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Laboratory Analysis of the Rheology of a Polymer-based Mud Produced from Magnetic Water as a Fluid Used in Oil Well Drilling

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Highlights

- Investigation of rheological behavior of polymeric fluid by magnetic water for using as a drilling fluid or in enhanced oil recovery process
- The effect of magnetic field on fluid rheology
- The effect of adding a polymer called PAC or polyamide to water bentonite mud at different concentrations on the performance of rheological behavior and water viscosity of drilling mud

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Abstract

This study investigated the application of iron oxide nanoparticles in the presence of an external magnetic field to control the rheology of drilling fluids. Drilling fluid rheology is one of the most critical factors in determining the optimal fluid. Drilling fluid must have good rheological properties to carry the drilled cuttings. On the other hand, polymers in the water-based drilling fluid control fluid loss. In low-density oil-based fluids, where the water content is low, rheological control is generally difficult since there is a limitation in selecting additives. In this study, the ferromagnetic fluid has been generated by adding nanoparticles of Fe_3O_4 to silicon oil. By adding ferromagnetic fluid to the oil-based mud under the influence of the external magnetic field, we examined the rheological behavior of the oil-based drilling mud. The external magnetic field can be applied in actual conditions in the middle of a magnetic drilling string. The results showed that the magnetic nanoparticles improved the drilling mud rheological properties. Moreover, the viscosity of the oil-based fluid without nanoparticles was measured 2 cP and increased to 33 cP by adding 4 wt % of iron oxide nanoparticles under an external magnetic field of 0.321 T. The magnetic field was also used for water-based mud (WBM), and the results showed that in water-based fluids containing polyanionic cellulose (PAC) polymer, the magnetic field did not have much effect on the rheological properties of the drilling mud compared to oil-based mud (OBM). Since water is the main component of the water-based fluid, increasing the magnetic field reduces the viscosity of the water-based fluid. The magnetic field increased fluid’s rheology by adding iron oxide nanoparticles to the polymer-based fluid. The viscosity of the water-based fluid containing nanoparticles increased to 850 cP under the magnetic field.

Keywords: Drilling fluid rheology; Ferromagnetic fluid; Iron oxide nanoparticle; Magnetic field.

