STM, this early history is most importantly reflected in the initial vision of molecular manufacturing as it is outlined in three important works. Overall, an understanding of development and the criticism of this vision is integral for comprehending the realities and potential of nanotechnology today.

Nanotechnology is a branch of science and technology where the size particles between 1–100 nm are studied [1],[2]. It can be used to solve a lot of problems associated with drilling engineering.

The Nanoparticles have high area to volume ratio which gives them a high surface area for interaction with surrounding medium, hence for any application the quantity of nano particles required will be less and hence there is cost advantage when using Nanoparticles. [3-5].

The applications of Nanoparticles in drilling fluids is mainly to form a thin layer of non-erodible and impermeable Nanoparticle membrane around the wellbore which prevents common problems like clay swelling, spurt loss and mud loss due to circulation [10],[11]. These nano-particles can also eliminate use of additives, shale inhibitors, rheology modifiers and can be very easily removed during clean-up before completion operations [8]. The aim of this research is to check the fluid loss values when Nanoparticles are used as fluid loss additive. The improvements in rheological properties are also studied.

2. NANOFLUIDS AND FLUID LOSSES

Amanullah and Al-Tahini defined Nano-fluids for oil and gas as “Drilling, drill-in, stimulation or any other fluids used in the exploitation of oil and gas that contain at least one additive with particle size in the range of 1-100 nanometers”. They also classified nano fluids as simple nano-fluids and advanced nano-fluids. Simple nano fluids contain nano particles of only one dimension. Advanced nano fluids are one with multiple nano sizes. These types of fluids significantly reduce the total solids content in the mud. The laws that govern the nano particles surface behavior or interaction with surrounding medium are different from the normal laws which govern the behavior of macro and micro-scale behavior. This was investigated by researchers [13]. They observed different behavior of carbon Nano-tubes and fullerenes derived from the same graphite mother source.

The main application of nano particles would be to control the spurt and fluid loss into the formation and hence control formation damage. According to Amanullah and Al-Tahini show that the nano particles can form a thin, non-erodible and impermeable mud-cake [2]. Due to its high surface to volume ratio the particles in the mud cake matrix can easily be removed by traditional cleaning systems during completion stages. Thus, the Nano particles can be used as rheology modifiers, fluid loss additives and shale inhibitors with unparalleled properties for very small concentrations of the particle [14]. Thus, the smart fluids based on nano fluids can be a used effectively in horizontal, directional shale drilling due to formation of a barrier between drilling mud and shale, as nano particles can easily penetrate into the shale and hence drastically reduce the shale-drilling mud interactions and stabilizes the wellbore .

The laboratory procedure involved plugging the pore throat of the shale samples with silica Nano particles of 20 nm. The shale pore sizes are an average of 10 to 30 nm. The conventional drilling fluids have much larger particle diameters in the range of 100 microns. The particle sizes should not be larger than one third of the pore throat size to form an effective bridge and also particles should be at least 5% by volume of the drilling fluid [1].

Based on the experiments conducted by Sensoy, Chenevert, they concluded that use of nano particles in the drilling mud reduced the fluid penetration into the Atoka shale up to 98% and Gulf of Mexico formation by 17 to 27%. Also they concluded that reduction in concentrations of Nanoparticles will increase the fluid penetration into the formation and hence they recommended a minimum concentration of at least 10 wt. % of 20 nm nano particles to be used. 20 nm size particles proved to be more effective than 5nm particles in plugging the pore throat of the formation. Other areas where Nano particles can be used are in controlling the water flow problems often-encountered onshore and deep water drilling process. Engineered nano particles with gluing, filling and cementation properties can be used while drilling in shallow waters which are usually loose sands and are highly porous and permeable formation.

The use of engineered nano particles increases the intra-granular strength and reduces permeability and porosity of formation. It can also be used in formations which require sand control.

3. CARBON NANOTUBES

A key breakthrough in carbon nanochemistry came in 1993 with the report of needle-like tubes made exclusively of carbon. This material became known as carbon nanotubes (CNTs). There are several types of nanotubes. The first discovery was of multi walled tubes (MWNTs) resembling many pipes nested within each other. Shortly after MWNTs were discovered single walled nanotubes (SWNTs) were observed. Single walled tubes resemble a single pipe that is potentially capped at each end.

