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The experimental investigation of the effect of nono-silica particles on heat specific properties of water based drilling fluids and rheological properties

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Abstract
The drilling fluid or drilling mud plays various roles during drilling operations, including well cleaning, cooling, supplying necessary pressure on the well, cooling drilling bit; if correctly done, it will increase its lifespan and improve drilling performance. One of the most important properties associated with heat transfer into the well is the specific heat capacity. Increasing the special heat capacity of drilling mud improves the heat transfer in both streaming and static conditions, because this parameter improves the convection heat transfer coefficient. Today, many studies have been carried out on nanotechnology applications in the industry. Useful studies have been conducted on various industries in the field of heat transfer. The application of nanotechnology in drilling mud has not been deeply investigated to improve the performance of drilling mud during heat transfer. In this study, the impact of silicon oxide nanoparticles on improving the performance of heat transfer behavior and specific heat capacity of drilling mud is examined. Due to the structure of nanoparticles that enter the fluid as tiny and active particles, this additive is expected to improve the heat transfer process; and also the selection of nano-silicon, as a less expensive material, is also cost-effective. The results of this study indicate that a mixture of nano-silica along with polymer materials with a combination of specific concentration leads to presentation of a drilling fluid with a better control over the rheology and an increase in the thermal heat transfer coefficient due to the increase of the specific heat capacity, resulting in improving the performance of drilling fluid.

Keywords: Water-Based Drilling Fluid, Nano Silica Particles, Specific Heat Capacity, Rheological Control, Smectite-based drilling fluid

1. Introduction

Nanotechnology refers to materials and systems whose structure and components show new behavior due to nanometer dimensions, properties, physical, chemical, and biological phenomena. Materials with nanoscale particle size are in the area between the quantum effects of atoms and molecules and the properties of the mass. With the ability to construct and control the structure of nanoparticles, the resulting properties can be changed and the desired properties in materials can be designed. The drilling mud is a fluid that is pumped from the inside of the drill string tubes to the bottom and comes out of the drilling holes, and then carries the logs of drilling to the surface from the annular space between the well walls and drilling pipes. (Skalle. 2011 and Sarkar *et al*. 2013) [1, 2]. The specific heat capacity in solids is greater than in liquids and in liquids more than gases. This is justified by the use of molecular-kinetic theory. The molecules in the gases have high-speed motion, and a slight change in the temperature of a gas leads to increasing its volume. Thus, the specific heat capacity in the gases is low, while increasing the movement of molecules and the volume of liquids due to the increase in temperature is lower than the gases, and therefore the liquids have a higher specific heat capacity than the gases. The specific heat capacity of solids in the case of solids is greater than that of liquids because of the high thermal energy that they need to increase their volume. Nano silica is one of the most widely used nano additives applied in drilling mud. Silica nanoparticles can have different effects on the drilling mud, such as: reducing fluid loss, improving the stability of the well (reducing the destruction of the formation), reducing the torque forces, and maintaining the properties of drilling mud in high-temperature high-pressure conditions.

