RA Journal of Applied Research
||Volume||1||Issue||08||Pages-313-321||Sept -2015|| ISSN (e): 2394-6709
www.rajournals.in DOI : 10.18535/rajar/v1i8.04

Estimating The Weighting Effect Of Nanoparticles Of Mud-Solids And Formation-Imported-Solids While Drilling.

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ABSTRACT

Nanoparticles impregnation into water-based mud has proven beneficially qualitative in shale oil formation drilling and cost effectiveness in total well drilling budget. Nanoparticles modified drilling mud have further shown tremendous improvement in its performance and stability to temperature and formation pressure changes with depth and importantly, cutting lifting and suspension capability in the annulus. Consequently, this study is set to prove that, the fraction of nanoparticles in the pore-throat of drilled shale cuttings can instill significant increase on the hydraulic pressure head of drilling mud. Also set a precursor in the analysis for basic design of nanoparticle modified drilling mud, and for optimized drilling operation by petroleum exploration and productionindustry. The results obtained in cause of this research were exhaustively communicated in semi-logical, critical and analytical form for easy understanding. However, these discussions adopt sectioning with respect to the phases format applied in the methodology. These results concluded that the hydraulic pressure head is actually affected by these fractions of nanoparticles in a minor rate. Thus, caution should be imbibed in increasing the concentration by weight of drilling mud density when using nanoparticles as mud additives to avoid shale instability problems.

KEYWORDS: Shale Oil Formation,Mud Filtrate, Nanoparticles**,** Hydraulic Pressure

1.0 INTRODUCTION

For the past decades, drilling mud rheological advancement has been achieved in relationship to hydraulic pressure characterisation. Obviously, the effects of nanoparticles in the modification of the rheology of muds during drilling operations have triggered the concern of the petroleum industry, to successfully design mud programmes in drilling through shale oil formations. Furthermore, this rheological advancement is based on the effective and efficient formation-pore-plugging of nanoparticles into porous-and-permeable formations.On the contrary, shale is of low porous and of low permeability; this reason qualifies nanoparticles best choice for drilling shale oil formation. Therefore, It is of no doubt that the "beware of nanoparticles," the catch phrase that begot nanotechnology into the petroleum industry cannot be overemphasized. However, many researchers have used this dawning nanotechnology to evaluate the consistent recordings of altered hydraulic pressure and other salient drilling mud challenges with bias to the weighting effects of nanoparticles of mud-solids, particles corroded from drilling strings, and formation-imported-solids, which comprehensively mix with the initial designed drilling mud at drilling operations through shale oil formation.

Consequently, for the past years, research has focused on the effects of nanoparticles in drilling operation.Accordingly, Maen(2012) conducted a study on the performance of nanoparticles on mud cake formation and fluid loss in explorative formation. Maen's findings suggested positive effect of nanoparticles on drilling operation as reduced cake thickness and fluid loss. Similarly, Riveland (2013) in course of investigating the effect of nanoparticles to enhanced oil recovery, Riveland appraised nanoparticles as favorable to drilling even shale oil formation, due to its thin filter cake formation ability. Furthermore, in demystifying nanoparticles filter cake formation, it is established that the solids (nanoparticles) are significant part of what dictate the mud rheological properties (Jamal *et al.*, 2013). In the same vein, Samsuri and Hamzah (2011) disclosed that cutting transportation capacity of drilling mud depends on the mud rheological properties and flow rate, particles sizes, sizes distribution, drill bit penetration, mud density and particle settling velocity. Furthermore, Samsuri and Hamzah demonstrate that the use of nanoparticles in the design of drilling mud for drilling operation improved fluid loss impedes and reduced filter cake formation. However, these mud rheological properties; specially cutting lifting enhancement feature of nanomaterial designed mud is hydraulic pressure head functionality.