4. EXPERIMENTAL APPROACH:

Experimental work was done at The American University Labs and Petroleum Research Institute, This work passed through the following steps:

4.1 Preparation of material included that graphite tubes and milling,

4.2 Material Size Inspection with microscope,

4.3 Preparation of injecting sample,

4.4 Mud measurements before and after treatment include that measured of the Mud weight and Viscosity,

4.5 Mixing the nanoparticles with the oil base mud mixer,

4.6 Prepare Sandstone samples; they are illustrated of measuring porosity and permeability before injection of treated mud and after injection; first experiment Injection process; Injection cell (EPIT, baker); Saturation cell. In addition to Second experiment PPT include that Graphite tubes, Top down approach to synthesize nano particles through milling (Figure 3), Milling apparatus for mechanical high-energy ball milling (planetary ball mill PM400) and at 250 RPM, for 8 hours (Fig. 1).

Figure1. Planetary Ball Mill. (PM400).

4.2. Material Size inspection with microscope

Characterization using SEM (Scanning Electron Microscopy) that the Nanotechnology uses two main kinds of microscopy. The first involves a stationary sample in line with a high-speed electron gun. Both the scanning electron microscope (SEM) (figures.2&3) and transmission electron microscope (TEM) are based on this technique. The second class of microscopy involves a stationary scanner and a moving sample. The two microscopes in this class are the atomic force microscope (AFM) and the scanning tunneling microscope (STM).

Microscopy plays a paradoxical role in nanotechnology because, although it is the key to understanding materials and processes, on a nano-scale samples can be damaged by the high-energy electrons fired at them. This is not a problem with STM. The SEM, TEM, and STM need well prepared samples (Figure.4) that are also electrically conductive.

In SEM experiments, electrons emitted from a filament are reflected by the sample and images are formed using either secondary electrons or backscattered electrons. However, in the case of SEM, a field emission microscope (FE-SEM) is necessary to investigate the nanometric scale (electrons are emitted from afield-emission gun).FE microscopes could reach resolutions of the order of 1 nm using a cold cathode. If they are equipped with an energy dispersive spectrometer (EDS), chemical composition can be obtained. Then, size distribution, shape and chemical composition of nanoparticles can be investigated by FE-SEM. Finally, SEM imaging is performed on dry powder (figures 5&6).

Figure 2. Scanning Electron Microscope (SEM).

Figure 3. Transmission Electron Microscope (TEM).

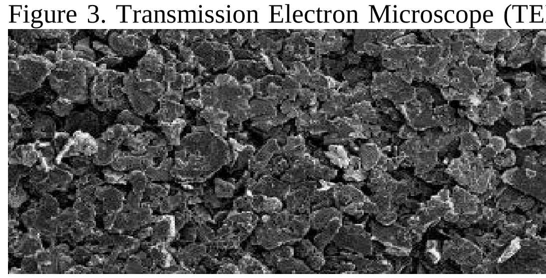
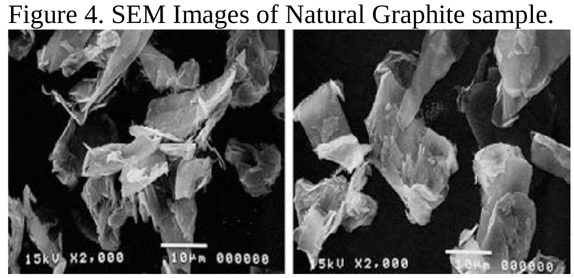


Figure 4. SEM Images of Natural Graphite sample.



Figures.5&6: SEM images of graphite after milling.

4.3. Preparation of injecting sample,

During Experimental procedures, we could use to injection cell, Manual saturator, Dean stark for cleaning and Saturation cell. In addition to, permeability measurements and Porosity measurements are progress. To complete injection test, we can used Injection cell and Saturation cell.