So far, various companies and institutions have been using this nanoparticle to improve the properties of drilling mud, including the Schlumberger company, which has used silica nanoparticles with commercial grades 30R25 KLEBESOL and 30 R9KLEBESOL. The Company SWACO50I-M, a subset of the Schlumberger Company, has also widely used nano-silica to increase the properties of mud. The University of Texas at Austin, the Petroleum University of China, the China Shengli oilfield drilling company and the China Geological University are other centers that have used nano-silica as an additive in drilling mud in cooperation with SWACO I-M Company. (Tour, *et al*. 2012 and Long, *et al*. 2012) [12, 3]. Sarkar *et al*. (2013) [2] evaluated the performance of nanoparticles in drilling mud to improve drilling mud properties as a case study. In their study, as most previous studies have pointed out, nanoparticles have played a major role in improving the performance of properties. (Sarkar, *et al*. 2013) [2] Tour *et al*. (2012) [3] examined the ability of graphene nanoparticles in drilling mud. Their study represents the improvement of the drilling mud properties in the control of filtration and mud rheology by graphene. Diasati *et al*. (2013) [4] examined the effects of nanoparticles in the oil and gas industry and provided different strategies to face the challenges ahead in this industry. Lang *et al*. (2012) investigated the effects of nanoparticles in drilling mud and their effects on protecting and preserving oil reservoirs as particles preventing damage to reservoirs. Also, rheology control as well as improving enhanced oil recovery (EOR) of oil reservoirs using nanoparticles has been well studied and examined. Sadegh Hassani *et al*. (2016) [11] in a study examined the effect of nanoparticles on the specific heat capacity of drilling fluid, and their study also represents the rheological properties of drilling fluid. Mesfin *et al*. (2016) demonstrated that the performance of silicon dioxide nanoparticles in the bentonite mud system depends on its concentration and the types of salt and polymer systems used, and also the optimum concentration of the nano formula can be very effective on the rheological performance and behavior of bentonite drilling mud. Petar *et al*. (2017) examined the effect of SiO_2 and TiO_2 nanoparticles on the properties of water-based drilling mud and the results of their research have shown that the combination of SiO_2 and TiO_2 nanoparticles improves the rheological properties of the water-based drilling mud. During the drilling operation, heat and friction are generated significantly in the bit and between the drill string and the well wall. The contact between the drill string and the wall of the well during the drill string movement can create an opposite torque and also cause the pipes to stretch during the pipe. The circulation of the drilling fluid transmits heat from the friction site, possible loss of bit and Reduces damage to drilling string. The drilling fluids the bit teeth that penetrates into the rocks and helps to smooth between the drill string and the wall of the well and reduce the torque and tensile force. Therefore, whatever the drilling fluid can ease the heat away from the bit side and absorb more heat from the bit, it will have a higher efficiency. This will return to the drilling mud's thermal capacity. By increasing the Specific heat capacity of the drilling fluid, the amount of heat absorbed by the bit is greater, which results in a quick bit cooling, especially in deep drilling, which speeds the flow of drilling fluid at the bottom of the well. This factor plays a major role. The synthesis of this research in relation to previous studies, due to the small diameter of silica nano-oxide particles, and also as an active solid additive, by creating micro-turbulence flows in drilling mud and absorbing more heat, increase the specific heat capacity in drilling mud. And also improves the rheological properties of the water-based drilling mud. In this study, the effect of nano-silica on the specific heat capacity of the mud, which is one of the important parameters in heat transfer inside the well, will be investigated.

2. Introduction of silicon oxide nanoparticles and its function on drilling mud properties

Silicon dioxide or silica is the most abundant material in the earth's crust. This compound, with the chemical formula SiO_2, has a structure similar to diamond; it is crystalline and white which its melting and boiling point is relatively high and is found in nature in crystalline and amorphous forms. Colloidal nano silica is a silicon dioxide whose particle size is in the nanometer dimensions. A colloidal nano silica is composed of particles that can be released in a bullet shape with a diameter of less than 100 nm, either in the form of dry powder particles or suspended in a liquid solution that the liquid, the most common type of suspended colloidal nano silica, shows multi-use applications such as anti-wear, anti-fire, anti-reflection properties of surfaces. These experiments have shown that the reaction of soluble silica colloidal with calcium hydroxide is much faster compared to microsilica, and very low amount of these substances have the same effect as pozzolanic effect of the high amount of microsilica at an early age. This material property is due to the fineness of suspended colloidal nano silica particles. There is no surprise that microsilica particles typically have a specific surface area of N_2 containing 15-25 m^2 / gr, while colloidal nano silica particles are with 180 m^2 /gr. Applied studies conducted include the application of the results of silica nano in the form of a solution in grout. Rheological properties testing of grout formula does not show any bleeding and segregation compared to the micro-silica grout, as well as it gives a 28-day compressive strength of more than 155 mpa. In this study, silicon oxide nanoparticles with an average particle diameter of 10-20 nm was used. (Domari Ganji, *et al*. 2015) [6].