Typically, cutting transportation in the annulus solely anchors on the hydraulic pressure head of the mud column. This in turn depends on the mud density controlled by the particle sizes and distribution (nanoparticles) as additives. Nonetheless, these nanoparticles form impermeable membrane on the wall of the formation that prevents fluid loss to formation. The main application of nanoparticle in drilling mud design is to form a thin layer non-erodible and impermeable nanoparticle membrane around the wellbore which prevent common challenges like shale swelling. In fact these shale swelling challenges serves the underpinned reason for this research study as it further possess the following challenges; shale oil formation instability, wellbore instability, bit balling, cutting disintegration, drill pipe stocking leading to increased torque and drag, hole enlargement and closure (VanOort, 2003; Mitchell, 1993; Al-Bazilli 2006). The non-erodible impermeable nonaparticles around the wellbore inherently with the cuttings that were breaking out of the formation (shale oil formation) may be weighty and have significant effect on the hydraulic pressure head of the mud column. This paper however, is aimed at estimating the percentage increase in hydraulic pressure head due to increased cuttings weight caused by nanoparticle cake formed on the pore-throat and coagulated-throats of the drilled cuttings and its surface. The results obtained will be used to examine the effect of nanoparticles while drilling through the shale oil formation Nano-Pore-Throats with the drilling mud column.

2.0 METHODOLOGY

2.1Materials

The experiment was performed using a bespoke rig; the rig specification is made in line with recommended standards for rig design.Six

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samples of Atoka shale were separately collected at same depth to avoid porosity variation with respect to depth. The samples were appropriately preserved and transported for purposes of consistency with field conditions. A wellbore of 8.5" was drilled into the Atoka shale oil formation sample with a penetration rate 4ft/hr producing 170ml volume of cutting having a porosity of 0.44nm.Each of shale samples were drilled using silica nanoparticles modified mud with nanoparticles concentrations range of 10wt%, 15wt%, 20wt%, 25wt%, 30wt%, and 35wt%, respectively. And to each of the experiment, some corresponding 28 pieces of (87.0, 87.2, 87.3, 87.6, 87.8, and 88.0)μm sizes of cuttings were collected at the screen for the analyses.

2.2 Data Extraction Technique and Formulae Used

2.2.1 Phase I: Nano-Particles Drilling Mud Modified Rheological Properties

Drilling mud properties are the vital parameters that interprets the quality of a proposed drilling mud, and in this work, these qualities onAtakoMud+Nyacol 9711 silica NPs are appraised using API RP 13B-1, 2012, recommended formulas and procedures.

2.2.1.1 Effect of Nanoparticle on Mud Rheological Properties to Shale Pore-Throat Plugging

Shale nano-scaled pores warranted the use of nanoparticles as mud additives to plug the pores by forming filter cake internally and at the wellbore wall. Here-in, this is examined in the laboratory using API specified Filter Press and appropriate tools to measure the thickness of the cake.

2.2.2 Phase II: Evaluating the Volume of Nanoparticles Formed Mud Cake in the Pore-Throat Volume of Shale Oil Formation Cuttings

It is established that shale oil formations are of low-permeability and low-porosity. Furthermore, their pore-throats are confirmed nano-scaled. On this premise, this research assumed that the pore-volume is filled only with nanoparticles, and therefore the mud cake volume formed is equivalent to the pore-throat volume.

2.2.2.1 Mud Cake Volume cum Pore-Throat volume Estimation

Katze and Thompson (1986) assumed that the product of porosity and permeability is equal to pore-volume. Similarly, Nelson and Batzle (2006) related permeability to the porosity and pore-diameter to evaluate pore-throat volume. Therefore, this work uses these principles to estimate its internal mud cake volume.

$K \approx 4.48\emptyset^2 d^2$ … 2.1 (Katze and Thompson, 1986)

Where $\emptyset = (K/4.48d^2)^{1/2}$ … 2.2

$Pore\text{-}Throat\ Volume\ (P_V) = \emptyset * k$ … 2.3 (Nelson and Batzle, 2006)

Cumulative Pore-throat Volume (CP_V) $=\sum_1^{28} PV$ … 2.4

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2.2.3 Phase III: Estimation of Cumulative Mud Cake Weight

Using mathematical principles for 'measure of central tendency'.