After collecting three core samples of sand stone from Abu-Rawash formation, put the samples in the cleaning system for 3 days until they became cleaned, after that, we put the samples in the drying oven for one day at 65°C. Then, the measured porosity and permeability for them by porosimeter and Permeameter. After that, we made saturation for all the samples by the manual saturator with the mud mixed with nano-particles. Left the samples saturated in the mixture of mud fluid treated with nano-particles for 3 days. After that we cleaned the samples again by our cleaning system. We left the samples in the cleaning system for 7 days until we were sure that the samples are cleaned. Finally, after drying the sample, measured again porosity and permeability for the samples and we achieved to these results.

The saturation of a plug by using manual saturator with a selected liquid is performed as part of the preparation cycle of specific SCAL measurements, e.g. Formation Factor, Capillary Pressure and Relative Permeability.

The manual saturator enables the end user to obtain remarkable saturation of cleared and dry core samples by simple process. Saturation is done because all the SCAL measurements like formation factor, capillary pressure, brine permeability, relative Permeability, wettability and compressibility is done at 100 % saturation.

Cleaning for the sample by using Dean Stark is done by cleaning system. The main function of the Dean stark is to calculate the hydrocarbon reserves we have to calculate the saturation of each fluid phase inside the rock. We used toluene for cleaning the core samples from the mud fluid mixed with the nano-particles.

For permeability measurements, The permeability of a porous medium to a certain fluid is the capability of that porous medium to transmit that fluid, the evaluation of the permeability follows from Darcy's law.

$$K = \frac{Q\mu L}{A\Delta P} \quad \ldots\ldots\ldots.. (1)$$

Klinkenberg (1941) discovered that permeability measurements made with air as the flowing fluid showed different results from permeability measurements made with a liquid as the flowing fluid. The permeability of a core sample measured by flowing air is always greater than the permeability obtained when a liquid is the flowing fluid

For Porosity measurements, Porosity is defined as the ratio of the pore spaces to the total volume of the rock; it may be expressed in percentage and / or fraction. Each sample is well cleaned and dried. The dried and cleaned plugs were individually placed in the matrix cup of small volume porosimeter, which is a type of gas expansion porosimeter. The grain volume of the plug was measured and then the porosity was calculated by the equation:

$$(\phi) = (Vb - Vg) / Vb \quad \ldots\ldots.. (2)$$

Where:

ϕ = Porosity, in fraction,
V_b =Bulk volume, in cc.
V_g =grain volume, in cc.

The Objective of this experiment is to determine the effective Porosity ϕ_e of a core sample of one inch diameter by introducing an inert gas as Helium "He" into the core.

4.4. Mud measurements before and after treatment

The electronic balance was used to measure the weight of the graphite nanoparticles to be added to the oil based mud before each mixing.

4.5. Mixing the nanoparticles with the oil base mud mixer:

This stage of the experimental procedure involves mixing the synthesized graphitic nanoparticles with the oil-based mud obtained; we will have two separate samples of mud which will undergo all the tests simultaneously, one with the graphitic nanoparticles blended and one without in order to provide a comparative example to ensure the observed improvements are due to the added component, and to determine the extent of improvement if any upon adding the synthesized nanoparticles.

Most drilling fluid formulations contain a base liquid and additives which must be dissolved or mechanically dispersed into the liquid to form a homogenous fluid [8]. The resulting fluid may contain one or more of the following: water-dispersible (soluble) polymers or resins, clays or other insoluble but dispersible fine solids, and soluble salts [9], [12]. The fluids are mixed or sheared for times appropriate to achieve a homogenous mixture and are then set aside to "age." Drilling fluid aging is the process in which a drilling fluid sample, previously subjected to a period of shear, is allowed to more fully develop its rheological and filtration properties [4],[6],[7]. Aging is done under conditions which vary from static to dynamic and from ambient to highly elevated temperatures.

The graphite nanoparticles were added in different concentrations lb/bbl or gram/kg and the properties of the obtained drilling fluid were repeatedly tested to determine the effect of adding the additive in different concentrations on the rheological properties of the mud and on the filtration, permeability plugging and loss circulation obtained from the other tests.

