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A review on the potential application of nano graphene as drilling fluid modifier in petroleum industry.

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Abstract. The current attachment of oil and gas industry with nano technology has led nano particles to be utilized in drilling fluid as they are good candidate due to their thermal, mechanical and chemical stability. The newest star of nano particles are nano graphene which carries the mentioned attributes. Graphene, a nano particle recently used in drilling mud, has caught significant amount of attention in drilling industry due to its extremely low fluid loss, formation of less rough mud cake and Newtonian fluid behavior. This paper reviews the usage of nano-graphene in drilling mud based on laboratory studies and the very recent field trial. Addition of nano graphene to drilling fluid has shown significant increase in rate of penetration, reduction in torque and increase in life span of drilling bit without negatively impacting rheological properties of drilling mud. It concludes that the gap between academic achievements and industries are huge which encourages more collaboration of academics and engineers.
Keywords: Nano-graphene; nano-particles; drilling fluid.

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I. INTRODUCTION

The individual layer of crystalline carbon with a thickness of an atom is an agreed definition for graphene. The two-dimensional structured material is one of the thinnest, yet strongest matter known to date[1, 2].The structure was known to instability until 2004, when a novel research conducted at University of Manchester changed the common belief [3].Currently, graphene has been known as mother of all carbon allotropes because all configurations are derivations of graphene. Figure 1.1 shows that if a single sheet of graphene takes ball-shape it is known as buckminsterfullerene and multi-walled carbon are known as nanotube.

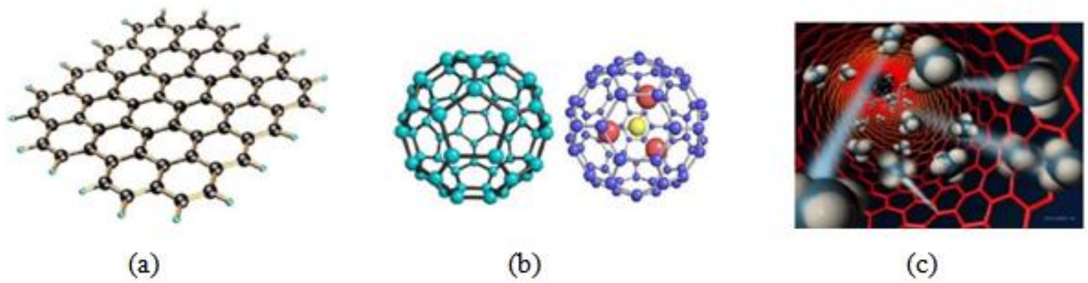

Fig. 1.1.(a)mono layer graphene molecule (b) fullerene molecule and (c) multi-walled Carbon nanotube with iron nano particles[4].

The term "graphene" was first introduced by Boehm *et al* [5] in 1986. For decades, graphene was a theoretically existing material and was assumed not to be a discrete matter due to its instable status. The isolation and extraction technique designed by Andre Grein in 2004, made graphene a commercially viable material afterwards. Later in 2010, the relatively simple and effective method "Scotch tap method" won them Noble prize[6]. The technique was based on peeling the tiny flakes of graphite from substance. It got popular due to extracting the monolayer, bi-dimensional graphene from substances with least defect.

Recently graphene has attracted significant amount of attention in oil and gas industry due to its fascinating properties. The single layer substance with arrangement of honeycomb lattice, graphene, is lighter but stronger

than steel[7]. It exhibits excellent thermal conductivity of 5000 [$\mathrm{W\,m^{-1}k^{-1}}$], mechanical property with a tensile strength of 130 gigapascals, optical transmittance of approximately 97%[8]. Apart from the outstanding properties of graphene, it has captivated more attention because of abundance, low cost and environmental friendly.
Graphene has a fascinating attributes that has attracted myriad industries from touch-screen phone developers to solid gas detectors. Graphene has been chosen for touchscreen phones due to having layers with extremely high electrical conductivity and optical transparency. Another graphene property is the layers with high carrier mobility and low noise which has the potential to replace silicon used in transistors. Theoretically, graphene poses a large surface area of 2600[$\frac{m^2}{g}$] [9].The high area to mass ratio of graphene has enabled the matter to play constructive role in creation of ultra-capacitors. Moreover, the single carbon sheet, graphene, can absorb significant amount of hydrogen. Study reports that at a single sheet of graphene at 100 [atm] and 298 [K] absorbs more than 3 [wt%] of hydrogen [10]. Therefore, this property has made graphene a good candidate for solid gas diagnosis.