$$\frac{Cumulative\ weight\ of NPs\ one}{Cumulative\ volume\ of NPs\ one} = \frac{Cumulative\ weight\ of\ NPs\ two}{Cumulative\ volume\ of\ NPs\ two} \quad \ldots \quad 2.5$$

$$\frac{CNPsW1}{CNPsV1} = \frac{CNPsW2}{CNPsV2} \quad \ldots \quad 2.6$$

2.2.3.1 Fractional Estimations of NPs Weights and Volumes

Fractional volume of solid = 100* solid volume divided by total sample volume. Solids in this case are nanoparticles. Mathematically,

$$\varphi_{\mathrm{NPv}} = 100 * \frac{NP\ solid\ vol}{Total\ mud\ sample} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

$$\varphi_{NPw} = 100 * \frac{NP\ solid\ weight}{Total\ mud\ sample\ weight} \ldots\ldots\ldots\ldots\ldots\ldots 2.8$$

Therefore, percentage Density of Nanoparticles Faction,

$$\rho NPs\% = \varphi NP_w \div \varphi NP_v \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

Cumulative fractional density will be,

$$\sum_1^{28} \rho NPs\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.10$$

2.2.4 Phase IV: Evaluating Hydraulic Pressure Head Using the Cumulative NPs Density

In over drilling operations, the hydraulic pressure head is the controlling parameter as it can cause wellbore instability if not carefully handled. This parameter depends on the mud density and depth of application (Bourgoyne *et al.*, 1986). Hence, the model for estimating the hydraulic pressure as follows:

HP = 0.052*MUD*TVD ....2.11(Bourgoyne *et al.*, 1986)

This work onlyconsidered the weight of nanoparticles formedin the pore-throats.

3.1.1 EFFECT OF NANOPARTICLES ON MUD RHEOLOGICAL PROPERTIES TO SHALE PORE-THROAT PLUGGING

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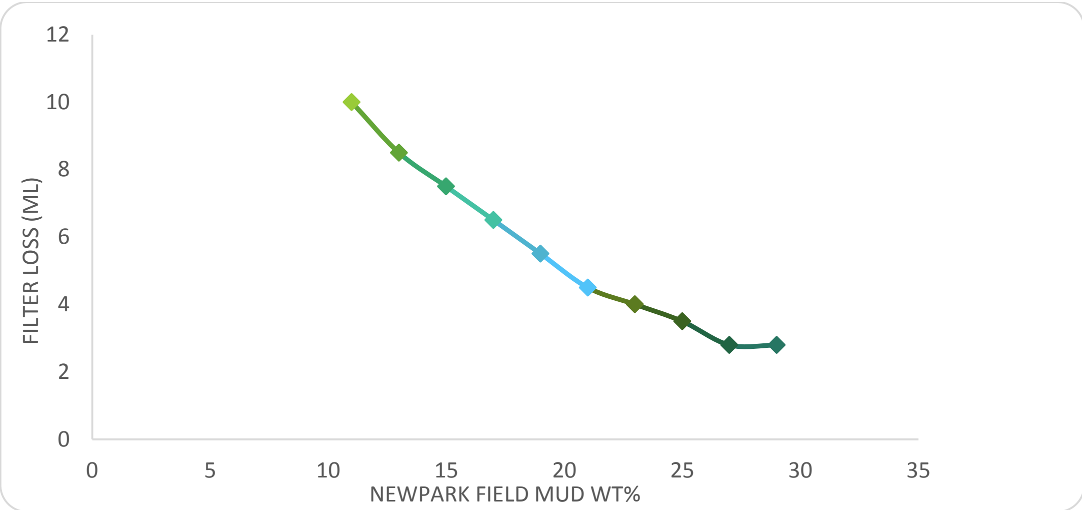

