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Comparative Analysis of PAC-L Additive with Silica Nanoparticles of a Water–Based Formulation

Nnaemeka Uwaezuoke, Kevin C. Igwilo, Emmanuel C. Anya*

Department of Petroleum Engineering, Federal University of Technology, P.M.B 1526, Owerri, Nigeria

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Abstract

Silica-nanoparticle (SiO_2, NPs) as a nano-technological unit has a huge potential for improving a drilling fluid property which have immensely attracted higher global utility in the last couple of years in the oil and gas industry for all kinds of drilling and reservoir engineering activities. A comparative analysis of the performance of a silica-nano reinforced drilling mud, conventional drilling mud (control mud) and a drilling mud formulated with no fluid loss additive (PAC-L) to control/prevent high filtrate loss and to improve mud-cake thickness was conducted. 0.2g, 0.15g, and 0.1g (concentration) of PAC-L were dispersed into the respective drilling muds and rheological properties were measured. It was observed that the nanosilica reinforced mud exhibited improved properties compared to conventional PAC-L mud formulations.

Keywords: *Conventional drilling fluid; Nanosilica; PAC-L; Rheological properties; Reinforced drilling fluid.*

1. Introduction

A drilling fluid is a viscous fluidic mixture used to aid drilling various kinds of boreholes (vertical, directional) into the earth subsurface for extraction of solid-minerals, crude oil hydrocarbons, natural gas, and water from the earth's subsurface. They are fluids typically used in drilling operations and carries along the drilled rock cuttings from bottom of the hole being drilled, such that the concentration of cuttings around the drill bit is minimized [1]. The success and cost of a drilling process is largely dependent on the composition and asset embedded in the drilling mud being utilized in a drilling operation [2-4]. Drilling muds also help to primarily control the well against pressure challenges encountered while drilling wild formations in the reservoir through the combination of density and addition pressure from the mud fluid column at the surface facility. The performance of the drilling fluid is of upmost importance to every personnel involved with the operation and to all aspect of drilling operations. Drilling fluids especially water-based mud are reactive to clays and this leads to time – dependent boreholes problems in shale reservoir. However, high temperature has been shown to affect flow properties [5]. Some important properties of drilling fluid can be classified into (i) fluid loss, (ii) gel strength, and (iii) mud cake strength. The rheological parameters can be characterized in-situ [6], alongside the behavior of drilling mud in circulation. High fluid loss and low mud cake thickness are some challenges encountered during drilling operations because of high hydrostatic pressure differential coexisting between the formation and well head. On account of this high pressure occurrence the drilling mud losses its liquid phase (filtrate) completely into the drilled formation due to deficiency in the drilling mud properties to withstand high temperature and pressure condition on account of being either poorly formulated or having substandard drilling mud constituents/ chemical additives to avert this issue. However, PAC-L is mainly a naturally modified polyanionic cellulose polymer. It provides fluid loss control in bentonite – based drilling fluid and increase water absorption capacity. They are readily dispersible in water, improves filter cake properties of bentonite mud.

Nano particles are invisible packed unit of molecules, electrons, protons, atoms that are found inside the nucleus/inner core layer of nano-materials occurring naturally or made artificially example include: Fe_2O_3, Al_2O_3, Clay, Ti_2O, Fe_3O_4, SiO_2, CuO, MWCNT, clay hybrid. They are generally of spatial dimension ranging from 1-100nm in diameter and also with an average atomic size of 0.4nm in thickness they are of high significance in building nanostructures and some of their very important properties include lower melting points, higher specific surface areas, specific optical properties, mechanical strengths, and specific magnetizations that might prove to be attractive in various industrial applications. Thus, the introductions of nanotechnology have been recently considered to explore its potential to avert these issues. Nanoparticles have been subdivided, and surface functionalized with array of metal ions, small molecules, surfactants or polymers, covalent like bonds created. It can also be synthesized by some organisms [7-10]. The listed types of nanoparticles whether polymer, ceramic or metallic-based nanoparticles exhibit properties dependent upon their core, shell, and dimensions [11]. Properties of silica nanoparticles and recommended rheological properties are presented in [12].