Graphene particularities were not out of petroleum industries' attention. For several years, graphene has served encountering a billion-dollar issue in the particular industry. Studies shows that loss circulation costs oil and gas industry one billion dollar each year [11]. The hexagonal arrangement of carbon atoms in graphene sheet has caused the material to pose an extraordinarily flexible behavior. This is effective in sealing the fractures that can occur during drilling operations. In engineering context, sealing the fractures induced in wellbore is termed wellbore strengthening. These induced fractures during the drilling operation in the wellbore leads to losing control on equivalent circulating density which causes operating companies hefty amounts annually. Recent obsession of respective industry is towards addition of nano scale materials in drilling fluid for wellbore strengthening purposes. Nano is a term corresponding to ten millionth of a centimeter. It means a nanometer is thousand times smaller than a red blood cell which in atomic scale is equivalent to 10 breadth of hydrogen atoms [12]. If nanoparticles are defined based on their sizes then collide particles which are additives to the drilling fluid for many decades are accounted as "nanotechnology". Katherine *et al [13]*defines nanoparticles as "small colloid particles" despite several methods that has been developed for categorizing nanoparticles. Interestingly, it is not all about size but properties of materials and their behavior in myriad environments, temperature and pressure. The change from micro to nano has changed the governing laws of materials as well. The concept was proved by Noble prize winner Richard Smalley from Rice University. He could successfully show that carbon nanoparticles behave differently compare to marco-sized particles of carbon (graphite)[14].

In current era of petroleum industry, engineers are seeking for drilling fluids that are highly stable mechanically, chemically and thermally. The reason behind such demands are due to gradual complexity of drilling operations by passage of time. Engineers now explore and unlock hydrocarbon in ultra-deep sediments where the temperature and pressures are severely high. Besides, stabilizing drilling fluids using nano-particles, these particles are environmentally benign as the portion of these tiny particles used in the drilling fluids are substantiallylow.

Although oil based drilling fluids are known for their better performance but has attracted a significant amount of critics due to environmental issues. On the other hand, nano-particles that has been used with water based mud has outperformed the same nano-particles used in oil based mud. Nano-particles which has been studied for these purpose were iron based and calcium based. Theoretically there are several reasons that these tiny particles are more compatible with water based mud rather than oil based mud. Firstly, these two nano-particles has higher affinity towards organophillic clays due to presence of hydroxyl group at the surface of clays, as in water based drilling fluid the main compositions are organophillic clays and H_2O, it contributes significantly towards stabilization of system. Secondly, dispersion forces such as electrostatic attraction and Van der Waals forces, are performing comparatively better in water based mud. These forces help nano-particles to be dispersed in the system very well which in case of oil based mud these forces are inoperative[15].

The latest nano-particle that has newly been piloted is nano graphene. These tiny particles of graphene were used in one of the fields in Myanmar by Scomi[16]. The issue which compelled Scomi to utilize nano-graphene was frequent wear of drill bit. Consequently, performance of these nano-scaled particles exceeded operator's expectations.

II. SEALING MECHANISM OF GRAPHITE

Loss circulation simply means when volume of circulated drilling fluid is less than that of its input. The reason behind occurrence of loss circulation is when mud weight is greater than fracture resistance of the formation. As the reservoir pressure decreases with the passage of time, there is a drop in pore pressure which results in weaker hydrocarbon bearing rocks on other hand, neighboring rocks posing lower permeability maintains their respective pore pressure. Consequently, this situation limits the accessibility of drillers to mentioned zone. For decades, engineers have tried to strengthen these weak zones that are referred as wellbore strengthening. Several methods have been introduced for this purpose[17-19].Temperature alteration of wellbore is one of the methods [18] introduced for wellbore strengthening. In this method mud heaters are required to heat up drilling fluids but this approach is compatible for wellbores with high bottom hole temperature. Another method offers sealing induced fractures by introducing granular particles to drilling fluid but the downside of research is stated to be only applicable to permeable rocks [17]. An interesting approach discusses the idea of initiating fracture in wellbore can have incremental effect for hoop stress near wellbore [19].