Figure 3.1a Drill Mud loss into shale formation using Field Mud

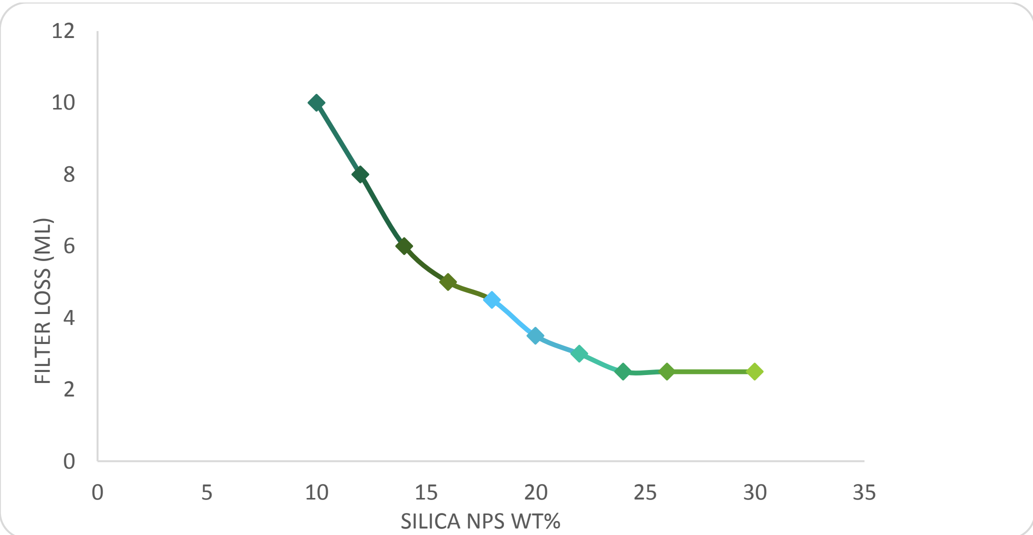

Figure 3.1bRate of drill mud loss using Field Mud+ Silica NPs

Controlling the rate at which drill mud invade shale oil formation is the major reason for the use of nanoparticle modified fluid in drilling unconventional formation. From figure 3.1a it can be interpreted that drilling mud in-filtration into shale oil formation is significantly high and reduces slowly with increasing Field mud concentration. The slow reduction in mud loss indicate a gradual mud cake build-up in the pore-throats of the shale sample and stabilizes at 2.8ml while continues invasion at 30wt% field mud concentration. Similarly from figure 3.1b, it can be depicted that the addition of Nyacol 9711 silica NPs reduces the rate of mud invasion to a minimum of 2.5ml at 30wt% NPs concentration. This shows that there exists a reducing external cake formation while inversely an increasing internal pore-throat cake formation that causes the

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pore plugging effect on the nano-scaled pore-throat volumes occurs. Finally from the behaviours of figure 3.1b, it is inferred that silica NPs mud cakes are actually built,and same plug the pore-throats during application in shale oil formation drilling operations.

3.2.0 Result of Estimated Volume of Nanoparticles Formed Mud Cake in the Pore-Throat Volume of Shale Oil Formation Cuttings

3.2.1 Mud Cake Volume cum Pore-Throat volume and Estimated Cumulative weight

Shale oil formation is characteristically a fine-gained soil that prospectively accommodate hydrocarbon. Its fine-grained nature with respect to depth of burial gives it that unique compaction feature. Compaction of this formation is enhanced by the reduced zeta-potential of the constituent clay to clay ionic attractive forces between particles or clay-platelets. This phenomenon imposes the Atoka shale formation with very small intra-grain spaces recognized as pore-throats of the formation as a pathway for hydrocarbon migration. Depicting from equation 3.1, the pore-throat volume is directly proportional to the product of porosity and permeability which as evaluated to be influenced by compaction forces as stated earlier. Furthermore, the dependent variables of the pore-throat are: the pore diameter, permeability and porosity.

$$\textit{Pore-Throat Volume } (P_V) = \emptyset * k \quad \ldots \quad 3.1$$

Subsequently, equation 3.2 also estimates the cumulative pore-throat volume dependently on the number of shale cuttings selected and obtained at the screen randomly.

$$\text{Cumulative Pore-throat Volume } (CP_V) = \sum_1^{28} PV \quad \ldots \quad 3.2$$

