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Effect of Fe_4O_3 Nanoparticles on the Rheological Properties of Water Based Mud

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Abstract: Maintaining the viscosity and fluid loss ability during drilling operation is core for a drilling fluid to perform its functions effectively. The unfriendly conditions such as high temperature and pressures encountered as drilling operations cut deeper into formations require robust drilling mud formulae that would provide thermal stabilization of the drilling fluids while maintaining their rheological integrity. This research work investigates the stability of the oxides of Iron nanoparticles on the rheological properties of water based bentonite mud. The work focused on the effect of the nanoparticles on the rheology of the bentonite drilling fluid, as well as, their degree of thermal stabilization on the working fluid. The interactive effects of the iron oxide nanoparticles, temperature and shear rate on the shear stress of the drilling were also analyzed. We also showed quantitative relationship of the nanoparticle, temperature and shear rate at the optimization points of the shear rate.

Key words: Viscosity, thermal stabilization, rheological properties, nanoparticles, formulae, bentonite mud.

Nomenclature

Np: Nanoparticles

1. Introduction

Drilling fluids are very essential components of all earth excavation operations, including and most especially in oil and gas exploration and production. They may be defined as all of the compositions used to assist the generation and removal of cuttings from a borehole in the ground.

Drilling fluids have gone through major technological evolution, since the first operations performed in the US, using a simple mixture of water and clays, to complex mixtures of various specific organic and inorganic products used nowadays [1]. These products improve fluid rheological properties and filtration capability, allowing to easily penetrate heterogeneous geological formations under the best conditions [2].

A report by a health and safety laboratory (Offshore Technology Report-OTO 1999089) indicated that early drilling operations used just water to remove cuttings from drilled holes. The major limitation to the use of only water was due to its ineffectiveness in removing cuttings and how it limited the achievable drilling depth. It further indicates the drilling of a successful well in Texas, 1901 using a drilling fluid with finely grounded hole cuttings and sticky clay from surface deposits mixed into water, which was more effective in suspending cuttings and allowing them to be transported away from the bit and out of the hole more effectively, resulting in faster and deeper drilling capabilities.

Drilling operations are now at the advanced level now where complex drilling situations including high temperature and high pressure zones are encountered. More concern in the drilling operations now is the need to circumvent problems posed by the high temperature zones during drilling operations [3, 4].

The advancement of drilling operations into HTHP formations demand the usage of drilling fluid formulae that will withstand high temperatures by stabilizing the integrity of the rheology of the drilling fluid under such conditions [5-7].

Different types of chemicals and polymers are used

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in designing the drilling mud to meet some functional requirements such as the appropriate mud rheology, density, mud activity, fluid loss control property and temperature [8]. Studies of nanoparticles have shown their unique abilities in their functionalities such as thermal conductivity, electrical conductivity, optical features etc. Particularly, the thermal ability and the larger surface area of these nanoparticles are the motivation for this study to show the extent of stability that will be imposed on the drilling fluids against temperature [9, 10].

2. Experimental Procedure

2.1 Chemical Synthesis of Iron Oxide Nanoparticles

We carried out the synthesis process by one pot synthesis. And 0.65 g of ferric chloride and 0.12 g of iron powder were added to 20 mL hexane solution containing 6.0 g of dedecylamine and 3.5 mL of oleic acid at room temperature.

The resulting mixture was transferred into a 60 mL teflon-lined stainless autoclave.

The autoclave was sealed and maintained in an electric oven at 180 °C for 24 hours and then cooled to room temperature naturally.

The product was washed in absolute ethanol several times followed by centrifugation at 1,500 rpm for 5 minutes and finally dried in a vacuum at 60 °C for 8 hours.

The magnetic nanoparticles were obtained after this process with average size of 100 nm and a spherical morphology.

2.2 Preparation of Bentonite Drilling Fluid

We used bentonite as a base for the preparation of the drilling fluid for this study.