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1. Introduction

Improving the rheological properties of fluid has high importance. In the drilling industry, mud is composed of mineral and organic chemical materials produced in a liquid state and is used in the drilling of oil and gas wells. This complex is composed of two phases of liquid and solid, and it is continuously pumped through the drill string and wellbore, returning to the mud pits. Oil-based mud (OBM) is mostly used in drilling troublesome shaly formations because of providing chemical shale inhibition, but according to the new approach in the drilling industry for using newly developed fluid, a chemical material issue used in drilling fluids has been turning into an important subject in the drilling field. Some of the idealistic goals in the drilling fluid section are using lower-cost fluids, not using oil-based muds that damage the environment and wellbore stability, and preventing wash-out, which has always been seen a research subject. In deep wells with high pressure and high temperature, drilling fluid can lose its function, so replacing some components with resistant materials may improve the conditions (Hajiabadi et al., 2018). However, since the oil mud formulation has been modified by reducing the concentration of the colloidal material, the thermal stability is also compromised. This research tried to design a modern polymeric fluid using magnetic water to improve its rheological properties for drilling muds and injection fluids into the reservoirs. In this study, general properties of polyanionic cellulose (PAC) in the drilling were investigated, and then its function in the presence of magnetic fluid was evaluated. This work is a new connection between modern methods in the drilling industry. It can be used easily and has economic benefits. Appropriate selection and continuous control of mud systems in operation are important factors in the successful level of that drilling operation, indicating that choosing a suitable mud system leads to an improved drilling operation, and selecting an improper drilling fluid system causes problems and increases operational costs. Drilling fluid composition is designed according to the conditions and supplies. Nowadays, polymeric fluids involve a vast part of the drilling industry. Bentonite has been used in drilling fluid composition for ages, and it is one of the components of most water-based muds (WBM). In addition to making appropriate viscosity, there are several reasons for using bentonite in the mud, such as enhancing carrying capacity and well cleaning, lowering the amount of filtrate loss into the permeable layers, mud cake creation with low permeability on the wellbore, improving wellbore stability in weak cemented sections, and decreasing mud loss. It is common to use sodium-containing bentonite in drilling fluids due to its exceptional rheological properties (Adelzadeh, 2010). One of the important and modern aspects of this research is the magnetic field effect on the rheological properties of the polymeric fluid, which has no history of study. Magnetic fluids are categorized in the modern grounds of science, and this study is like a bridge between oil engineering and new sciences which can show the properties of magnetic fluid containing polymer. So far, not many works have been conducted in this field, and this research can be a new ground for publishing science (Esmaeilnezhad, 2017). Recently Hoseini Hashem et al. (2019) have published results of using magnetic water for decreasing surface tension in oil reservoirs at a reputable magazine. They deduced that using magnetic water is an effective way to lower surface tension and enhance oil recovery. If the external magnetic field changes the structure of water clusters and, thus, water properties, one can expect some changes in the wetting properties using the magnetized water. Hashemizadeh et al. (2014) investigated the effect of magnetic water for oil recovery with water injection in the reservoir. They revealed that magnetic water had a negative effect on oil recovery, but they modified the article later and observed that the effect was positive. Hajiabadi et al. (2019) studied the effect of formation damage with magnetic water and showed that it could highly reduce the formation damage. Naemavi (2013) searched for partially hydrolyzed polyacrylamide polymer (PHPA) polymer in oil and gas well drilling fluids. Their results showed that this polymer had shale inhibitive properties when used in water-based muds rather than viscosifier, where polyanionic cellulose (PAC) can be used. Sabaghi et al. (2015) researched the effect of polyacrylamide and nanocomposite of barite (weighting agent)/polyacrylamide as additives on the drilling mud properties. Their results showed that fluid viscosity increased for more polyacrylamide addition, and mud loss decreased. It was also shown that the higher the nanocomposite added, the lower mud cake and fluid loss observed. Salmasi Salimzadeh et al. (2006) studied different common polymers used in drilling industry experiments to detect rheological properties suitable for the geometry of horizontal wells and some other things like shale controlling experiments. In that research, it was shown that xanthan polymer, compared with other polymers, had a higher YP/PV value and favorable mud cake building characteristics, and less formation damage, which is useful in making the turbulent flow to create a medium for drilling cuttings in the horizontal section of the well accompanied by a good carrying capacity of the mud. Hence, xanthan polymer was introduced as an appropriate polymer. Fereydooni et al. (2012) studied the effect of cellulose on the rheological properties of drilling mud. For this purpose, they investigated the effect of PAC on loss curing and mud cake thickness on a mass scale and nanoparticle scale. Their results revealed that nanoparticles produced with the size of 100 nm could have a tremendous effect on mud loss curing and reduction in mud cake thickness compared with that of mass-scale PAC. Nasiri et al. (2012) studied the effects of Polythin and Polydrill, two artificial polymers for improving rheological properties of drilling mud on the water-based mud. They concluded that Polythin polymer caused a reduction in mud rheological properties and ease of pumping mud. They showed that it could also prevent bentonite from settling, and those polymers increased fluid heating stability and maintained mud rheological properties at high temperatures. The present study discusses the effect of magnetic fields on fluid rheology.

2. Research methods

This study analyzed the first rheological performance of bentonite-mud without polymer. Then, the effect of adding PAC polymer or polyamide into the water-based mud with bentonite at different dosages on the rheological properties and viscosity of WBM was investigated. After that, the effect of the magnetic field on the rheological properties of the polymeric mud was examined. It should be noted that iron oxide nanoparticles at a dosage of 4 wt % were added to each mud to make the nanoparticle-containing fluids. The sample fluid was poured into a cell, and then a specific magnetic field was applied to the fluid by a permanent current coil surrounding the vessel located in the rheometer apparatus; fluid rheology was measured while applying a magnetic field. The vessel is shown in Figure 1. Fluid and their components used for making WBM and OBM are listed in Tables 1 and 2. The magnetic muds made are shown in Figures 2 and 3.

