Non Damaging Drilling Fluids for a Sustainable Future of Oil & Gas Industry

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ABSTRACT
Drilling Fluids are complex heterogeneous fluids used in the drilling of oil and gas wells. The key factor that should be kept into consideration while designing the drilling fluid is its cost and its effect on environment. The complex drilling fluid constitutes 15-20 % of the total cost of petroleum well drilling operations. The new wells drilled for producing the black gold today go through or into zones in the formation that have previously been producing or have already produced. The justification for this could be that a prevailing reservoir needs to be drained from another location conducive to augmentation of the hydrocarbon recovery. Thus, the use of conventional drilling fluids to drill such pay zones, especially in the case of depleted reservoir is no longer acceptable, due to its damaging effect to the wellbore and its harmful effect on the environment. Drilling mud systems that are barite and bentonite free have been developed which provides a lighter alternative to conventional muds while maintaining the required rheological profile. The main advantage of these systems is its non-damaging nature towards the pay zone and their ability to form filter cakes which prevent filtration losses. Such a system of drilling fluids is called drill in fluids or non-damaging drilling fluids (NDDF). The aim of this chapter is development and utilization of such types of drilling muds that are economically feasible, environment friendly and easily decomposable. The mud system synthesized also addresses the unique problem of maintaining a low solid and low density while preventing any abnormal lost circulation problems and also maintaining a non-invasive filter cake on the wellbore. This chapter is specifically written for energy soldiers and research groups who would find vital information for a sustainable future of oil and gas industry.
Keywords— NDDF, Drilling fluids, Depleted reservoir, Pay zone, Rheology

I. INTRODUCTION

Numerous technical problems are encountered in the drilling and completion phases for wells drilled in depleted reservoirs. These problems often put a question on the economic viability and feasibility of such fields. The conventional or traditional way of using water-based drilling mud is not considerable as the reservoir pressure decreases below the water hydrostatic pressure. Conventional drilling fluids contain a large quantity of solids, and the overbalance pressure provided by their density favor invasion of solids into the formation and filtration loss. This is a damaging phenomenon which makes it difficult for reservoir fluids to be produced by plugging the pores and the flow paths near the wellbore. In general, the problems encountered due to the use of conventional mud is summarized into*:* formation plugging by compositional solids e.g. clay, by foreign solids like drilled cuttings, hydration of clay envelop around pay zone particles by filtrate, change of wettability by the filtrate and whole mudinvasion into pay zone due to induced lost circulation [1]. The reduction in reserves causes the reduction in pore pressure. This basically weakens the reserve carrying rocks. In spite of that, a stable pore pressure will be maintained in neighboring low permeability rocks. This becomes a critical problem, because drilling fluid density required to support shale exceeds fracture resistance of sandstone formations. It eventually leads to induced losses, which occur when the drilling fluid density values supersedes the fracture resistance of the depleted pay zones [2]. This situation makes the drilling of depleted pay zones very difficult. What is required is a drilling fluid whose density matches the pore pressure and fracture resistance of the reservoir, and at the same not lead to blocking of pores and flow paths near the wellbore. Such a drilling fluid also needs to provide the option of an easy clean-up of the wellbore in the future. The class of drilling fluids used for this combination of functions is called a Non-damaging Drilling Fluid (NDDF). NDDF is principally a barite free polymer mud system, primarily intended to utilize in pay zone sections to prevent formation damage and to keep the pay zone undamaged. The formulation of NDDF incorporates highly biodegradable, long and high molecular weight polymer chains. This adds on advantages to the drilling mud. That is, drilling solids will get encapsulated in order to avoid dispersion or to coat the shales for inhibition. Therefore, the inclusion of this highly biodegradable polymers aids in boosting the viscosity and also to decrease fluid loss [3]. An NDDF is a combination of materials which reduce the percentage of solids in the fluid to prevent pore clogging, and incorporate certain 'bridging' materials which act as fluid loss control agents and effectively reduce the lost circulation of fluid into the formation