3.3.0 Result of Estimated Fractional NPs Cumulative Volumeand Weight

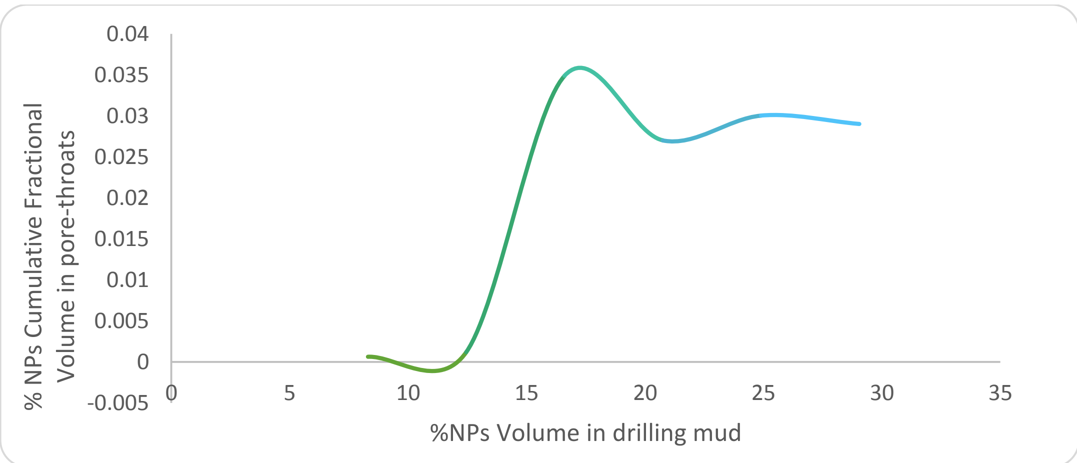

Figure 3.2a: Percentage faction of NPs volume in drilling mud Vs Cumulative fractional NPs volume in nano Pore-throat

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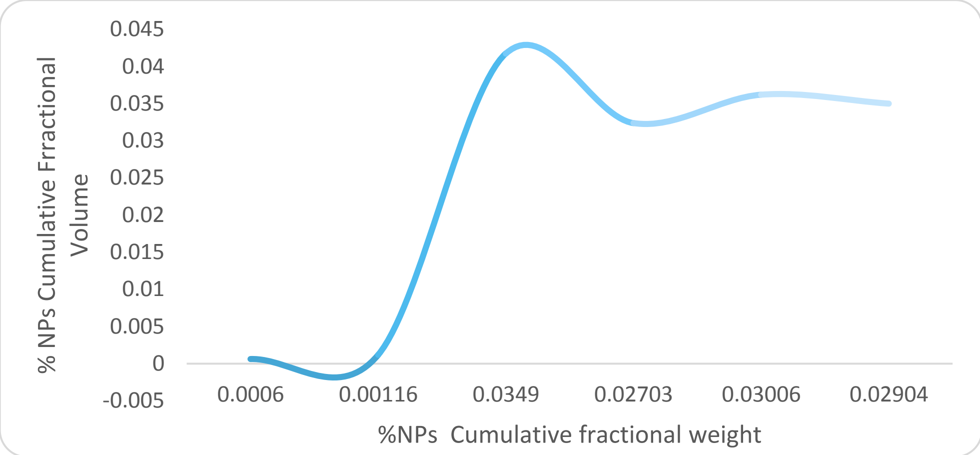

Figure 3.2b: Percentage cumulative NPs fractional volume against weight extracted from pore-throat

Figure 3.2a shows the plot of the percentage cumulative fraction of nanoparticles that invades the nano-pore-throat of the formation from the respectively used percent of increasing nanoparticles concentration. The figure shows that a little fraction of nanoparticles leaves the parent mud in the wellbore into the pores of the formation. This little fractional incremental value is observed subsequently as the percentage fraction of nanoparticles concentration increases. These values are quantitative indication of the very small scaled pore sizes noted with shale formation. Similarly, as can be learned from figure 3.2b showing result of the percentage cumulative fractional volume and weight of NPs internal mud cake formed in the pore-throat of Atoka shale oil formation as shown on the line plot.At the vertical axis of figure 3.2b the fractional volume appears increases upward through the axis at a very small rate. The small increases in estimated values of the fractional volume infer the nano-sized porosity anisotropy of shale formations. Concomitantly, at the horizontal axis of same figure 3.2b, the corresponding cumulative fractional weight of these NPs cake volume vindictively shows small values as a dependent variable on the volume of these NP cake. Furthermore, the fluctuation of the line plot is due to changes in pore diameter during the vibration impulse propagation as drill bit breaks the formation and due to the force of fall of cutting on the receiving screen. Conversely, the small increase in the weight values is in accordance with the characteristic feature of shale formation pore volume anisotropy as assumed filled with nanoparticles alone been confirmed to be nano-sized in porosity and diameter.