Table 1
The composition of the oil-based mud.

Component	Weight/volume percent
Gasoline	400 cc
Limestone	12 wt %
Silicon oil	100 cc

Table 2
The composition of water-based mud.

Component	Weight/volume percent
Water	400 cc
Bentonite	12 wt %
Salt	2 wt %
PAC	0.82 wt %

Figure 1
The magnetic system.

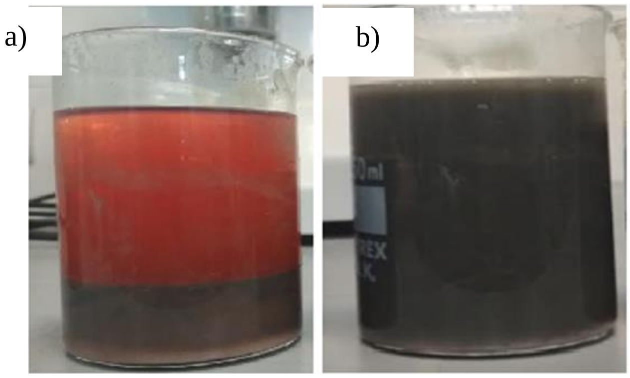

Figure 2
The oil-based mud a) before adding iron nanoparticles and b) after adding iron nanoparticles.

Figure 3
The polymeric fluid containing iron nanoparticles.

3. Results and discussion

3.1. Water-based mud

In this section, the results of the rheology of WBMs were analyzed. WBM with bentonite and without nanopolymer showed different rheological properties. As shown in Figure 4, mud viscosity decreased with an increasing magnetic field due to the enhancement of the penetration coefficient of water molecules under a magnetic field. A water molecule consists of two hydrogen and oxygen atoms in an H–O–H arrangement. The connection between these two hydrogen atoms to the oxygen atom is like V and with an angle of about 105°. Water molecules are dipole so oxygen has a negative charge and hydrogens have a positive charge. Thus, if some water molecules are placed near each other, an attraction appears between hydrogen from one molecule and oxygen from another molecule, called hydrogen bonding. When a water molecule is under a magnetic field, it directs toward that field because it is dipolar, and then the molecule pattern is stretched. The angle between two hydrogen bonding becomes weaker between close water molecules, and water molecules are practically located in clusters. This structural change reduces surface tension and more penetrance. Therefore, the magnetic field has a negative effect on the water-based mud viscosity. Figure 5 shows the changes of fluid shear stress at the gelation point in the presence of a magnetic field for WBM. Shear stress has an inverse relation with increasing magnetic field as a parabolic trend. In other words, increasing the magnetic field causes a reduction in the mud gelation point. The apparent viscosity of base fluid was 5 cP at a shear stress of 100 1/s, which lowered to below 1 cP under a magnetic field of 0.319 Tesla. Moreover, shear stress at a low shear rate (gelation point) under this field was equal to 1 MPa.