2. Applications of nanoparticle in oil and gas industry

Production of oil and natural gas has immensely brought about a huge gain economically, environmentally, financially, technologically to man and his surroundings holistically. Due to this fact, has drastically augmented the rising, daily and persisting world energy demands and energy consumption globally and locally. Due to this fact, new and novel technologies in oil production such as directional drilling and horizontal hydraulic fracturing rapidly require implementing new technologies in oil and gas production. For instance, in drilling activities drilling fluids play a significant role in drilling oil and gas reservoirs etc. But due to technical, economical, and environmental issues, they are challenging subject matter which requires thorough study and understanding to.

In addition, the drilling fluid has some significant basic functions such as (i) lubrication and cooling bits and drill strings (ii) ability to release the cuttings at the surface, (iii) reduction of adverse effects to formations around the wellbore. Nanotechnology has gained attention in the last decade in the oil and gas industry. More often, one main usage of nanomaterials in the oil and gas industry is in the section of developing novel kinds of drilling fluids. This investigative result and analysis showed that NPs could be used as suitable additives to improve drilling fluid properties. Their mechanical properties have been measured, and the advantages of mechanical, hydrodynamic, thermal, electrical, chemical properties and interaction potential of NPs [13-15] compared to other materials make them suitable. Also, the micro and nanofibers have been shown to possess many applications [16]. Moreover, NPs have extensive capabilities drilling in high pressure and high temperature (HPHT). Silica based NPs have been used to conduct tests at ultra-high temperature and pressure [17-18]. In summary, nanoparticles improve drilling fluid properties which include;

(i) Mechanical properties

Rheology and fluid loss stability characteristics and properties of non-damaging drilling fluids with silica NPs were evaluated in a study [19]. The non-damaging drilling fluids in this investigation produced by polyamine indicated that silica NPs reduce fluid loss by 31% and thinning behavior of mud increase within NPs concentration. [20] investigated the effect of clay NPs on rheological and mechanical properties in water base drilling fluids. Experimental tests were conducted in static fluid-loss prepared with and without clay NPs consisting. The results showed nano-clay controls the fluid loss into the shale layers, thickness of mud cake and is resistant to high temperatures and fluid loss. This research showed that the viscosity of solution always increased with temperature decreased but this decrease rate change with additional nanoparticles. Also, modified clay NPs have been tested for application in deep hydrocarbon wells [21]. In another research, [22] added silica NPs in WBM and their results illustrated that the novel drilling fluid can decrease 35.61% shale cuttings. Their results showed that the nano-particles due to the repulsive forces between the NPs and the drilling fluid additives caused a slight reduction in PV. More deeply, [23] studied different concentrations silica NPs drilling solutions for increase drag and lift forces target. They concluded that NPs additives increase efficiency of cuttings transportation as well as, enhanced colloidal forces.

(ii) Thermal stability

There are some researches about high temperature/high pressure and high temperature/low pore pressure drilling fluids in recent years, but they are still a huge challenge to drilling industries. In recent years, numerous investigations have been reported for application of NPs as thermal stabilizer in the formulation of drilling fluids. The possibility of incorporating magnesium, aluminum and silicate NPs in WB drilling fluid was investigated by [24]. The mixture prepared with the WB improved the rheological, filtration properties, and thermal stability. Moreover, the application of the magnesium aluminum silicate NPs in WB drilling could substantially decrease the use of conventional one, which is beneficial for environment. [25] reported that nanoparticles of magnesium aluminum silicate can exhibit excellent thermal stability. Another research [26] further highlighted that addition of NPs in drilling fluids enhance their thermal and electrical properties.

(iii) Wellbore stability

Many researchers have studied the effects of nanomaterials on improving wellbore stability in unstable formations. The combination of polyethylene glycol and nano-silica was investigated in a recent research work and results have indicated that this formulation could be an appropriate shale stabilizer in water-based drilling muds [27]. In addition, the blend was used as effective agent to plug shale pores and cracks. Graphene derivatives can be as a filter (pore-plug) in oil base drilling fluids due to suitable stability in the aqueous medium. However, the performance of graphene derivatives in water base drilling fluids is an issue because of poor dispersion in aqueous media etc. Further applications of nanoparticles in drilling fluid technology are highlighted [28].