[4]. There are various physical and chemical properties of bridging agents that make it one of the most important components of a drilling fluid [5]. Sometimes, however, even bridging materials are not sufficient to prevent the lost circulation of the drilling fluid. To tackle this situation, NDDFs have a much lower density than conventional drilling fluids. This is achieved by maintaining a low solids content and the use of polymer viscosifiers like Xanthan Gum to provide the required thixotropy to the fluid without compromising the required density. As the name suggests, NDDF is considered as a non-damaging formulation and also it is superior in opposition to conventional muds. The oil flow will get obstructed, if the mud filtrate of conventional drilling mud forms around the pay zone. But in case of Non-Damaging drilling mud, saline filtrate is formed as an inhibitor. This basically, inhibits the clay swelling. Bridging agent which is present in the Non-Damaging formulation bridge the pore throats. This bridging process aids in formation of filter cake externally. Thus, it can be removed conveniently in contrast to conventional mud system.

II. DRILLING FLUIDS: PROPERTIES AND FUNCTIONS

In early 1900's, drilling fluids were incorporated in oil and gas industry in its original form. The significant use of drilling mud is to remove the drilled cuttings continuously. The advances in drilling engineering demands more progress and complexity from drilling fluids. So, as to improve the applications of drilling mud, various kinds of additives were incorporated and made it more sophisticated. The evolution of drilling fluids made it more safe, economic and acceptable for well completion. And it can be utilized for various other functions as well. It basically includes the following: removal of rock cutting and cleaning the rock formation beneath, proper removal of drilled cuttings through annulus to surface, cooling the bit, suspension of drilled cuttings in fluid if in case circulation got still, appropriate pressure maintenance for enhanced wellbore stability, supporting the system while cementing as well as well completion, aids in formation of filter cake with low permeability, thus the formation inflow can be prevented, delivers required hydraulic power to down-hole equipment, formation damage can be reduced and so on. Appropriate drilling muds must be selected for its proper functionality. For proper selection of drilling muds, various governing factors which influence its characteristics features must be identified as it is very crucial. Properties of formation, temperature range, pore pressure as well as permeability of the formation are the major parameters which governs the drilling mud selection.

A. Rheology

Apart from the above-mentioned characteristics, there are some significant parameters that has to be considered for proper functioning of drilling fluids. Rheological properties are considered as the most controlling factor for all the drilling functions. It basically concerned about the fluid deformation as well as the flow of matter. Rheological properties can be studied from analyzing the fluid flow velocity profiles, viscosity of drilling fluid (Marsh funnel viscosity, Plastic Viscosity and Apparent viscosity), annular borehole cleaning and friction pressure losses. Rheology (such as density, viscosity, gel strength etc.) can be tested throughout the drilling operations [6].

B. Drilling Fluid Additives

The properties of drilling mud and the incorporation of additives are modified according to the reservoir requirements [6]. Various characteristics properties like rheology, density, filtrate loss, solid content as well as the chemical properties must be precisely analyzed and thoroughly measured during the process. Viscosifiers, weighing materials, viscosity reducers, fluid loss reducers, flocculants, corrosion inhibitors defoamers, emulsifiers and pH controllers are the various additives incorporated in drilling muds for the better performance.

C. Types of Drilling Fluids

As the technology is going ahead, various rigorous advancements are happening in various fields of drilling. One of that is the progresses in drilling fluids. The initial implementation of advanced technology happened in rotary drilling process between 1887 and 1901. This paved way for the rapid development in number of available drilling fluid types. Thus, it become a necessary to classify the drilling fluids according to certain criteria. Therefore, drilling fluids can be categorized with respect to special criterion. Drilling fluids can be classified on the basis of their principal component into water, oil and gas base drilling fluids. This is considered as the most commonly used classification.