In this study, 350 mL of fresh water was measured using a measuring cylinder and was added to 22.5 g of bentonite using the measuring scale and stirred in the bucket until no more lumps were observable by the help of an electric mixer. The drilling fluid was left to stay overnight (16 hours) to swell. Bentonite drilling fluid with Fe_4O_3 Nanoparticles were prepared by adding 0.5 g, 1 g, 1.5 g of the nanoparticles after the fluid is left overnight and stirred vigorously and homogenized with an electronic mixer for about 2 minutes.

The bentonite fluid and the treated bentonite fluids were used for the various experiments.

3. Experimental Results and Discussion

The viscometer analysis was completed for the iron oxide Np. Analysis and discussion mainly centers on the effect on the fluid model and the thermal stability of the drilling fluids. We also used the statistical analysis to show the interactive effects of the nanoparticles, temperature and shear rate on the shear stress (being the surface response variable) of the drilling fluid.

3.1 Effects of Nanoparticles on Drilling Fluid Behaviour Models

The homogeneous expression of the aluminium and iron oxide particles in the drilling fluids posed some changes in the behaviour of fluid as compared to the zero presence of the nanoparticles. The results as follows show (see Figs. 1 and 2 below) the degree of influence in the model behaviour of the drilling fluids.

3.1.1 Effects by Fe_4O_3 Nanoparticles on Water Based Mud

We observed that the mud retained all the desired rheological properties at elevated temperature range during the testing process. A plot of shear stress/shear rate of the mud containing iron oxide nano-particles assumed a Bingham Plastic model as shown in Figs. 1 and 2. Plots show shear thinning behavior more clearly, which indicates effective rearrangement of gel-networks of particles under shear stress. Nanoparticles introduction into drilling fluid provides higher viscous property and yield stress than the bentonite mud without nano-particles. This can be explained as due to the dispersion ability of the tiny particles to be well-distributed more effectively on the

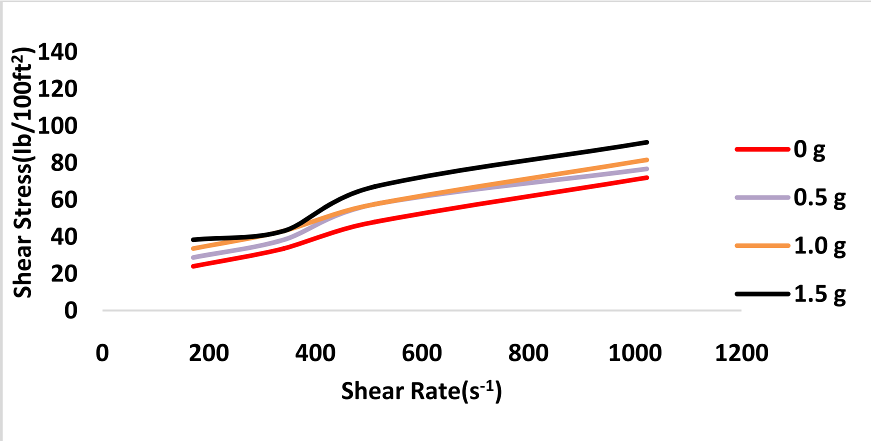

Fig. 1 Rheogram showing water based mud with iron-oxide nanoparticles 40 °C.

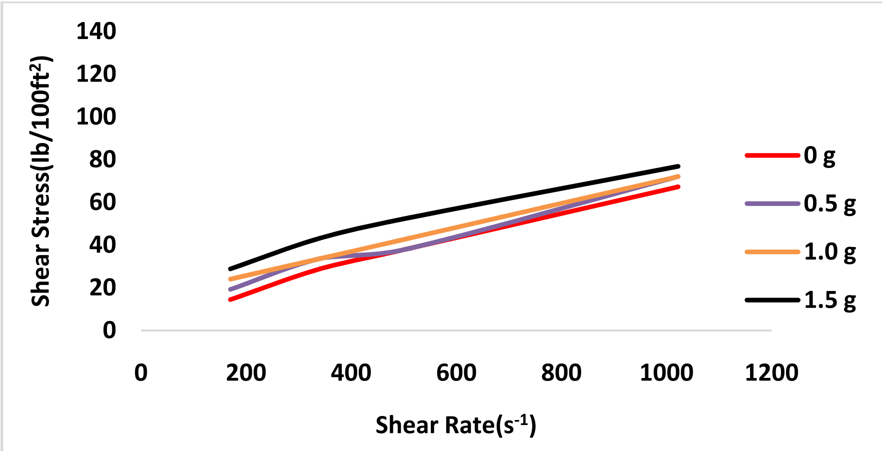

Fig. 2 Rheogram showing water based mud with iron-oxide nanoparticles 90 °C.

surface of bentonite.