The aim of this research is to carry out a comparison between a nanosilica reinforced drilling mud, conventional drilling mud (control mud) and a drilling mud formulated without a fluid loss additive. The mud formulations are compared based on fluid loss, mud cake thickness, and other rheological properties.

3. Materials and method

3.1 Materials

Here, a basic outlay of materials used during the experiment, practical procedures, in-depth methods and experimentation approach utilized, source data and information gathered, result analysis and comparisons are presented. All the raw materials used and their function(s) during the experiment include (Table 1):

Table 1. Materials used and functions.

S/n	Material	Function(s)
i	Fresh water	Base fluid
ii	Bentonite	Viscosifier
iii	NaOH	pH control
iv	Barite	Weighting agent
v	Polyanionic cellulose (PAC-L)	Fluid loss control and mild viscosifier
vi	Carboxy-methyl cellulose (CMC)	Fluid loss control
vii	Nanosilica (nanoparticle) or clay (hybrid)	Fluid loss and rheology control

All raw materials in Table 2 were all utilized and prepared in adequate quantities in the laboratory for both experiments involving the nanoparticle reinforced drilling mud from a nano-materials (nano-silica, nano-clay) to solve various filtration and mud-cake thickness challenges using API specification. Laboratory equipment/apparatus which were used for this experiment and their respective functions include (Table 2).

Table 2. Laboratory equipment/apparatus.

S/n	Equipment/apparatus	Function(s)
i	Centrifuge	Separates various components in a fluid mixture
ii	Electronic mud mixer	To mix fluids with solids
iii	Filter paper	Used to recover solid particles i.e. serves as rock
iv	Measuring cylinder	Volumetric fluid measurements
v	Mud balance	To measure mud density
vi	Viscometer (Fann type)	Viscosity measurement
vii	API filter press	Fluid loss measurement
viii	Flexible steel ruler	Filter cake thickness

3.2. Method

This approach involves variation of PAC-L fluid loss control additive different formulated drilling mud samples. They are conventional mud, a nanosilica reinforced mud and a drilling mud with no-PAC-L additive as a suitable novel methodology to reduce issues relating to fluid loss, gel strength and mud cake thickness. The results were compared. The basic idea for this test involves comparing performances of a conventional drilling mud and nanosilica reinforced drilling mud when experimental variation of PAC-L dispersed as fluid loss control additive into a formulated conventional drilling mud with a specific volume and concentration, and nanosilica reinforced drilling mud formulated with a specific volume and concentration. To determine a refined approach to fluid loss issues and mud cake thickness challenges between conventional drilling muds, nanosilica reinforced drilling mud and another conventional mud formulated to combat filtrate loss and mud cake thickness problems in a high temperature high pressure condition. This fluid loss additive (PAC-L) were dispersed into various formulated water-based drilling mud containing bentonite, barite, NaOH, soda-ash, nano-silica as components.

3.2.1. Procedure for preparing a conventional and nanosilica reinforced drilling mud

Using the standard procedure and constituents for preparing a standard 9ppg mud weight as a blueprint or prototype to prepare a conventional mud and a nano-particle reinforced drilling fluid each about weighing 9ppg mud weight which was used for the practical demonstration.

i. Formulation of a conventional drilling mud

Step I: Firstly, sample materials (CMC, bentonite, PAC-L, barite, soda-ash) were weighed on a weighing balance for proper mixing ration required for mud weight of 9ppg for conventional water-based mud.

Step II: 332 mL of distilled water was measured and poured into a mud mixer cup mounted onto the Hamilton beach mud mixer.

Step III: The water is stirred using a multi-mixer while 0.25g of soda-ash was added into the water under agitation. Mixing lasted for about 2 mins.

Step IV: 15g of bentonite was added, and the solution stirred for 5 mins.