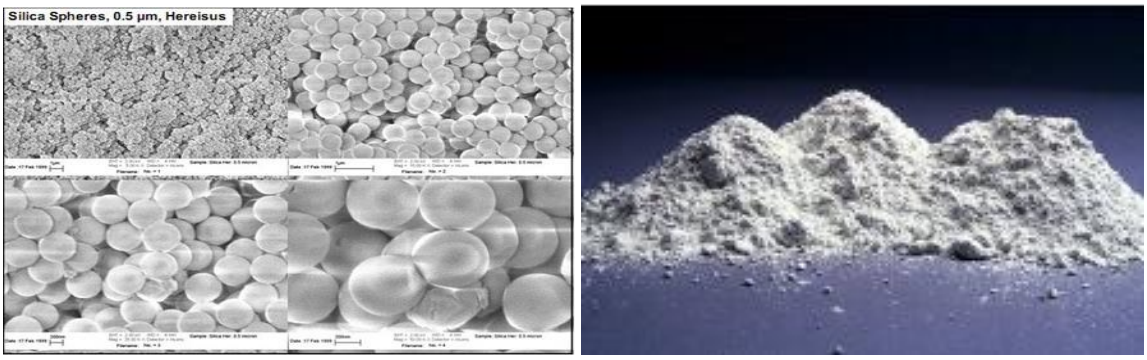
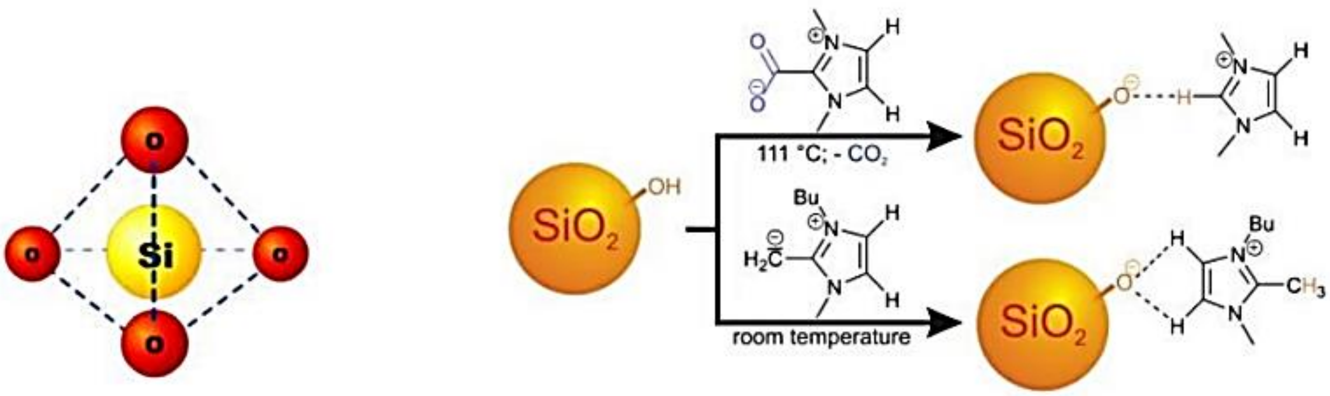


Fig 1: Nano-silica powder and silica nanoparticles in nano-meter dimensions (Domari Ganji, *et al*. 2015) [6].

In general, silica oxide nanoparticles have a negative surface charge because of their nature. This negative surface charge is due to the tetragonal structure of silicon. In Figure 2, the structure of nano-silicon is well shown. To change the surface charge properties of nanoparticles, researchers functionalize them with other coatings. The change in the physical properties of the drilling mud due to the addition of nanoparticles is mainly because of the change in the repulsive and attractive forces between the clay plates. As previously stated, clay minerals have surface charge plates, and the presence of a particle with an opposite or agreed charges with clay plates causes these plates to be absorbed or repelled. Overall, the attraction of clay particles around each other causes the filtration properties of the drilling mud is weakened and the gelatinous amount of drilling mud is increased. On the other hand, the presence of nanoparticles with the same sign charge of the clay plate results in dispersion of clay plates, and this phenomenon leads to the achievement of appropriate rheological properties. Figure 3 shows the interactions of nanoparticles with clay plates. In this study, the effect of nanoparticles and their interaction with clays in drilling mud on the properties of its heat transfer has been evaluated. The heat transfer properties generally improve with better dispersion of clay plates, as well as the uniform load distribution on the surface of the nanoparticles leads to considerably increase the heat transfer coefficient. (Suresh, *et al*. 2011 and Murshed, *et al*. 2012) [7]



a) Polar structure of silicon oxide nanoparticle, b) Hydrophobicity of particles with functionalizing non-polar material