In 2004, the concept of allowing small fractures in wellbore wall and keeping these fractures open using small bridging particles was discussed by introduction of "stress cage" concept. When the impermeable bridging particles holds fractures open, it actually provides pressure isolation of fractures. If mentioned fractures are located near wellbore, then hoop stress would increase which is termed as "stress cage". The fracture sealing or bridging method is suitable for permeable and non-permeable rocks. For permeable rocks, a perfect sealing mechanism for fracture mouths are not required its due to leakage of fluid passing through bridge and eventually finding way through fracture to the rock matrix as shown in Figure 2.1. Hence, no pressure build-up in the fracture therefore no propagation of fracture is possible[20].

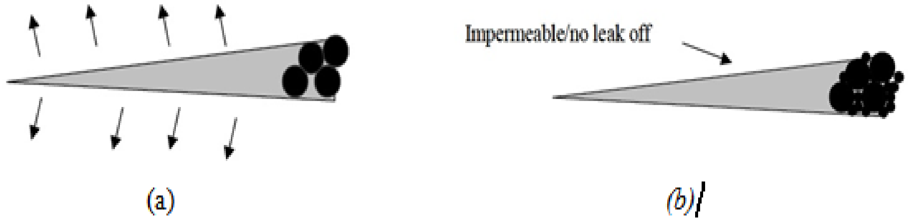

Fig. 2.1.(a) Fracture sealing of permeable formations (b) Fracture sealing for impermeable formations [20].

Conversely, for impermeable rocks a perfect sealing mechanism are needed in order to seal the fractures to avoid their propagation. To achieve a perfect seal mechanism for rocks such as shale containing extremely low permeability, drilling fluids known as "ultra-low fluid loss muds" are proposed[20].To support the idea of fracture sealing using drilling fluids with extremely low fluid loss, *Goud and Joseph[21]*reports the usage of graphite for sealing purpose. Multiple particularities of graphite have caught the attention for bridging fractures. These includes inertness of graphite which does not damage rheological properties of drilling mud and flexibility of graphite that can bridge fractures' mouth efficiently. The sealing mechanism of fractures with graphite is begin by pumping the circulating material which caused the mouth of pre-existing fractures at downhole to expand and bridging particles can temporarily seal the fractures as illustrated in Figure 2.2 (a).

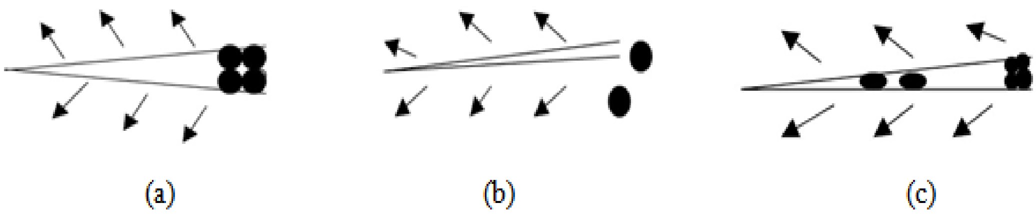

Fig. 2.2.(a) Temporary seal of fractures (b) Reduction in fracture size (c) Suspension of graphite in fracture[21].

With ceasing the pumps, bridged particles at the mouth of fractures would be thrown out of fracture, this results in reduction of fracture size. The size reduction of fracture has been illustrated in Figure 2.2 (b). However, with drilling fluid containing graphite, the seal formation would no more be temporary but a permanent bridging due to graphite's resilience property. After the circulating material is pushed into fracture, graphite deforms and would be trapped into the fracture even after pumps stop. The trapped graphite can be seen in Figure 2.2 (c).