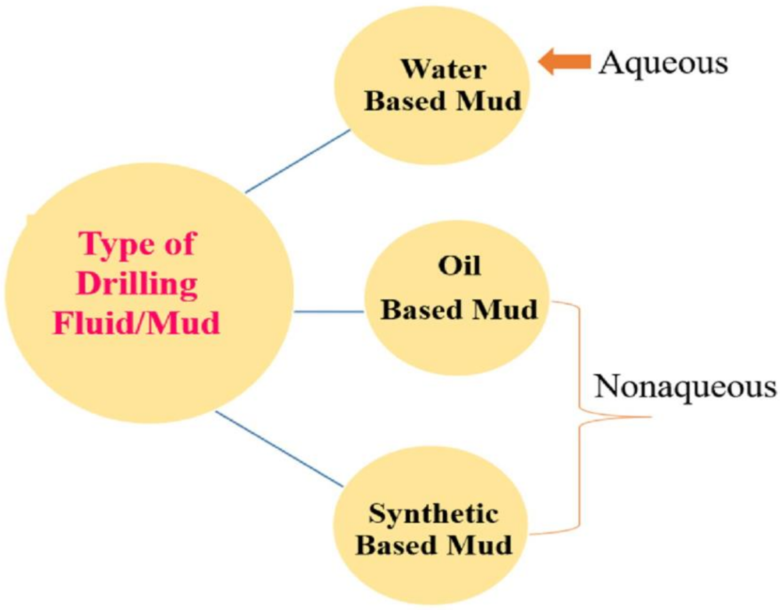

Figure 1: Types of Drilling Fluids/ Mud

According to the compositions and functions, Water Based Muds (WBMs) are classified. The categorization is also based on whether it can used for pay zone or non-pay zone drilling. Because of their low cost, conventional compositions are recommended to formulate WBM for non-pay zone drilling with very less concerns about formation damage. However, for a drilling fluid to be utilized for pay zone drilling, the significant property should be considered is minimal or non-damaging effect on the pay formation. In Oil Based Mud (OBM) instead of water, liquid hydrocarbon is used as continuous phase. Because of its favourable viscosity characteristics, low flammability, and low solvency for rubber elements in drilling equipment, conventional OBM contains diesel as the continuous phase. Light crude oil is also widely used as a base fluid; however, due to the relatively high levels of aromatics and n-olefins present in crude oils, they generally surpass the toxicity limit, encouraging the use of low toxicity mineral oils and ester base synthetic oil. Water can be purposefully or unintentionally portrayed in oil-based muds during drilling activity for economic gain. And the third category is Pneumatic fluids, used in hard-rock areas, and in special cases to prevent formation damage while drilling into production zones or to circumvent severe lost-circulation problems. Both air and mud are pumped into standpipe at a time in aerated mud drilling. In addition, it can be employed when it is impossible to drill with air alone because of water sands and/or lost-circulation situations [*7*].

D. **Conventional muds Vs NDDF**

There are several obvious advantages to using water base muds over oil base muds. Examples of such economic advantages include being less detrimental to the formation area than oil-based muds (in terms of wettability alteration) and the capacity to dispose of cuttings on-site, as opposed to coated cuttings produced by oil-based muds. Some of the major advantages of WBMs make it more convenient as well as wise choice. Water-based muds have made significant advances, allowing them to be used as an alternative to oil-based muds in some cases. However, using water base muds in complex wells such as deviated and S-shape wells becomes more difficult due to higher friction and stuck pipe issues. One of most significant reason is that water-based muds, unlike oil-based muds [8], are not naturally lubricious. Though lubrication additives can be added to water-based muds, oil-based muds are far more advantageous in such situations since they are readily lubricous. In addition to being lubricious, oil base muds provide a higher rate of penetration as well as a more stable wellbore due to their low tendency to soak the formation. Apart from the benefits which are discussed, there are some minor drawbacks for using OBMs in offshore:

a. There are some major environmental concerns as the OBM and cuttings which are generated while drilling are considered as toxic and that may affect the environment badly. Therefore, proper waste management is suggested.

b. The unsafe and harmful vapors which are generated from OBM can cause severe health problems to the workers. Protective measures must be taken to avoid skin irritation.

c. OBM is considered as very expensive in contrast to WBMs.

d. As the gas is soluble in oil, it is really tough to detect the gas kick during drilling using. This elevates the risk while drilling.

e. Cleanliness is really important. While drilling with OBMs, it is really difficult to maintain the work space tidy.

f. Rubber parts of the equipment's will get damaged if OBMs are used.