4.6. Prepare Sandstone samples

After prepare the Sandstone sample Porosity and Permeability measurements were run on those samples before and after the treatments. It was notice that permeability values for core sample one, were decreased from 147 MD to 125 MD, also for porosity values for core sample one decreased from 33% to 30%

4.6.1 Filtrate Volume

The volume of liquid filtrate collected after 30 minutes is reported in cubic centimetres (cc), to the nearest 0.1 cc. The test temperature at which the filtrate was produces is also recorded on the appropriate Drilling Mud Report [4]. The filtrate volume is calculated by the formula:

Filtrate vol., cm^3 = 2 (volume collected in 30 minutes, cm^3).

4.6.2 Filter Cake Thickness

The thickness of the resulting filter cake is measured at its center, and reported to the nearest 1/32 inch (0.8 mm).

4.6.3 PPT (Permeability Plugging Tester):

The Permeability Plugging Apparatus (PPA) is designed to provide more realistic downhole static filtration measurements. The PPA is useful in predicting how a drilling fluid can form a semi-permeable filter cake to seal off depleted under pressure intervals and help prevent differential sticking [14]. This is accomplished by allowing temperatures and pressures more representatives of well conditions and by the position of the filtration medium above the sample fluid.

The test cell [7] is positioned with pressure applied from the bottom of the cell and filtrate collected out the top. This prevents particles that settle during the static test from contributing to the buildup of filtration cake. This is important because it would not normally happen in a well. The cell pressure is applied by a two stage hydraulic hand pump. Pressure is transferred to the drilling fluid sample through a floating piston within the cell.

Test pressures up to 5000 psig (34, 474 kPa) at 500^{o}F (260^{o}C), the working pressure and temperature rating of the cell, may be safely used. The back pressure receiver may be used up to 750 psig (5171 kPa).

The cell is encased in a thermostat aluminum well during heating and filtration. The heating chamber encloses the filtering area. Both the heating jacket temperature and the cell temperature can be measured using metal stem thermometers. Insert the thermometer into the well of the heating jacket and the well of the cell. The temperature is adjusted by means of a knob on the thermostat.

For Interpretation and analysis for Permeability and Porosity, after performing the aforementioned experimental procedure and obtaining the results, we will now aim to interpret and analyze the results to determine the success and effectiveness of the nanoparticles additive in achieving its targets. Our experimental procedure was divided into two components: the first experimental procedure was aiming at determining the effectiveness of the nano-additive in reducing lost circulation by reducing the filtrate loss, which is achieved by forming a cohesive, thin and impermeable filter cake. The other approach in the second experimental procedure was causing slight formation damage in highly permeable and fractured areas by invasion of drilling fluid with suspended nanoparticles that aimed to reduce the permeability by blocking and occupying pore throats and passages therefore minimizing the perm-porosity characteristics of the problematic formation and inherently reducing mud losses and other drilling problems that could be caused by these formations.

It was important to note and analyze the effect that the additive incurred on the overall rheology of the drilling fluid and determine the cause of these changes and their treatments if necessary, as it is important for the additive to improve a certain function of the drilling fluid [12] without affecting the ability of other components of the drilling fluid to perform their functions within the specified environment.

4.6.4 PPT (Permeability Plugging Tester)

The permeability plugging tester provides a more realistic representation of the downhole conditions. Due to the test being conducted to simulate fluid loss and filter cake formation through a ceramic disk available through a wide range of porosity at a differential pressure of 500 psi and 300 degrees Fahrenheit. The ceramic disk represents the porous formation and the ability of the mud to filtrate through and the formation of the filter cake is analyzed. The results shown that will be displayed in the following figure (Figure. 7) represent the spurt loss which is the invasion value before the formation of the filter cake, the value taken at 7.5 minutes and the value at the end of the test for each sample.

The results show a significant decrease in the spurt loss, intermediate and total loss after the addition of the nanoparticles to the drilling fluid. The decrease in the spurt loss is due to the facilitated formation of the filter cake as a result of the increased interaction potential due to the increased surface area to volume ratio of the nanoparticles and their ability to form a compact impermeable unit. Due to the predominant role of surface area in Van Der Waal's, molecular and atomic forces, tiny concentrations of nanomaterials (2%wt) is expected to produce significant change to properties (27.7% fluid reduction) .Also another factor is the thermal stability of the nanoparticles at elevated temperatures thus maintaining their functions at high temperature and pressure opposed to possible thermal degradation of components at elevated temperatures.