Fig 2: Silicon oxide nanoparticles and functionalized silicon oxide nanoparticles (Suresh, *et al*. 2011) [7]

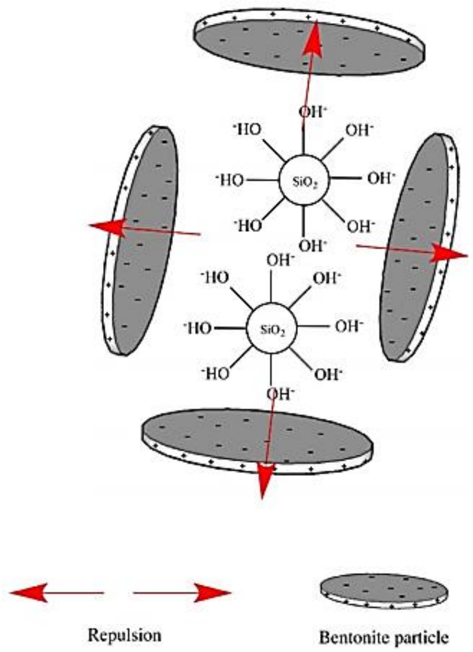


Fig 3: The effect of nanoparticles on the dispersion of bentonite plates

3. Research Methodology

At first, a base drilling mud sample is used as the basis for measuring other samples. Then, various other samples are prepared by adding nanoparticles at different concentrations. After that, the specific heat capacity is measured for two types of nanoparticles with different hydrophilic and hydrophobic properties at different concentrations and compared with the base mud. Then, the rheological properties of drilling mud are measured as other parameters affecting heat transfer. Rheology changes are measured with Viscometer Fann.

4. Design and construction of a water-based mud

At first, the preparation of fluids has been examined. In this study, 9 water-based fluids with different properties were created and compared with each other. In order to see the effect of an additive, the new fluid should be initially compared to a base fluid. So the base fluid is prepared at the beginning of the experiment. In this case, two types of water-based mud, one with clay bentonite and the other with clay smectite, made with other additives, such as salts, viscose fiber, etc., can be observed in Table 1. These two clays are commonly used as water-mixed clays as controls for viscosity and filtration in drilling fluid. Moreover, other additives are added to these base muds as a weighting agent such as barite or inhibition properties such as salts. A1-type mud is made with bentonite clay and A2-type mud with clay smectite. There are no nanoparticles added to these two types of muds, and we have just measured the properties of the base mud. During the construction of mud, the pH of mud was kept constant at the desired range using a PH meter. After making the muds and measuring their density and viscosity, the muds were placed inside a special cell for the heat capacity gauge device. After preparing the base fluids, their rheological properties and thermal properties such as specific heat capacity were measured, which these properties are further provided. The following results were obtained in order to determine the effect of adding silica oxide nanoparticles on the viscosity of the drilling fluids containing two types of clay using the Viscometer Fann. Table 2 shows the gelatinization changes of the drilling mud for two different base fluids at different concentrations of nanoparticles. Based on the results of various gelatin resistance table in different concentrations of nano, it is observed that by increasing the concentration of nanoparticles, the jelly resistance of the fluid increases. Based on the results of the jelly resistance of both A1 and A2 fluids by adding nanoparticles at different concentrations, Figure 4 shows changes in viscosity of fluids containing nanoparticles with base fluid A1. The properties of base fluid A1 additives are shown in Table 1 and this fluid enjoys the bentonite clay as the main additive. By adding silica oxide nanoparticles to this fluid, the apparent viscosity of the fluid has increased. As shown in Figure 4, viscosity of fluids has an incremental model similar to that of a power fluid at various concentrations of nanoparticles. Figure 5 represents the rheological diagram of a smectite-based drilling fluid containing nanoparticles. As can be seen, the apparent viscosity in this fluid has also incremental tendency and is closer to the power fluid model. The remarkable and important thing encountered during the measurement of viscosity with a fan machine was that, in contrast to the apparent fluid viscosity increase in these experiments, the gelatinization point of the drilling mud had decreasing trend with the addition of different nanoparticles, and this trend again became incremental from a specific concentration onwards. The reason for the decrease in the amount of gelatinous point at lower concentrations of nanoparticles is because of the fact that these particles have a negative surface charge and, they cause the dispersion and separation of these plates due to the penetration between the plates and the clay layers of bentonite or smectite, which also change the stability of surface charge in these clays. The result of this interaction is the changes of cation-exchange capacity (CEC) or the cation exchange of drilling mud, leading to a decrease in the gelatinous resistance in the mud. In addition, the increase in nanoparticles does not reduce the amount of gelatinization in the drilling mud after a certain other concentration, and merely the accumulation of nanoparticles themselves along with clay plates increases this property.