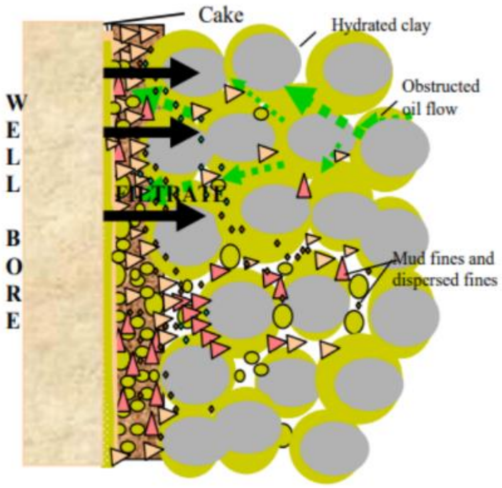

Figure 2: Pay zone damage due to conventional muds [9]

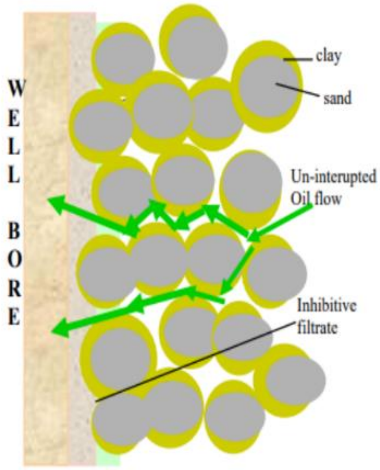

Figure 3: Pay zone with NDDF [9]

Non-Damaging Drilling Fluid (NDDF) is a method to enhance production by controlling formation damage throughout the drilling. The major advantages of NDDF over conventional drilling fluids is mentioned below.

a. Choking of the oil passage from formation to well can be avoided as it doesn't contain any fine solids like conventional mud.

b. Thixotropy – the most needed property of drilling fluid is provided by the additive XC polymer which is bio-degradable.

c. NDDF generates saline inhibitive filtrate, so clay swelling does not take place like conventional drilling fluids.

e. The bridging agent which is present in the NDDF bridge the pore throat and it basically forms an external filter cake. And it is easily removable when compared to the internal filter cakes generated using conventional drilling fluid.

g. Calcium Carbonate imparts high specific gravity to NDDF (Instead of barites in conventional muds) and it can be removed later using acids.

h. In the presence of dispersants fine clay particles can be generated inside the matrix. This will further clog the pores. Since NDDF does not contain any dispersant, no clogging takes place due to dispersion generated fines.

III. NDDF AS A SUSTAINABLE SOLUTION FOR DEPLETED RESERVOIRS

The success of any drilling operation is strongly related to the performance of the drilling fluid. The drilling fluid performance is a function of several factors such as drilling-related formation damage and wellbore [10]. However, the evaluation of any drilling fluid is based not only on its performance, but also on its cost and its effect on health, safety and environment. The key factor that should be kept into consideration while designing the drilling fluid is its cost and its effect on environment. The complex drilling fluid constitutes 15-20 % of the total cost of petroleum well drilling operations. The new wells drilled for producing the black gold today go through or into zones in the formation that have previously been producing or have already produced. The justification for this could be that a prevailing reservoir needs to be drained from another location conducive to augmentation of the hydrocarbon recovery. Thus, the use of conventional drilling fluids to drill such pay zones, especially in the case of depleted reservoir is no longer acceptable, due to its damaging effect to the wellbore and its harmful effect on the environment. But the drill in fluids or NDDFs are economically feasible, environment friendly and easily decomposable. The mud system synthesized also addresses the unique problem of maintaining a low solid and low density while preventing any abnormal lost circulation problems and also maintaining a non-invasive filter cake on the wellbore. Therefore, these types of drilling fluids can be considered as a wise choice for future drilling operations in opposition to conventional muds.

IV. DESIGNING OF LEAST DAMAGING DRILLING FLUID FOR DEVELOPMENT WELLS

The experimentation was based on the general methodology of formulation of a NDDF as used by Mandal [11] The mud system was modified as required to suit the requirements. The qualitative requirement was formulation

of a mud that contained low solids and a very low fluid loss. Such a mud system is desired to prevent problems like wellbore instability, lost circulation and differential sticking.
The general constituents used for the formulation of this NDDF are:

1. Base fluid: fresh water
2. Viscosifier: Xanthum Gum polymer
3. Fluid loss control / coating agent - PAC-LV (Polyanionic Cellulose-Low Viscosity), PAC-R(Modified Natural Polyanionic Cellulose Polymer)
4. Shale/clay inhibitor-Potassium Chloride
5. Weighing and bridging materials: FCC (Flaked Calcium Carbonate), MCC (Micronized Calcium Carbonate)
6. pH Controller: Sodium Hydroxide (NaOH)
7. Bactericide or Biocide: Aldehydes to control the bacterial degradation of Polymer/Starch used and Defoamer (1-Octanol) is added as per requirement

Salts are generally used as primary weighing agents while preparing a solid free mud system.In previous studies attempts were made to reduce this fluid loss and it was decided to use Micronised Calcium Carbonate as the primary weighting agent instead of NaCl to reduce the solid content. Micronized Calcium Carbonate (MCC) and Flaked Calcium Carbonate (FCC) are used as bridging and weighing agents in drilling through productive formations as they prevent the formation of internal filter cake and are 98-99.5 percent soluble in 7.5-15 percent Hydrochloric Acid (HCl) solution. The idea behind the development of drilling fluid was also to avoid fines and polymer plugging by optimizing the Particle Size Distribution (PSD) of fine and medium sized particles of calcium carbonate. The experimentation involved in the study tested the weighing agents at different concentrations against the test of the properties that the substances were supposed to imbibe into the drilling fluid. Calcium Carbonate has a specific gravity of 2.60 which is significantly higher than that of NaCl which is 1.2. Compared to NaCl, less amount of $CaCO_3$ is added to prepare the NDDF. Now it became easy to control the rheological properties of the system. This was done to obtain an optimum amount of the substances that were required to be used in the NDDF.

XC (Xanthan Gum) Polymer which is a premium grade viscosifiers was used along with PAC-LV (Polyanionic Cellulose-Low Viscosity) to maintain the viscosity. XC polymer is widely used because it possesses the ability of building viscosity in fresh and salt water both in the absence of any other additive. Low Viscosity-Polyanionic Cellulose (PAC-LV) was used to control fluid loss while ensuring that there is less appreciable change in viscosity. It has a similar molecular structure to carboxymethyl cellulose (CMC). However, it is considered better than CMC in terms of filtration reduction, anti-salt, anti-collapse, and high-temperature resistance. It can be used at temperatures up to 150°C. PAC-R (Modified Natural Polyanionic Cellulose Polymer) is generally incorporated in the design of NDDFs in order to minimize the fluid loss. Potassium Chloride was also added to the mud as shale inhibitor. Studies and field experience indicate that complete shale stabilization cannot be obtained from polymers only and that soluble salts must also be present in the aqueous phase to stabilize hydratable shales. Now prior to performing various rheological test before hot rolling the pH of the mud was checked and pellets of NaOH were added to maintain it in the range of 9.0-9.5. Glutaraldehyde (biocide) was further used in the design to prevent bacterial degradation of biodegradable polymers.

Experiments were conducted to study the effect of biocide (Glutaraldehyde) while performing the LPLT test on formulation of NDDF. 7 mud formulations (Table 1) were prepared with different concentrations of Flaked and Micronized $CaCO_3$ in the absence of Glutaraldehyde and Potassium Chloride (KCl) and the same were prepared in the presence of Glutaraldehyde and Potassium Chloride (KCl).

A. LPLT Test

Seven solutions of flaked and micronized $CaCO_3$ having concentrations as shown below were prepared by adding them in 1000 ml water respectively. After preparing the solutions at different concentrations, the first set of the drilling fluid system having the following formulation were prepared:

1) Xanthan Gum Cellulose Polymer – 0.5 %
2) PAC LV (Polyanionic Cellulose Low Viscosity)- 1.5%
3) PAC R (Modified Natural Polyanionic Cellulose Polymer)- 0.15%
4) NaOH - 0.1%

The other set of 7 NDDF formulations were prepared using the same solutions and additives for first set after performing the reheological test along with the inclusion of 2% biocide (Glutaraldehyde) and 3% Potassium Chloride (KCl).