3.2 Thermal Effect

The focus of this study revolves round the investigation of the ability of the nanoparticles to give a degree of thermal stability to the drilling fluid as it is subjected to varying temperature conditions. The results from iron oxides nanoparticle treated drilling fluid subjected to the high temperature conditions, suffices the evolving theory and the already done studies on the thermal stabilization abilities of these nanoparticles. The following graphical expressions give the performances of each nanoparticle under this study. As depicted by the graphical results in Fig. 3, the shear stress of the fluid slightly decreased or remained the same as we elevated the temperature from 40 to 90 °C for a particular weight of nanoparticle dosage. But, as we decreased the dosage for the same volume of drilling fluid samples, the shear stress slightly increased across the four different weight dosage samples under the same varying temperature range. This implies a good temperature stability as the increment in the shear stress is not a monumental jump. It shows much clearer at the shear rate of 340.68 per second from Fig. 3d below.

3.3 Statistical Analysis

We employed in this experiment factorial design approach for which we were able to observe and analyze the combined effects of the iron oxide nanoparticles, temperature and shear rate on the shear stress using JMP software package [11].

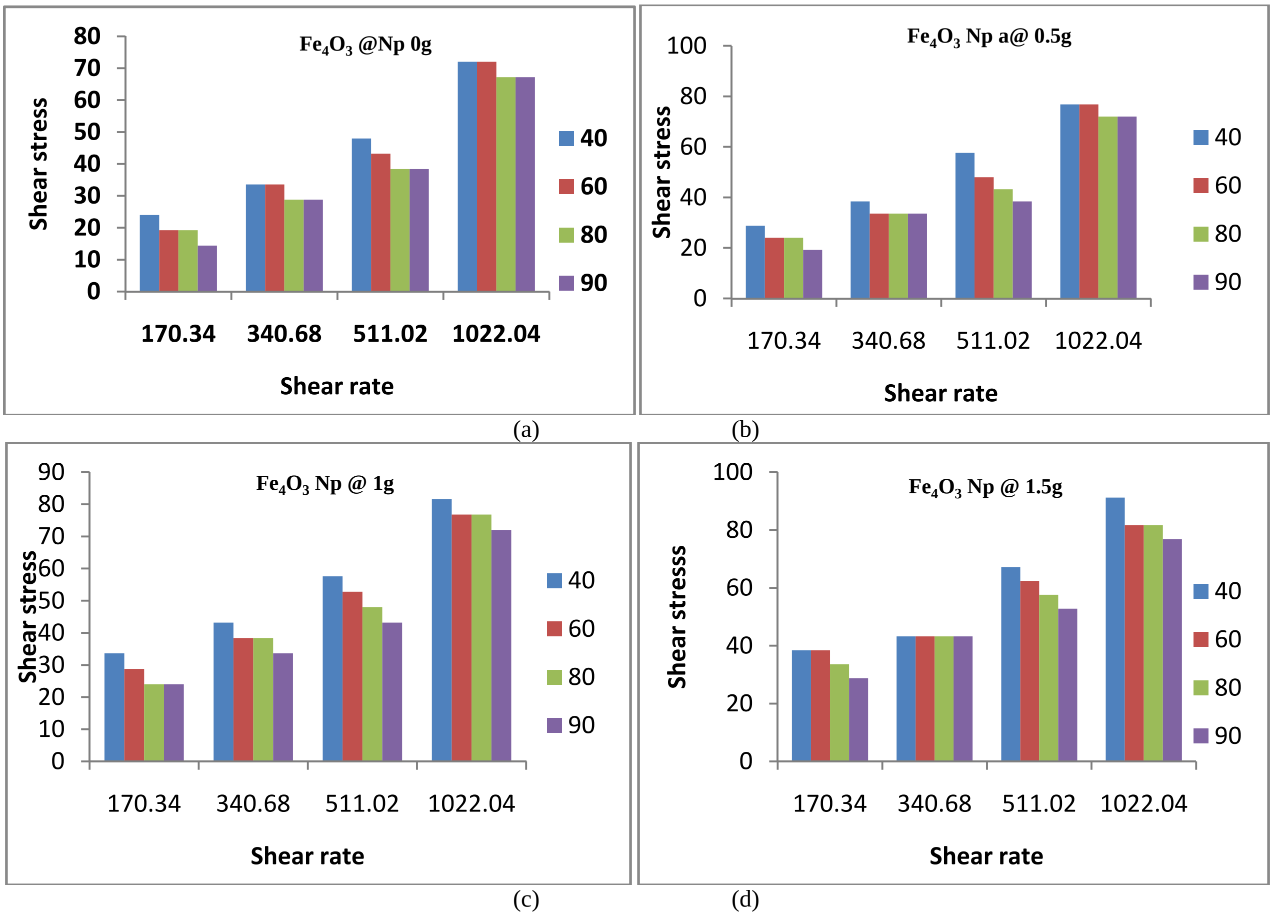

Fig. 3 **Summary of thermal effect on iron oxide nanoparticle treated water based drilling fluid at varying composition.**

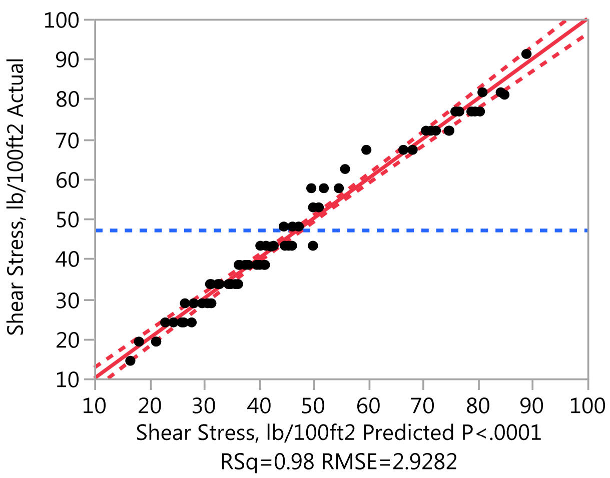

Fig. 4 **Actual by predicted plot for shear stress.**