Table 1: The combination of the tested muds

Mud name / Additive Name (gr)	A1	A2	A3	A4	A5	A6	A7	A8	A9
Distilled water ml	350	350	350	350	350	350	350	350	350
Bentonite gr	30	0	30	30	30	30	30	30	30
smectite	0	30	0	0	0	0	0	0	0
NaCl (gr)	35	35	35	35	35	35	35	35	35
CMC	5	5	5	5	5	5	5	5	5
lignite	1	1	1	1	1	1	1	1	1
Red starch	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Lignosulfonate	4	4	4	4	4	4	4	4	4
Barite	40	40	40	40	40	40	40	40	40
	PH 9.8-10	PH 9.8-10	PH 9.8-10	PH 9.8-10	PH 9.8-10	PH 9.8-10	PH 9.8-10		

Table 2: Gelatinization resistance of different fluids in various nanoparticles concentrations

Nanoparticle concentration (wt %)	Jelly resistance of fluid A1 (lb/100ft^2)	Jelly resistance of fluid A2 (lb/100ft^2)
0	2.4	2.6
o.1	2.3	2.2
0.5	1.8	1.9
1	1.5	1.7
1.5	2	1.9
3	2.6	2.5
5	3	3.3

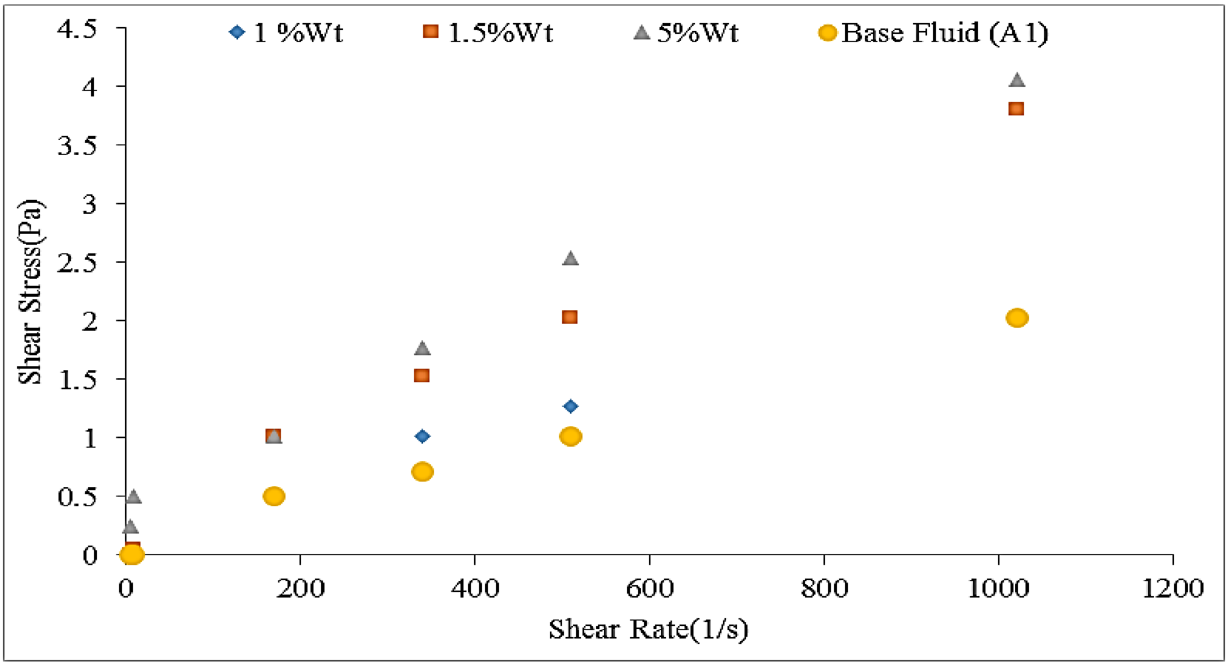


Fig 4: Rheological diagram of bentonite-based drilling fluid at various concentrations of silicon oxide nanoparticles