Mud engineers has been adding graphite to drilling fluid for decades to strengthen wellbore and prevent loss circulation. If graphite can plug those macro fractures such efficiently and effectively, then nano-graphene can effectively seal the nano and micro fractures induced in wellbore. As mentioned earlier, to bridge fractures in impermeable rocks bridging particles ought to form an extremely impermeable mudcake downhole. In other words, drilling fluids with ultra-low fluid loss needs to utilized in the field. The recent industry obsession is to use nano-particles in drilling fluid for this purpose and one of the most suitable candidates are nano-graphene. The reasons include, it's ultra-low fluid loss in high pressure and high temperature conditions, rheological compatibility of nano-graphene sheets with water and oil based muds[21, 22].

III. **DISCUSSIONS**

3.1 Laboratory experiments

The experimental studies showed that addition of nano graphene sheets can drastically improve fluid loss in API standard and also in high pressure and high temperature conditions. Addition of nano graphene sheets to water based mud has outperformed nanosilica in terms of fluid loss[23]. It was observed[23] that graphene nanoplatelet in water based mud has recorded the lowest fluid loss in High Pressure High Temperature (HPHT) condition and API fluid loss.In this mud, plastic viscosity was improved upon addition of graphene nanoplatelet due to friction between nanoplatelets and micro additives.

Another report indicates[24] the addition of nanographite to drilling fluid would not only keep the fluid loss low and consistent compare to conventional drilling muds with the passage of time but also forms mud cakes with comparatively less friction .This research shows that after 40 minutes of filtration test, normal mud has a significant loss compare to nanographite based drilling fluid. In addition, the roughness of Nano graphite based mud is significantly low in 40 and 60 minutes of test. This attests that nano-mud are less affected by increments of pressure downhole [24].

In order to investigate nano-graphene's compatibility with drilling fluid and the effect of this nanoparticle on mud rheology, multiple studies has been conducted to date [25-27]. The study on addition of graphene nano-sheets to oil based drilling fluid has shown that even thoughmentioned drilling fluid is a Bingham fluid but it's behavior resembles closely to Newtonian fluid because the shear stress of reported mud is zero[22]. Figure 3.1 showsthe behavior of respective drilling mud in high temperature.

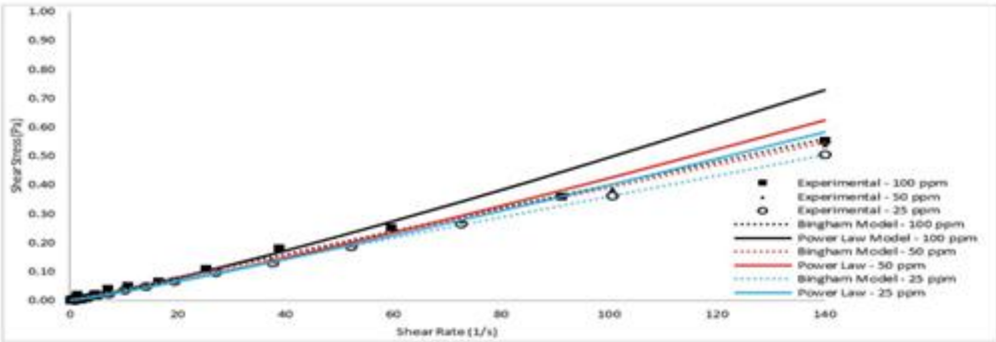

Fig. 3.1: At 50℃ temperature power law deviates from obtained data at higher shear rates [22].

Weight concentration of graphene nano-sheets for this particular study was 25ppm, 50 ppm ad 100ppm. It was observed that with increase in concentration of nanoparticles in drilling fluid viscosity of respective mud increases[22]. Other researchers have reported similar trend from their investigations [22, 26, 27]. From these studies, it can be concluded that with compromising minor viscosity factor drilling operators can enjoy other benefits of nano-graphene drilling fluid such as low fluid loss and increasing life span of drilling bits due to good lubricity of nano-graphene drilling fluid[16].