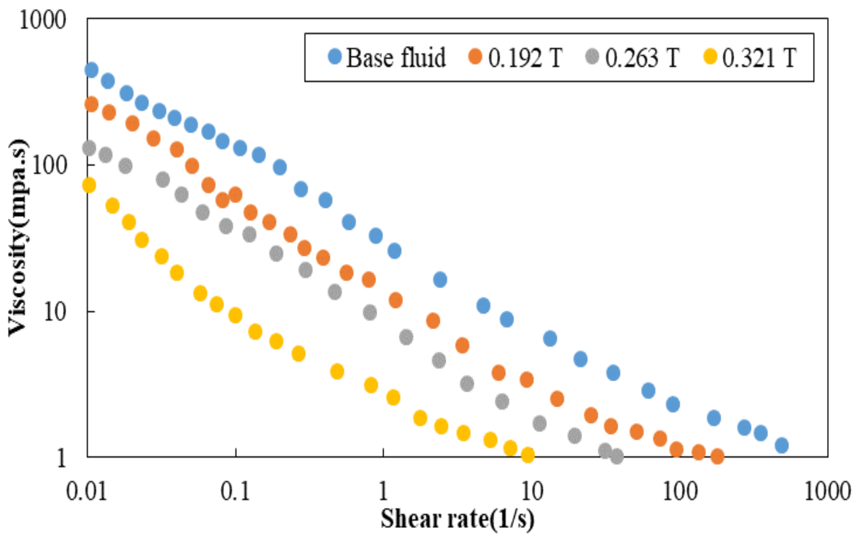

Figure 4
The variation in the viscosity with increasing the magnetic field.

A few changes appeared in the viscosity with adding nanoparticles into the fluid. Figure 6 shows the rheology and viscosity changes of the WBM containing 4 wt % of iron oxide nanoparticles. As evident, magnetic field amplification has no observable changes on drilling mud viscosity and fluctuates about the base mud viscosity due to the lack of production of magnetorheological fluid. When this fluid is placed under a magnetic field, its particles are magnetized, and intra-forces between them cause the creation of chain structures in the fluid. Iron particles in the WBM settle because of having a high density, so they do not have the ability of chain creation, and there is no change in the fluid rheology.

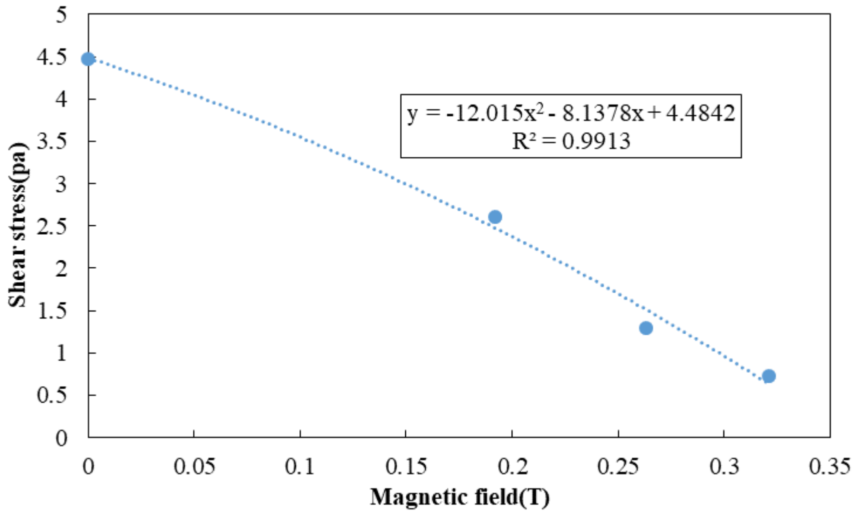

Figure 5

The variation in the shear stress with the magnetic field for the water-based mud.

Figure 7 shows rheology changes containing 0.86 wt % PAC and 4 wt % nano iron oxide. As shown, there is a sharp change in fluid rheology at higher magnetic field strengths because of the lack of magnetic nanoparticles settling in polymer-containing fluid and no creation of nanoparticle chains in the polymer. These chain structures prevent fluid from moving and deforming. The number and strength of these chains increase at a higher magnetic field intensity, so the higher the magnetic field intensity is, the closer the fluid to the solid state is. It transforms to a semi-solid state which is called magnetic saturation. This prevention of the transformation of the fluid can be seen as viscosity changes. As can be seen, the fluid containing nano in the presence of polymer has better rheology controlling. In other words, adding a polymer can strengthen the magnetorheological properties. Figure 8 shows the shear stress changes with the magnetic field for the WBM. The shear stress directly relates to increasing the magnetic field, following an exponential trend. The viscosity of the base mud was equal to 5 cP at a shear stress of 100 1/s, which increased to 1050 cP when a magnetic field of 0.319 Tesla was applied. The viscosity of the WBM containing nano iron oxide and the polymer measured 21 cP. The viscosity and gelation point of the drilling mud reached 852 cP and 150 MPa, respectively, with increasing the magnetic field.