Fig. 4 shows the predictability of the experiment and as given by the R-square value of 0.98 indicates that the errors registered in our experiment are minimal. This expresses high confidence in our predicted model which can be used to further study the iron oxide nanoparticle effects on the drilling fluid at higher temperature regimes(above 100 ^oC).

The following factorial model or equation is the prediction model from the experiment. See Eq. (1). This model as shown and explained from the residual plot in Fig. 4 has minimal errors of predicting the effects of the nanoparticles at high temperature on the rheology of the drilling fluid since it has high R-square value. Residuals are obtained as the difference between the observed and the predicted response variables.

$$S_{ST} = 84.4A - 10.9B + (0.023 - 1.25 \times 10^{-2}A - 2.2 \times 10^{-2}B)T - 89.2 \quad (1)$$

where,

T= temperature, ^oC

A= shear rate

B= Fe_4O_3 Np, g

S_{ST}= shear stress, Ib/100ft^2

Fig. 5 are the cube plots generated from the experiment to illustrate how the nanoparticle, the temperature and the shear rate interplay at the various optimized values of the shear stress.

For instance, to be able to combine the effects of drilling at the shear stress of 88.89 Ib/100ft^2, within a temperature zone of about 40 ^oC, then a 1.5 mass fraction of the iron oxide nanoparticle must be uniformly dispersed in the drilling fluid and drilling operation set at the shear rate around1,022 per second. On the other hand, minimum or no nanoparticles presence and the 90 ^oC temperature are required to obtain the least shear stress of 16.5765 Ib/100ft^2.