3.4 Result of Cumulative Fractional NPs Cake Volume Density and Its Effect on the Hydraulic Pressure Head.

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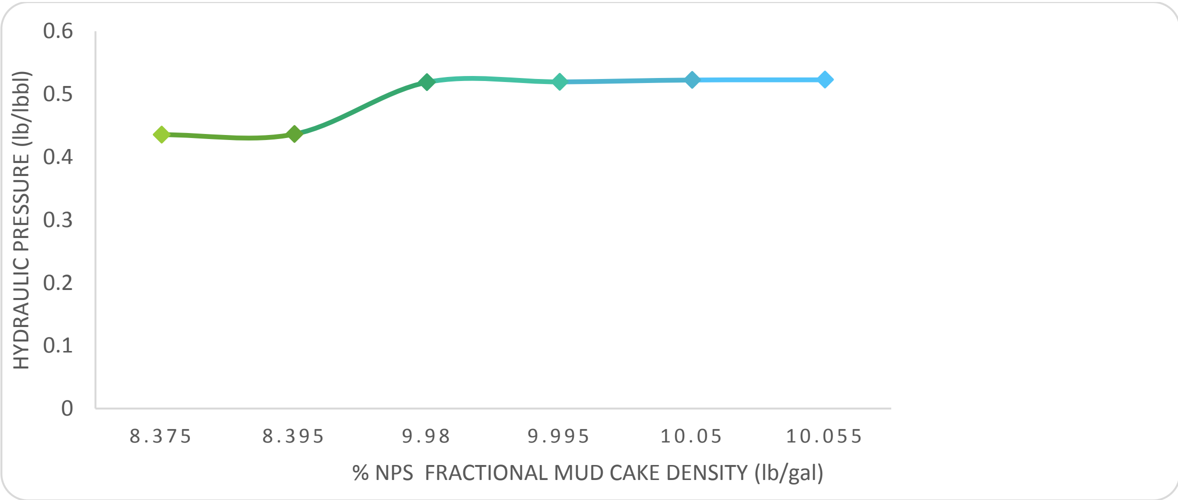

Figure 3.3: Graph of weighting effect of percentage NPs fractional mud cake density on the hydraulic pressure

The weighting effect of percentage nanoparticles cumulative fractional internal mud cake density on the hydraulic pressure head is shown in the figure 3.3. This shows that the effect of the fractional nanoparticles formed internally mud cake density is very minimal. This implies that, the fraction of nanoparticles that settles or invades the shale oil formation is infinitesimal, about 44% to 52%. This phenomenon was also suggested by bourgony*et al.* (1991). However, this suggest that in designing a drilling mud using nanoparticles as additives aimed at reducing mud filtrate rate actually will be achieved. On the contrary, increasing the concentration by weight of these nanoparticles due to intermediate targeted depth approach or observed increase in pore pressure without proper prediction of percentage weighting material to be added stands a risk of causing shale instability challenge. This is due to the fraction of nanoparticles that will stay put in the wellbore drilling mud portion as justified by this research, of the small fraction that actually invades the pores which shows insignificant effect on the hydraulic pressure head. Furthermore, the increased remaining portion of these weighting nanoparticles can cause increase of the mud viscosity therefore will reduce the cutting lifting capability of the drilling mud as one of the primary function of drilling musd. Consequently, cuttings settling at the bottom of wellbore may occur, hence reducing bit penetration rate and bit balling effect relating to other several severe challenges to the drilling of shale oil formation which under normal circumstances would have being a successful operations.

4.0 CONCLUSION

From this research, the following conclusion weremade;

- Using or adding nanoparticles as drilling mud additive undoubtedly shows very beneficial in improving drilling mud rheological properties to suit shale oil formation drilling without damaging the formation as proper design precursors are observed.
- Finally, the hydraulic pressure head is actually affected by fractions of nanoparticles in a minor rate. Thus,

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caution should be imbibed in increasing the concentration by weight of drilling mud density when using nanoparticles as mud additives to avoid shale instability problems.

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