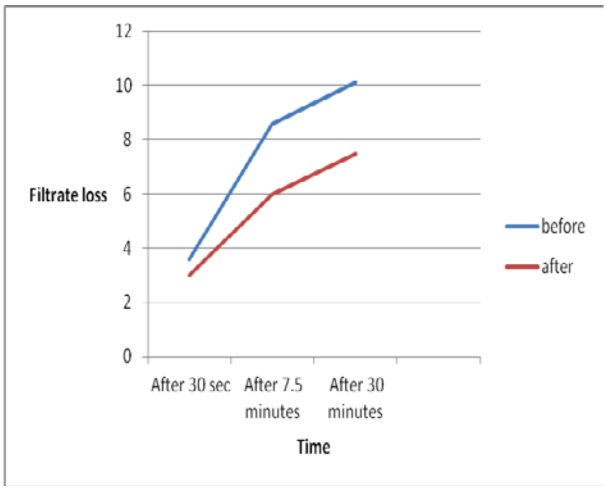


Figure7. Filtration loss versus Time.

Second Approach Analysis, Our second approach related to treating problematic formations which incur a large amount of lost circulation through reducing their perm-porosity characteristics by the addition of graphite nanoparticles to the drilling fluid and running the experimental procedure with core samples of previously determined characteristics.

The results as shown in the following figure shows a reduction in the porosity (Figure 8) and permeability (Figure 9), values of the tested pore samples ranging from 10-15% permeability reduction and approximately 8% porosity reduction. This reduction in the characteristics of the formation will significantly reduce lost circulation as invasion of drilling fluid into the wellbore is dependent on the formation properties as well as the properties of the drilling fluid. Sealing the permeable pathways and pore throats that enable suspended solid particles to escape as a result of the differential pressure will significantly reduce the lost circulation due to formations of high permeability or fractures without impacting the hydrocarbon recovery due to the distance between the problematic zone and the producing zone.

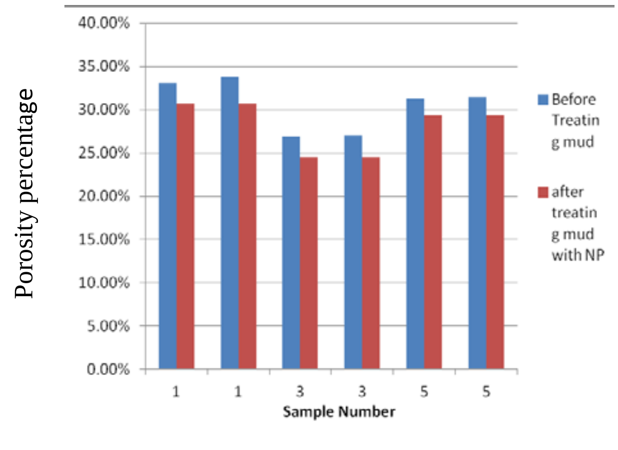


Figure 8 Sample Number Vs Porosity percentage.

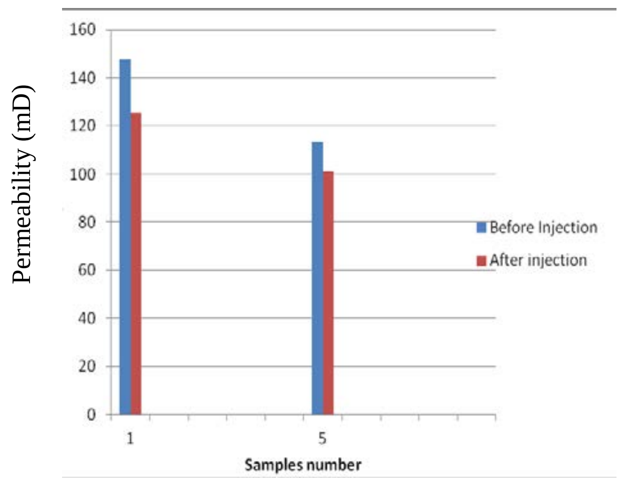


Figure .9 Sample number Vs Permeability.