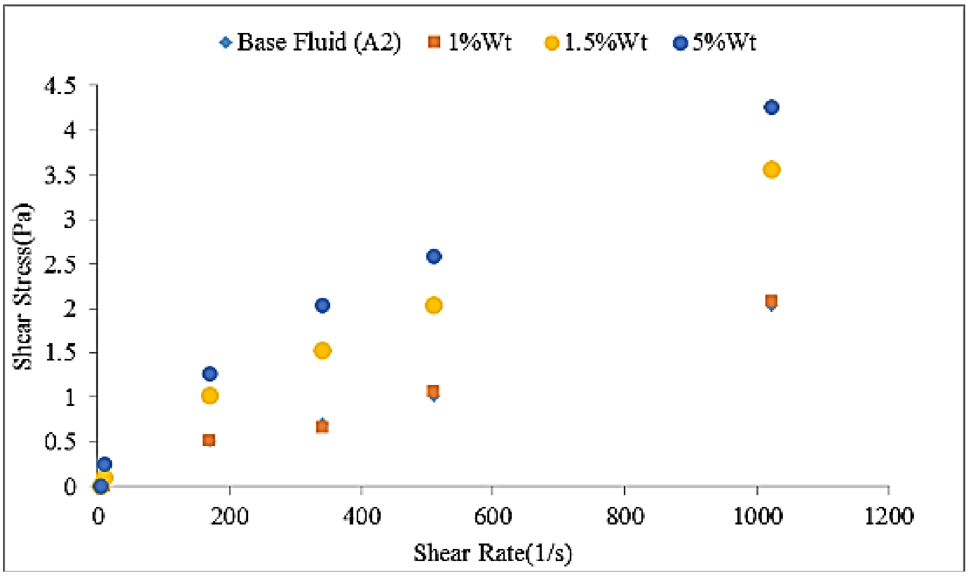


Fig 5: Rheological diagram of smectite-based drilling fluid at various concentrations of silicon oxide nanoparticles

5. Determining the heat capacity of the fluids

After determining the viscosity properties of the fluids, the heat capacity of the fluids as a measure of heat transfer will be examined. Initially, we conducted a test using pure water fluid for calibration of the heat capacity measurement device, and the results enjoyed an acceptable value for measurement. As known, the amount of water specific heat transfer capacity is equal to 4200 j/kgoc that the device measures the amount of 4178 j/kgoc and has an appropriate standard error. After that, the heat capacity of other fluids is measured and their results are compared. Table 3 shows how to calculate the heat transfer capacity of three different fluids. As is clear, the specific heat capacity is calculated by drawing changes in the amount of the specific heat to the changes in temperature.

Table 3: Heat properties of three produced mud samples

NaNo Concentration (%Wt)			0 %		3 %		5 %	
Time (minute)	Heat (J)	Specific Heat (J/kg)	Temperature (° C)	Temp. Difference (°C)	Temperature (° C)	Temp. Difference (°C)	Temperature (° C)	Temp. Difference (° C)
0	0	0	18.965	0.000	19.781	0.000	19.781	0.000
1	6000	20000	21.820	2.855	23.961	4.180	24.573	4.792
2	12000	40000	28.040	9.075	28.549	8.769	27.734	7.953
3	18000	60000	32.832	13.867	33.749	13.969	32.730	12.949
4	24000	80000	37.420	18.455	36.808	17.028	37.420	17.639
5	30000	100000	42.212	23.247	38.542	18.761	37.930	18.149
6	36000	120000	47.004	28.040	41.091	21.310	39.867	20.087
7	42000	140000	52.103	33.138	46.597	26.816	41.906	22.126
8	48000	160000	56.589	37.624	49.350	29.569	43.946	24.165
9	54000	180000	61.279	42.314	55.161	35.381	46.087	26.306
10	60000	200000	66.275	47.310	59.138	39.357	50.369	30.589
11	66000	220000	70.762	51.797	68.315	48.534	56.385	36.604
12	72000	240000	75.554	56.589	72.393	52.612	62.911	43.130
Specific Heat Capacity(j/kg°c)			4478		4520		4820	