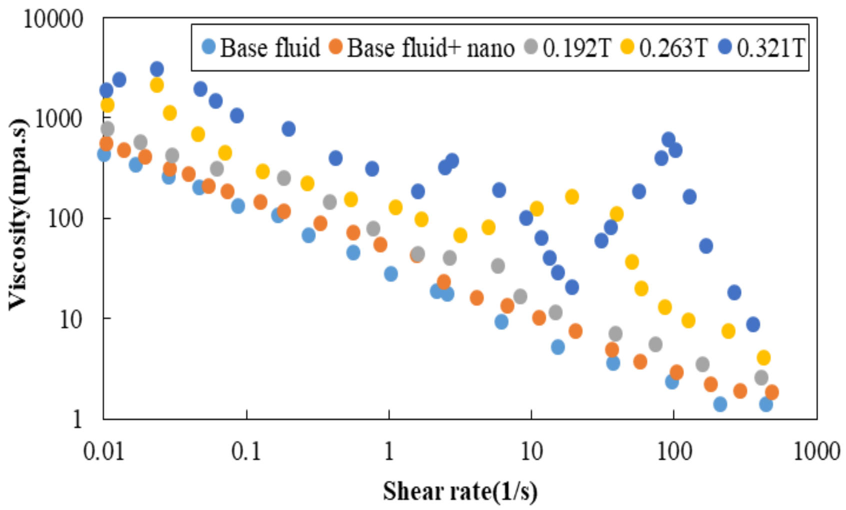

Figure 6

The variations in the rheology and viscosity of the water-based mud containing 4 wt % nanoparticles.

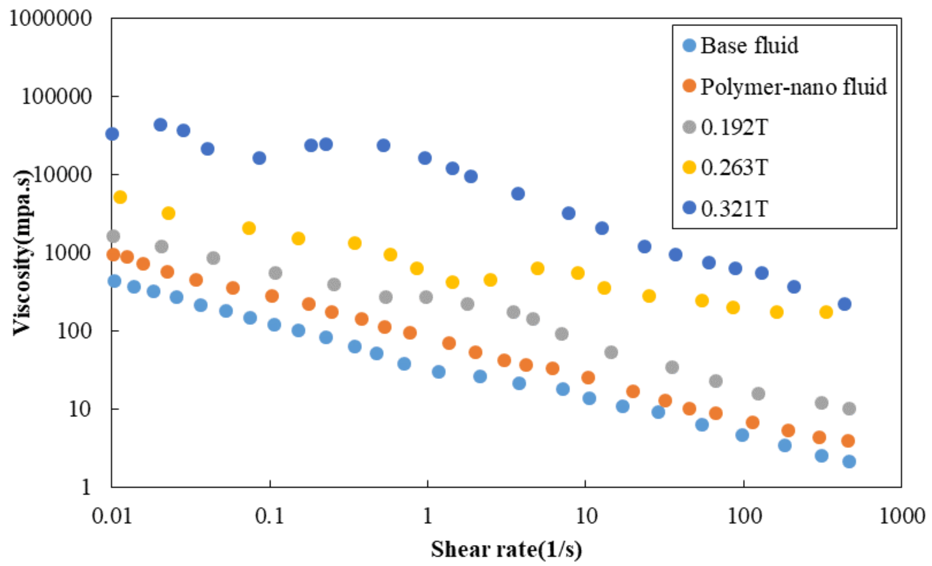

Figure 7
The variation in the rheology of the water-based mud containing PAC polymer with 0.86 and 4 wt % iron oxide nanoparticles.