From the permeability figure it can be observed that one of the samples was neglected in the calculations as a result of its low permeability value which would not provide evidence to any significant reduction due to the absence of a range to estimate the cause of reduction.

An important aspect when considering filtration losses is particle to pore size ratio. If the particles are very fine compared to the pore sizes whole mud will pass and bridging will not occur. In order for bridging to occur the ratio must be ½ or greater and intermediate value for invasion while bridging (spurt) will occur until the ratio is greater and filter cake forms. In order to facilitate the bridging and decrease spurt losses bridging agents are added to occupy pore spaces and decrease effective porosity to facilitate the formation of filter cake. These suspended nanoparticles perform this function by occupying the pore throats due to their small size and high interaction potential and reduce the effective porosity and permeability leading to the formation of a filter cake with less spurt loss and more uniform particle size distribution and texture. The formation damage is also explained by the formation of an internal mud cake as roughly circular ring in the invaded zone after spurt loss.

Another factor is the solids content. Due to larger surface area to volume ratio of the nano the amount required to perform the function of a component of the mud is much less which leads to the a decrease in solid content in the mud , this can decrease flocculation and help with the formation of uniform filter cake.

5. SUMMARY AND CONCLUSION

To summarize, throughout our research we have attempted to find a solution to a debilitating problem in the oil industry which costs the industry an estimated one billion dollars a year through rig time, treatment costs and other financial resources. Depending on the unique blend of characteristics of characteristics that the nanomaterial can provide in terms of the exponentially improved surface are to volume ratio, as well as increased chemical and thermal stability. My approach to solving the problem was twofold; the first approach involved conducting experimental procedures on HTHP Filtration tests and Permeability Plugging Tester (PPT) after adding the synthesized nanoparticles (using high energy ball milling) to oil based mud to observe the reduction in fluid loss as a result of the nano-additive, the results were positive indicating up to 27.7% fluid loss reduction due to the ability of the suspended nano-material to form compact impermeable mud cake as a result of its physical properties and increased surface area and interaction potential. The second approach involved inducing formation damage in problematic formation by decreasing the perm-porosity characteristics to decrease the invasion of drilling fluid into the formation to avoid loss circulation and other drilling problems as a consequence of lost circulation such as differential sticking. This was achieved by plugging the pore throats and passageway of the formations by suspended nano-particles in the drilling fluid to decrease effective porosity and permeability. Core plugs with pre-determined properties were re-tested after the saturation test and showed encouraging results with up to 15% permeability reduction and 8% porosity reduction. To conclude using nanoparticles as a drilling fluid additive showed positive results and with the recommendations in the following page more can be achieved not only in lost circulation but solutions for drilling problems combined using appropriate exploitation of nanomaterials properties.

6. RECOMMENDATIONS

To further improve our research and accuracy of results and conclusions the following steps should be taken:

- Increasing the number of samples will enable us to collect greater amounts of data which over a wider range of characteristics.
- Different sizes of Nanoparticles (like 5nm, 30 nm, 100nm etc) should be used to find an optimum particle size for reducing fluid loss to formation.
- Repeat PPT with several ceramic disks micron sizes, different temperatures and differential pressure to determine the effectiveness of the nano-fluid under different operating conditions and through different media
- Mix different concentrations of the nanoparticles with the drilling fluid to determine the optimum concentration that will provide maximum loss circulation reduction.
- The study done in this research is mainly focused on actual fluid loss characteristics of mud along with Nanoparticles; however the effect of adding other additives to field muds with weighing material, biocides etc may have a different phenomenon.
- The Nanoparticles might not be a good recommendation for highly porous formations; however it might be combined with regular bridging materials and help seal a wide range of porosity that might be present in the formation.
- Recommends increased collaboration between oil producers and Nanomaterial manufacturers.
- Study of fluids using high end Rheometer and other apparatus which may be used for studying permeability to estimate the reduction in permeability after the cores have been plugged by Nanoparticles. The experiments may be repeated at different sized Nanoparticles and other conditions.
- Increased attention to research and applicability of nanoparticles as through their custom tailored properties and thermal, chemical and physical properties may prove to be the solution to current and future industrial problems.

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