6. Discussion and Results

After drawing a diagram of the heat changes in terms of temperature, the gradient of these changes is equal to the specific heat. The amount of heat given to the fluid can be calculated through multiplying the amount of time to stay fluid in the device at the amount of power input from the heating element of the device that is equal to 100 watts. As well as, the temperature change of the sample fluid temperature is measured using a sensitive thermometer (Table 3). Figures 6 to 8 show the changes in the input heat according to temperature changes for three different fluids. The results of the experiments indicated that the heat transfer capacity increased suitably and significantly in various fluids prepared with increasing concentration of nanoparticles, and this increase in heat capacity at high concentrations of nanoparticles was kept constant and unchanged. As mentioned, the temperature of the fluid was measured at different times. This is because the element gives a constant flux to the fluid, and the constant flux at the time will be the amount of input heat. Figure 9 shows the changes in heat capacity at different concentrations of the bentonite-based mud. As can be seen, the final heat capacity is maintained at 4960 and significant changes in the sample do not occur with increasing concentrations of nanoparticles. The final increase of specific heat capacity in the smectite-based mud is maintained at 5370, and this does not change with increasing the amount of nanoparticles.

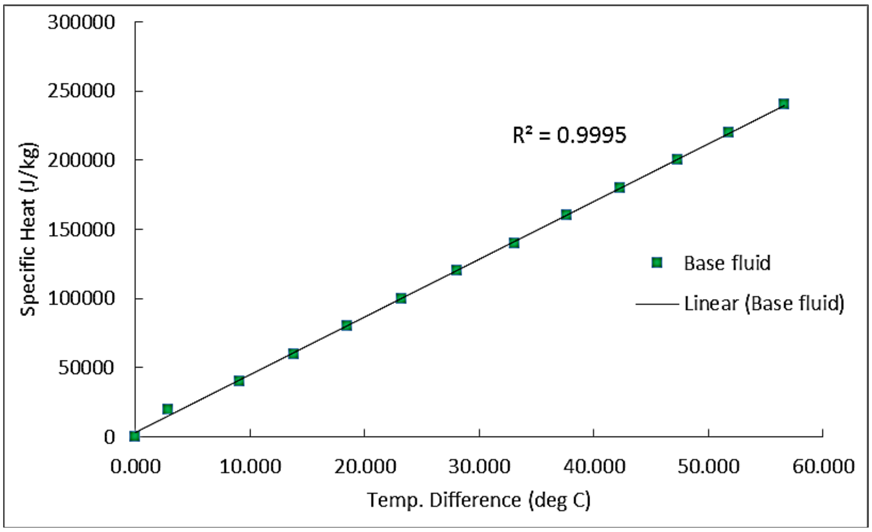


Fig 6: Specific heat change versus temperature change for water fluid (specific heat capacity = 4178 J/kg ° C)