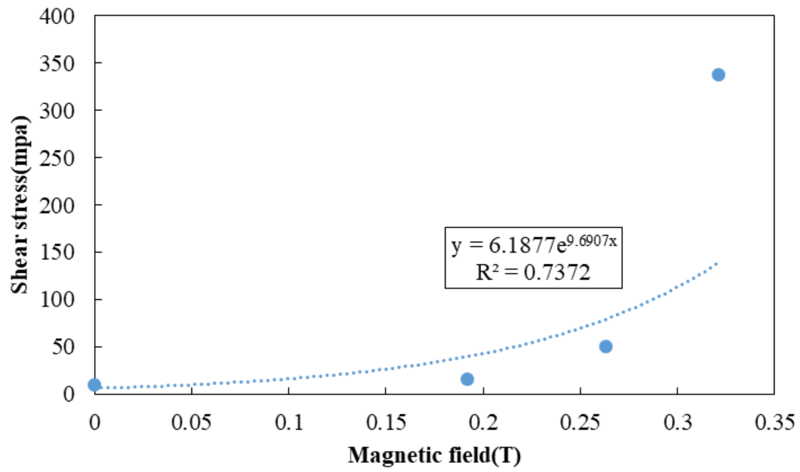

Figure 8
The variation in the shear stress of the fluid with the magnetic field for the water-based mud.

3.2. Oil-based mud

Figure 9 shows the variations in the rheology and viscosity of the oil-based mud containing 4 wt % of iron oxide nanoparticles. It was seen that the mud rheology increased at a higher magnetic field intensity, which could be an advantage of the OBM compared to the WBM, which was because magnetized nanoparticles did not precipitate in the OBM, and nanoparticle chains were not formed. These chain structures prevent fluid from flowing and deforming. The number of these chains and their strength increased with raising the magnetic field intensity. Thus, as the magnetic field intensity was increased, the fluid entered a solid state. This fluid transformed to a semi-solid state at a magnetic saturation state. This resistance from flowing can be seen as a viscosity change. The mud containing nanoparticles has reasonable control under the magnetic field. Figures 10 and 11 show the changes of the shear stress and apparent viscosity with the magnetic field. As shown, the shear stress and apparent viscosity directly relate to the magnetic field increasing, following an exponential trend. The apparent viscosity of the base fluid was 5 cP at a shear stress of 100 1/s, and it reached 150 cP under the magnetic field of 0.319 Tesla. The apparent viscosity of the nanofluid changed from 2 to 33 cP. Shear stress under this magnetic field and at a low shear rate (gelation point) was 430 MPa.

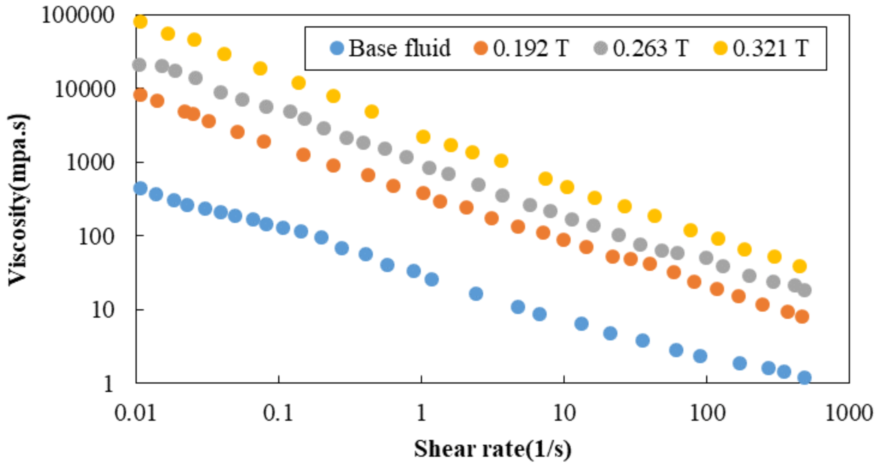

Figure 9
The variation in the rheology of the oil-based mud with 4 wt % iron oxide nanoparticles.