Table 1: Table showing quantity of individual weighting agent added to the samples

Sample No	Flaked CaCo3(gm)	Micronized CaCo3(gm)
1	50	50
2	75	100
3	100	100
4	100	125
5	125	100
6	125	125
7	150	150

Figure 4: LPLT Filter Press

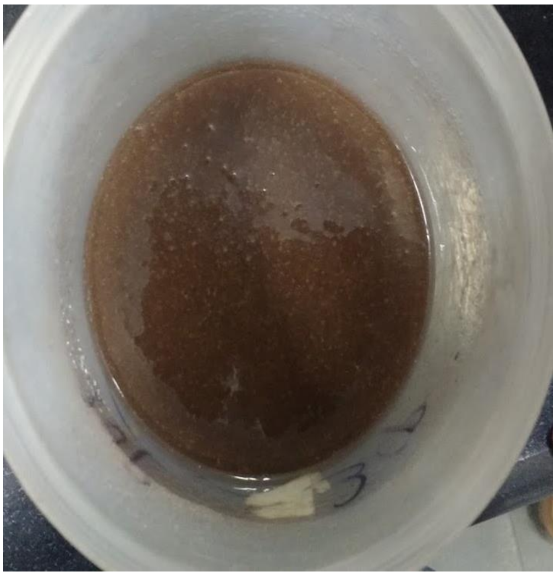

Figure 5: Prepared Mud Sample

V. AN IMPROVED NDDF DESIGN FOR SUSTAINABILITY

After performing the API Filtration tests for the 2 sets of NDDF with varying concentrations of Micronized and Flaked $CaCO_3$, the deviation in Fluid loss can be seen in and without the presence of Glutaraldehyde and KCl. A rapid degradation happens in the NDDF without biocide and makes the mud unsuitable for drilling operation. The biocide has a great role in NDDF to decrease the degradation rate of the Polymers and Starch and retain the mud properties within their optimum ranges. Even a very small composition e.g., 0.05% of Biocide has a great effect on the biodegradation rate. This can be elucidated from the Figure 4 that explains 2 sets of mud formulation with and without the addition of biocide (Glutaraldehyde). The mud cake thickness should be optimum while designing the drill in fluid. If the mud cake thickness will be more, the operators will face problem during production. On the contrary, if the mud cake thickness is very less, the formation damage will be maximum. It can also be observed from the Figure 5 that the addition of Glutaraldehyde has a huge impact on the mud cake thickness in LPLT test.

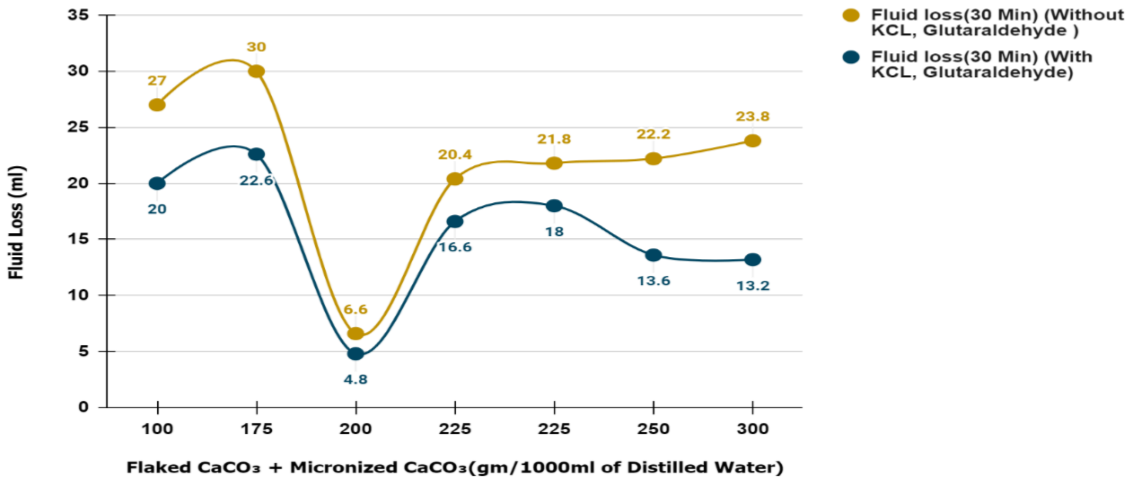

Figure 4: Variation of fluid loss (with and without addition of Biocide and Glutaraldehyde) for different mud concentration samples