Table 1 shows the measured effect of the individual parameters as well as their combine effects on the shear stress of the drilling fluid. The iron oxide nanoparticles gave the highest impact which implies positive performance in stabilizing the temperature. All the combine parameters gave a negative impact on the shear stress.

The contour plots simply show the performance of the shear stress as the parameters change as in whether they increase or reduce in measure.

Fig. 6 shows the interaction profile for all the parameters.

Fig. 7 indicates that the shear stress increases as shear rate increases and temperature reduces. Fig. 8 indicates that the shear stress increases as iron oxide nanoparticle increases and temperature decreases. And Fig. 9 shows that shear stress increases as iron oxide nanoparticle increases and shear rate decreases.

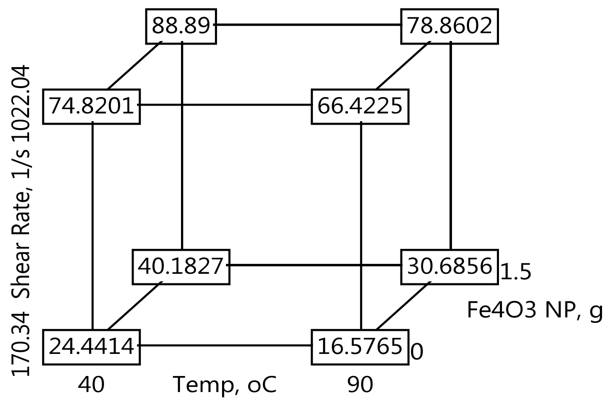

Fig. 5 Cube plot.

Table 1 Estimated parameters.

Term	Estimate
Shear rate, 1/s	0.0578255
Fe_4O_3 NP, g	9.45
Temp., ^oC	-0.177881
(Temp., ^oC-67.5)*(Fe_4O_3 NP, g-0.75)	-0.021763
(Shear rate, 1/s-511.02)*(Fe_4O_3 NP, g-0.75)	-0.001308
(Temp., ^oC-67.5)*(shear rate, 1/s-511.02)	-1.251e-5

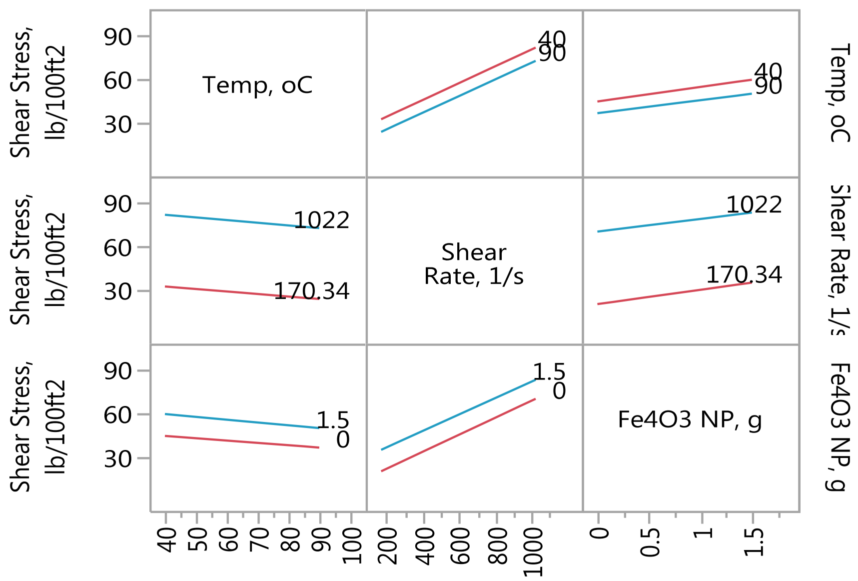

Fig. 6 Interaction profiles.