Ammanullah etal*[28]* claimed in his report that less solid content in drilling fluid has numerous benefits namely; it decreases formation damage during drilling operation, increases productivity index and has positive impact on rate of penetration. Currently, one of drilling fluids that contains least solid is nano-drilling fluid because nanoparticles has a huge surface area to volume ratio therefore a small quantity of this tiny particles in drilling mud are sufficient to improve parameters such as heat tolerance, thermal conductivity, high mobility and effective interaction between rock surfaces. The claim has gotten approval stamp from a field application in an onshore field in Myanmar [16].

3.2 Field Trials

Despite multiple experimental investigations confirming nano-graphene's extra ordinary performances in drilling fluid, nano-graphene has been only utilized once in field application to the date. The nano-graphene drilling fluid recipe was utilized in an onshore block in Mynamar field. In this field, operators encountered a hard formation composing sand interbedded with shale which reduced the rate of penetration(ROP) in these beds significantly. The lower ROP and hard formation led to drill bits wear which had to be changed as frequent as 3 to 4 days. Therefore, it raised cost of operations noticeably. Besides slow ROP, high torque was recorded which dragged engineers on the field to use numerous lubricant that ended up making negligible changes[16].

However, after implementing nano-graphene drilling fluid in the field, operator benefited in many aspects. Firstly, the cost was reduced as life span of polymer diamond compact (PDC) bit was increased up to 75%.The conditions of drilling bits can be observed before and after addition of nano-graphene todrilling fluid in Figure 3.2. Secondly, there was a significant improvement in rate of penetration from 3 m/hr to 9 m/hr. Moreover, it was reported that concentration of nano-graphene is as low as 2%. This minimum concentration was directly affecting ROP and torque. The more concentration of product the lower torque and higher ROP was recorded. This low concentration of nano-graphene has significantly impacted torque as shown in Figure 3.2.

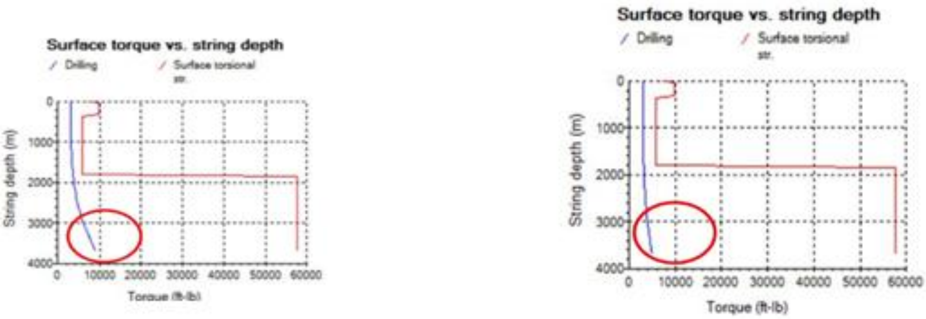

Fig.3.2.(a) Torque before using nano-graphene (b) Torque after using nano-graphene[16].

Fig. 3.3.(a) 6-inch drill bit's condition without graphene in drilling fluid. (b) 6-inch drill bit's condition with graphene in drilling fluid [16].

Nano-graphene particles were able to reduce overall torque up to 25% in this onshore field. With maintaining weight on bit (WOB), an increase of 125% was in ROP which is higher than any other lubricant used in this particular field. This field application also proved the hypothesis stating that nano-graphene is a good thermal stabilizer because the particular well had a high bottom hole temperature of 176℃.

IV. **CONCLUSION**

From our review, we conclude that nano-graphene is one of the most appropriate materials to be added in drilling mud for achieving higher thermal stability, rate of penetration and low fluid loss. Furthermore, it was identified that the gap between academia and engineers in industry are quite huge and there is a lack of collaboration between the two bodies as there has been extensive researches conducted in laboratories proving that nano-graphene is an appropriate modifier for drilling mud but it has been implemented only in one field.Lastly, oil and gas industry need to collaborate more with other industries who has already utilized nano-graphene. The collaboration will provide better understanding of nanoparticle's properties and also the process will develop more confidence for using the material in the field.

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