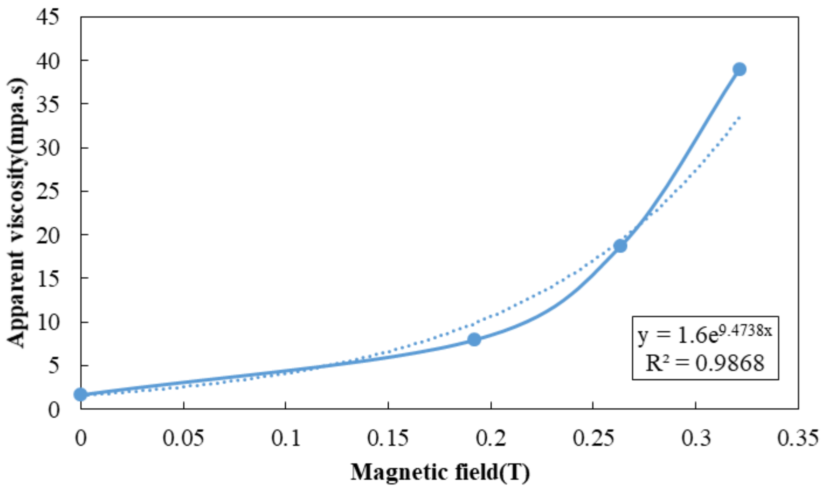

Figure 10
The variation in the apparent viscosity of the oil-based mud with the magnetic field.

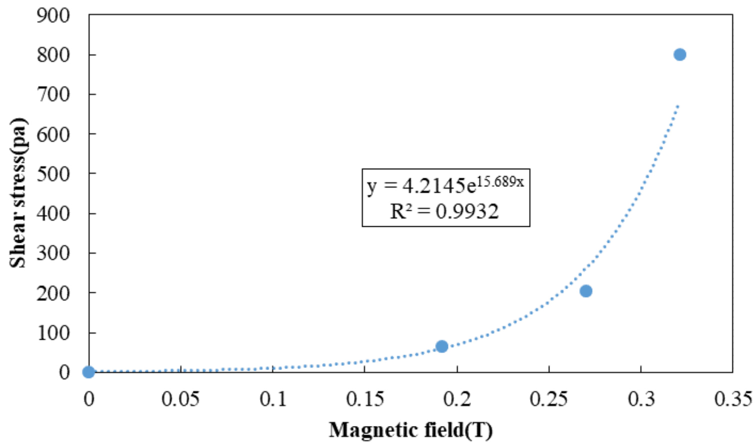

Figure 11
The variation in the shear stress of the oil-based mud with the magnetic field.

4. Conclusions

In this research, magnetic nanoparticles were investigated in an external magnetic field to control the rheology of drilling mud. The ferromagnetic fluid was made by adding nanoparticles of Fe_2O_3 into the silicon oil, and then its rheological properties were investigated under the effect of the magnetic field by adding it to the oil-based mud. An external magnetic field can be applied in the middle of the magnetic drilling string in actual conditions. From the results, the following conclusions can be drawn:

- The magnetic field had no substantial effect on the mud rheology of the water-based mud containing PAC polymer. Since the main component of the WBM is water, increasing the magnetic field decreased the viscosity of the water-based mud;
- The rheology of the water-based mud without nanoparticles was 3 cP. The viscosity and gelation point of the mud were reduced by increasing the magnetic field. The rheology of the base fluid fluctuated by adding 4 wt % iron oxide under a magnetic field of 0.321 Tesla;
- The viscosity of the WBM containing nanoparticles of iron oxide with polymer was 21 cP. The viscosity and gelation point of the drilling mud increased to 852 cP and 150 MPa, respectively, for a higher magnetic field intensity.
- The apparent viscosity of the oil-based mud without nanoparticles was measured at about 2 cP, which increased to 33 cP by adding 4 wt % of Fe_2O_3 under an external magnetic field of 0.321 Tesla;
- The variation in the primary shear stress or gelation point of the mud-containing nanoparticles under the magnetic field increased exponentially. Otherwise, it was a parabolic decreasing trend in the absence of nanoparticles.

5. Recommendations

The following suggestions are presented for future research:

- Investigating the effect of the magnetic field on the rate of oil-based fluid with gas rheology;
- Investigating the effect of the magnetic field on the hydrological water-based fluid rheology in the presence of different polymers.

Nomenclature

OBM	Oil-based mud
PAC	Polyanionic cellulose
WBM	Water-based mud

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