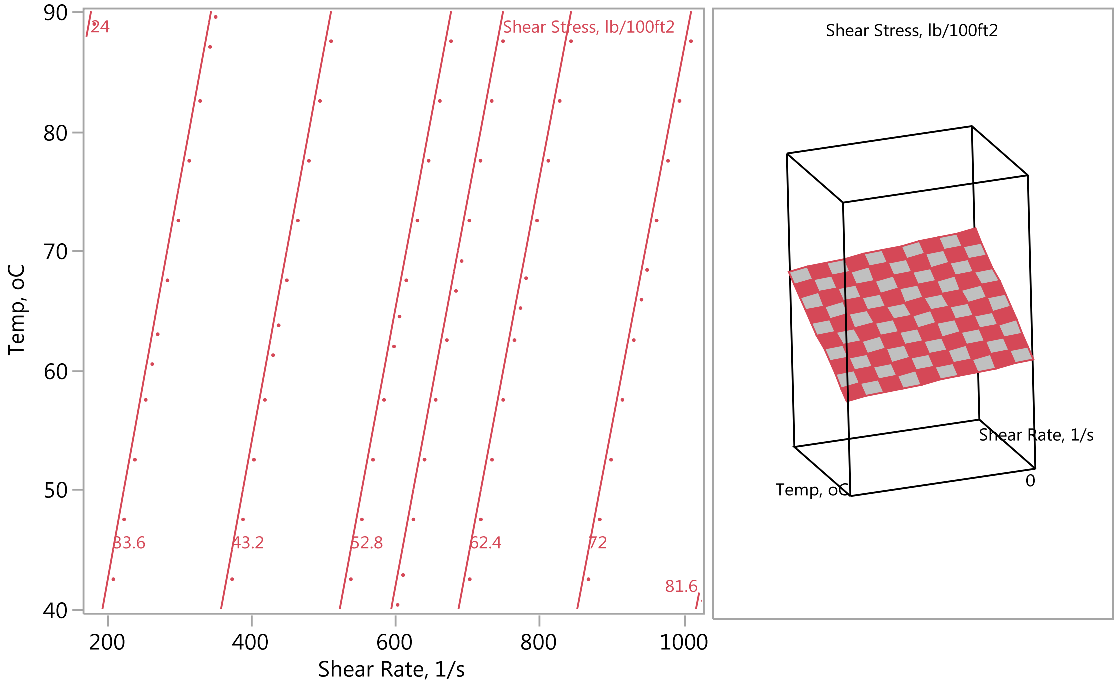

Fig. 7 Contour plot: effects temperature/shear rate on shear stress.