A total of 0.2g of PAC-L was added into the solution for another 5 mins. 1.5g of CMC was added, and the mixture was continually stirred for an additional 3 mins. The stirring was continued until at about a total 35 mins, then the 28g of an already weighted barite was added to formulate the drilling mud weighing 9 ppg.

ii. Preparation of nanosilica (SiO_2 NPs) reinforced drilling mud

Step I: Nanosilica (SiO_2, NPs) of respective amounts (1.5g, 2.0g, and 2.5g) were first dispersed into 332 mL distilled water, and 0.25g of NaOH (alkaline solution) in the mud cup before the dispersion of other drilling mud materials. Basically, according to [29], the dispersion of nanosilica must be stabilized to prevent the silica nanoparticles (SiO_2 NPs) from agglomerating and precipitating evenly out of the formulated drilling mud in form of colloidal particles. Nanosilica were dispersed under a strong pH condition above 9 to ensure stabilization and to ionize the surface of a nanosilica molecule with actively charged ion according to experimental research works on the stabilization of nanoparticles in high salinity, high temperature environment. Again, this solution of (water, NaOH and nano-silica) was stirred using the Hamilton beach mixer while 0.25g of soda ash was added into the solution. It was stirred for 2 mins.

Step II: 15g of bentonite and stirred for 5 mins.
Step III: A total of 0.2g PAC-L was added and stirred for 3mins.
Step IV: 1.5g of CMC was added, and the mixture was stirred for additional 3 mins.
Step V: The nanosilica (SiO_2 and NaOH) solution was then added into the mixture and then stirred again for 10minutes.
Step VI: The stirring is continued for at least 30 mins, and 27.99g of barite is added to formulate nanosilica reinforced mud sample of 9 ppg.

The rheological properties and mud density were measured. Similarly, the API fluid loss test procedure was used to obtain the fluid loss. The mud cake thickness was also measured and recorded.

4. Results and discussion

4.1.Results

American Petroleum Institute [30-31] standard procedures were employed to determine the fluid loss and other rheological properties as shown in Table 3 to Table 8, where PV (plastic viscosity) = (θ600 RPM - θ300 RPM) dial readings, AV (apparent viscosity) (θ600 RPM/2), and YP (yield point) = (θ300 RPM - plastic viscosity). The summary of the test results is shown in Table 9 and the filter cake thicknesses shown in Table 10.

However, low flat gel [32] was observed for conventional-mud with 0.2g PAC-L and nanosilica reinforced mud without PAC-L, whereas others exhibited continuous gels.

Table 3. Formulation and rheological properties of conventional mud with 0.2g PAC-L

Case 1: Sample A Conventional mud (control mud), with 0.2g PAC-L	Filtrate volume (mL)	Dial reading		Rheology ($lb/100ft^2$)			Gel strength ($lb/100ft^2$)	
		600rpm	300rpm	PV	AV	YP	10 (sec)	10 (mins)
Water – 332mL Soda – ash - 0.25g Bentonite – 15g CMC – 1.5g Barite – 27.99g NaOH – 0.25g **PAC-L - 0.2g** Mud weight = 9ppg	@ 5mins -8mL @ 10mins -10mL @ 15mins -11.2mL	40	30	11	20	20	5.4	7.0

Table 4. Formulation and rheological properties of reinforced mud without PAC-L

Case 1: **Sample B** (SiO_2,Nps) reinforced drilling mud	Filtrate volume (mL)	Dial reading		Rheology ($lb/100ft^2$)			Gel strength ($lb/100ft^2$)	
		600rpm	300rpm	PV	AV	YP	10 (sec)	10 (mins)
Water - 332mL Soda-ash - 0.26g Bentonite - 15g SiO_2 ,Nps - 2.5g CMC - 1.5g Barite - 27.99g NaOH - 0.25g **PAC-L** - **nil** Mudweight-8.98ppg	@ 5mins 7.8mL @ 10mins -10.5mL @ 15mins -11.0mL	41	30	11	20.5	19	6.0	7.5