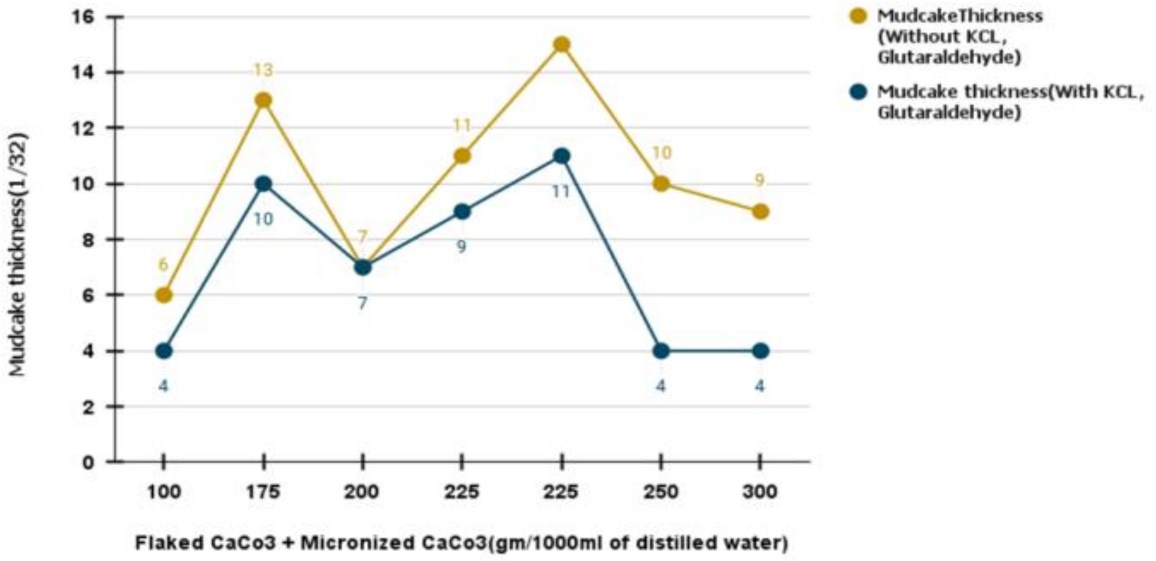

Figure 5: Variation of mud thickness (with and without addition of Biocide and KCl) for different mud concentration samples

VI. SUMMARY

All the reservoirs in the world are heterogeneous with different properties and characteristics in different locations. Therefore, the composition of any constituent or the value of any properties of NDDF to serve any function will not be specified. Water was used as the continuous phase in designing of non-damaging drilling fluids. The extensive utilization of water for designing NDDFs is ascribed to its low cost, its availability, its correspondence with human health, and the reasonable nature in its application. Modification of the composition of the NDDF to account for its inadequacies related to rheological properties resulted in the augmentation of its cost. However, the environmental compatibility and sustainability of such drilling fluids compared to conventional water and oil-based drilling muds have kept it the extensively used and widely accepted drilling mud. Properly sized Calcium Carbonate has been in use for a long time as a bridging agent. However, due to the requirements of the depleted reservoirs, a formulation with a very low solids content was required to be made. Initial tests were conducted using NaCl which gave a very high fluid loss. A control on the fluid loss was succeeded by an addition of Micronized Calcium Carbonate to bring down the solids content of the mud further, with the goal of maintaining the fluid loss of mud. The use of combination of Micronized and Flaked Calcium Carbonate served two functions – as a bridging as well as a weighting agent, unwarranting the use of NaCl while formulating the mud. This also brought down the solids content of the mud, since Calcium Carbonate was used to achieve two properties of the mud. The addition of biocides like formaldehyde are vital in the designing of NDDF, so that deviation in the rheological properties will be minimized.

NDDF can be disposed anywhere as the additives involved in the formulation of such types of mud are degradable and environmentally friendly. It can also be elucidated that the NDDF is giving almost same or better rheological properties as the conventional drilling fluid. So, all the properties of the conventional drilling mud can be obtained by varying the composition of components of non-damaging drilling fluid. It can also be concluded that non-damaging drilling fluids are most efficient, easily decomposable, cost effective and environmentally friendly. Preparation of such types of muds in future for further exploration of the black gold can save the Earth from deterioration.

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