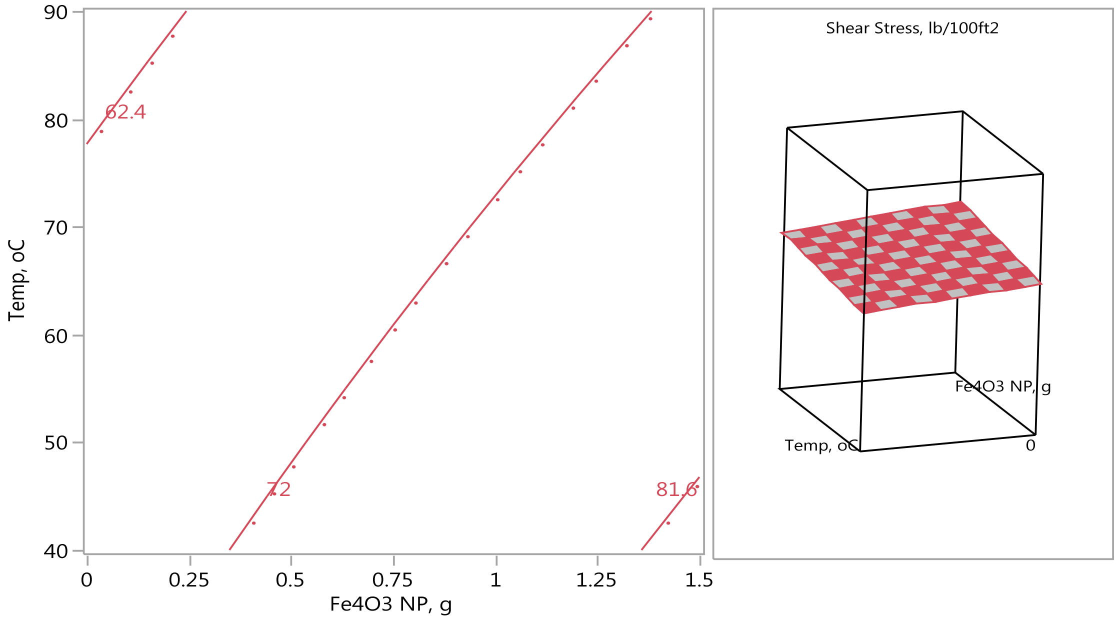

Fig. 8 Contour plot: effects temperature/Fe_4O_3 Np on shear stress.

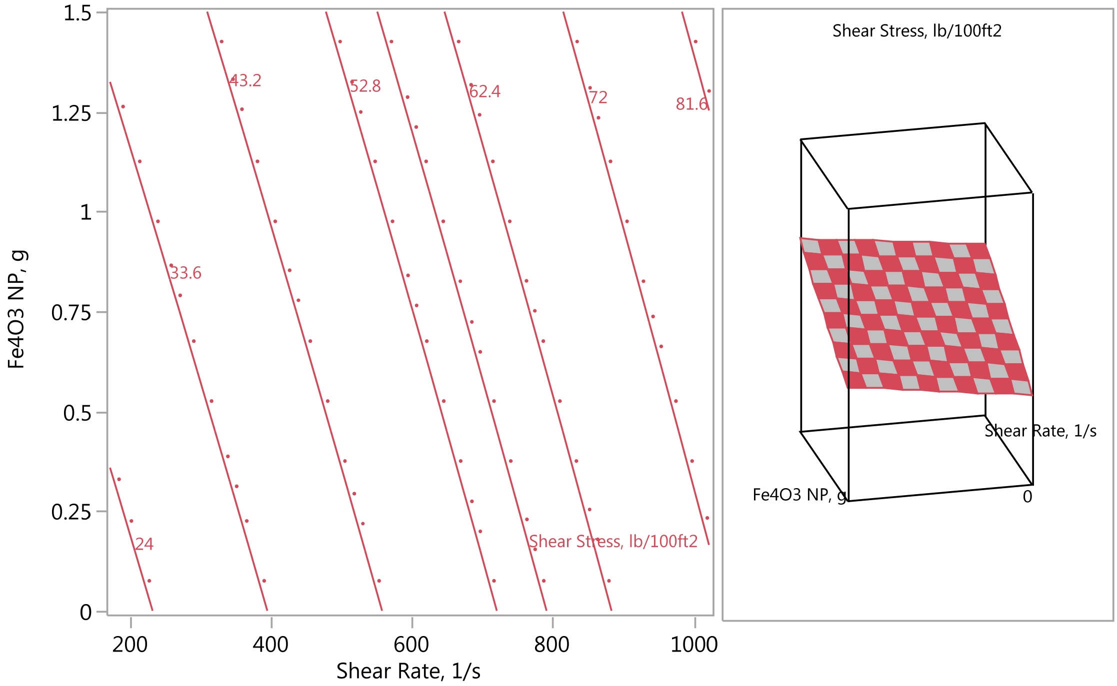

Fig. 9 Contour plot: effects Fe_4O_3 Np/shear rate on shear stress.

4. Conclusions

The high thermal conductivity of the Fe_4O_3 nanoparticles played very actively in the stabilization of the drilling fluid under the varying temperature conditions the fluid samples were subjected to under this study. The iron nanoparticles were able to maintain the shear stresses of the fluid as temperature increases at defined levels of shear rate. A predictive model to make engineering estimates of iron oxides nanoparticles mass fractions and shear rates when drilling operations must be made at higher temperature zones above hundred degrees Celsius was generated for this study. Interactive effects of the iron oxide nanoparticles, temperature and shear rate were also shown in addition to the cube plot that shows the optimization levels for all the parameters at the high and low levels of the shear stress of the drilling fluid.

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