Table 5. Formulation and rheological properties of conventional mud with 0.15g PAC-L

Case 2: Sample A Conventional drilling mud formulated with 0.15g (PAC - L)	Filtrate volume (mL)	Dial reading		Rheology ($lb/100ft^2$)			Gel strength ($lb/100ft^2$)	
		600rpm	300rpm	PV	AV	YP	10 (sec)	10 (mins)
Water - 332 mL Soda - ash - 0.25g Bentonite – 15g C.M.C– 1.5g Barite – 27.99g NaOH – 0.25g **PAC-L – 0.15g** Mud weight – 9ppg	@5mins -6mL @10mins -8mL @ 15mins -10.5mL	39	29	10	19.5	19	8	13

Table 6. Formulation and rheological properties of reinforced mud with 0.05g PAC-L

Case 2: Sample B (SiO_2 Nps) reinforced drilling mud formulated with 0.05g PAC-L	B	Dial reading		Rheology (lb/100ft^2)			Gel strength (lb/100ft^2)	
Water -332mL Soda - ash - 0.25g Bentonite - 15g NaOH - 0.25g Barite - 28g Nano-silica -2g **PAC-L - 0.05g** CMC - 1.5g Mud weight = 9ppg	@5mins -7.2mL @10mins -9mL @ 15mins -11mL	600rpm	300rpm	PV	AV	YP	10 (sec)	10 (mins)
		35	25	10	17.5	15	6.9	8.0

Table 7. Formulation and rheological properties of conventional mud with 0.1g PAC-L

Case 3: Sample A Conventional drilling mud formulated with 0.1g PAC-L	B	Dial reading		Rheology (lb/100ft^2)			Gel strength (lb/100ft^2)	
Water **-** 332mL Soda-ash - 0.25g Bentonite - 15g **PAC-L - 0.1g** NaOH - 0.25g Barite - 28g CMC - 1.5g Mud weight- 9.2ppg	@5mins -8mL @10mins -8.5mL @ 15mins -10.5mL	600rpm	300rpm	PV	AV	YP	10 (sec)	10 (mins)
		45	34	11	22.5	23	9	17

Table 8. Formulation and rheological properties of reinforced mud with 0.1g PAC-L

Case 3: Sample B Nanosilica (SiO_2 NPs) reinforced drilling mud formulated with 0.1g PAC-L	B	Dial reading		Rheology (lb/100ft^2)			Gel strength (lb/100ft^2)	
Water – 332mL Soda-ash - 0.25g Bentonite – 15g Nano-silica – 1.55g C.M.C – 1.5g Barite – 27.99g NAOH – 0.25g **PAC-L – 0.1 g** Mud weight – 9.2ppg	@5mins -7.2mL @10mins -8mL @15mins -9.7mL	600rpm	300rpm	PV	AV	YP	10 (sec)	10 (mins)
		45	31	12	21.5	19	11	20

Table 9. Results summary

Mud properties	Conventional-mud with 0.2g PAC-L	Nano-silica reinforced mud without PAC-L	Conventional mud with 0.15g PAC-L	Nano-silica mud with 0.05g PAC-L	Conventional mud with 0.1g PAC-L	Nano silica mud with 0.1g PAC-L
Mud weight (ppg)	9	8.96	9	9	9.2	9.2
600 RPM	40	41	39	35	45	43
300 RPM	30	30	29	25	34	31
Plastic viscosity	10	11	10	10	11	12
Apparent viscosity	20	30	19.5	17.5	22.5	21.5
Yield point (lb/100ft^2)	20	19	19	15	23	19
10 seconds gel (lb/100ft^2)	5.4	6.0	8	6.9	9.0	11
10 minutes gel (lb/100ft^2)	7.0	7.5	13	8.0	17.0	20
n = 3.32 log (600 RPM), (300 RPM)	0.414	0.450	0.427	0.485	0.404	0.471

Mud properties	Conventional-mud with 0.2g PAC-L	Nano-silica reinforced mud without PAC-L	Conventional mud with 0.15g PAC-L	Nano-silica mud with 0.05g PAC-L	Conventional mud with 0.1g PAC-L	Nano silica mud with 0.1g PAC-L
k = 5.51 (600 RPM) $(1022)^n$	12.62	10.07	11.24	6.75	15.20	9.11

Table 10. Measured mud cake thickness

	Mud – cake thickness (inch)
Case 1: Sample A Conventional drilling mud formulated with 0.2g PAC-L	0.1
Case 1 : Sample B SiO_2 NPs reinforced drilling mud with (0)g of PAC-L	0.109
Case 2: Sample A Conventional drilling mud formulated with 0.15g PAC-L	0.118
Case 2: Sample B SiO_2 NPs reinforced drilling mud formulated with 0.05g PAC-L	0.0781
Case 3: Sample A Conventional mud formulated with 0.1g of PAC-L	0.0937
Case 3: Sample B SiO_2 NPs reinforced mud formulated with 0.1g PAC-L	0.125

4.2. Discussion

No clear patterns or trends were observed in Tables 9. For the fluid loss at 15mins for all six samples of mud formulated, nano silica mud with 0.1g PAC-L gave 9.7mL as good performance to combat high fluid loss compared to other mud formulations, since fluid loss of less than 10 ml is usually recommended. It gave the best fluid loss value of all the SiO_2 NPs reinforced mud samples. Similarly, recorded gel strength at 10sec and 10 mins for nanosilica mud with 0.1g PAC-L gave the best solution with 11 lb/100ft^2 and 20 lb/100ft^2 respectively, at both time periods for all the mud samples. Furthermore, considering filter cake thickness and the recommended rheological properties, the nanosilica reinforced mud formulated with 0.1g PAC-L showed mud thickness, plastic viscosity, and yield point values of 0.125inch, 12cP, and 19lb/100ft^2 respectively. These are all comparable with the recommended values of PV (15-40cP), YP (2.5-20 lb/100ft^2). Moreso, the silica nanoparticle reinforced drilling mud is suitable for high filtrate loss and low mud cake thickness challenges control during drilling. Nano-silica mud is more effective since the concentrations of nano materials used in the drilling mud aggregates are little. The lesser the size of the particles, the higher the surface area of the particles, and the more reactive they would be in different colloidal, particle and nano mixtures.

5. Summary of the findings

For the tests carried out as CASE 1, both formulations exhibited pseudoplastic behavior, where the conventional mud with 0.2g PAC-L was more viscous. Similarly, CASES 2 and 3 tests, for conventional muds with 0.15g and 0.1g PAC-L respectively, also exhibited pseudoplastic behavior. In all cases, formulations with nanosilica reinforced materials have lower consistency factor and yield point values, but greater flow behavior indices. All the formulations exhibited gels that are not too progressive. The filter cake thicknesses measured are within acceptable American Petroleum Institute specifications. It could be deduced that the nanosilica reinforced samples yielded properties suitable for improved fluid loss control and other specifications necessary

6. Conclusions

Nanoparticles possess thermal, mechanical, chemical, magnetic, optical, electrical, and barrier properties. The influence of nanoparticles on the characteristics of the mud formulations was investigated by conducting the tests recommended for water-based formulations by the American Petroleum Institute. The improved properties exhibited by the muds were validated using conventional mud formulations used as control samples.

Further concluding remarks include;

(1) improved fluid loss property exhibited by the nano-reinforced mud
(2) stable gel exhibited by the formulation
(3) improved flow initiation due to decreased yield point values compared to the control muds
(4) exhibition of pseudoplastic behavior of the muds as a desirable property
(5) reduced viscosity for mud pumpability, yet adequate yield point values

Declaration of competing interest

No known conflict of interests has been declared by the authors.

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To whom correspondence should be addressed: Nnaemeka Uwaezuoke, Department of Petroleum Engineering, Federal University of Technology, P.M.B 1526, Owerri, Nigeria, E-mail: nnaemeka.uwaezuoke@futo.edu.ng ORCID: https://orcid.org/0000-0002-4729-4072