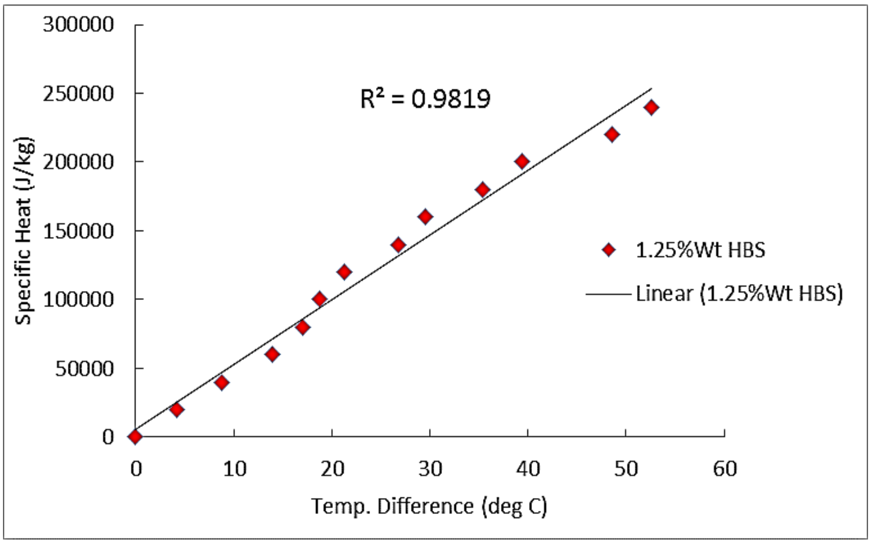


Fig 7: Specific heat change versus temperature change for the bentonite-based fluid containing nanoparticles with a concentration of 0.3% (specific heat capacity = 4520 J/kg ° C)

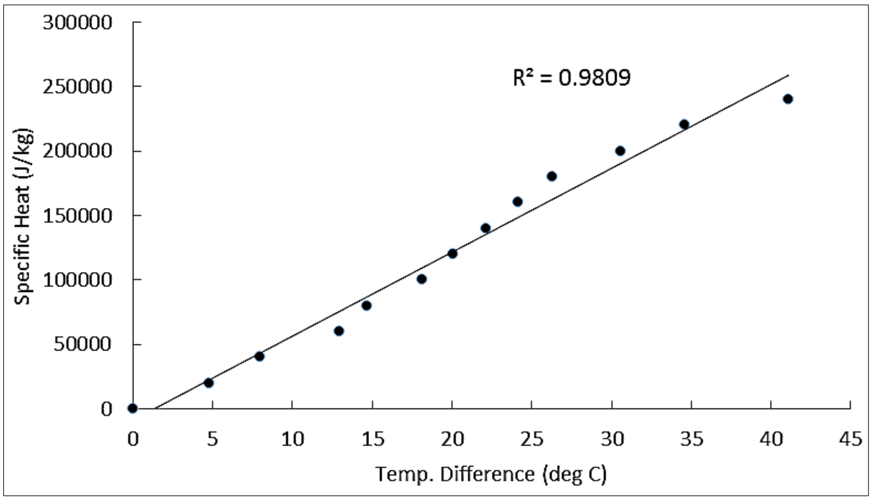


Fig 8: Specific heat change versus temperature change for the smectite-based fluid containing nanoparticles with a concentration of 0.3% (specific heat capacity = 4820 J/kg ° C)

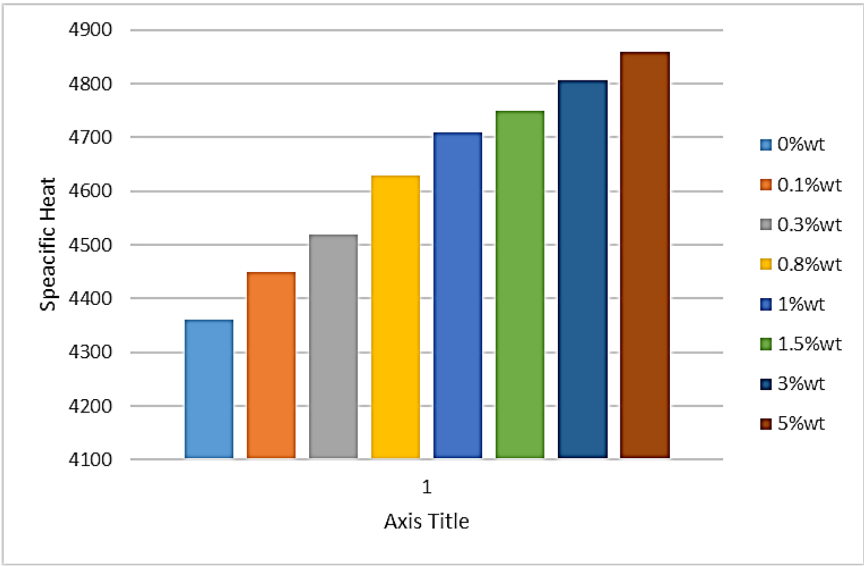


Fig 9: Final change of specific heat capacity for bentonite-based drilling mud containing nanoparticles at different weight concentrations

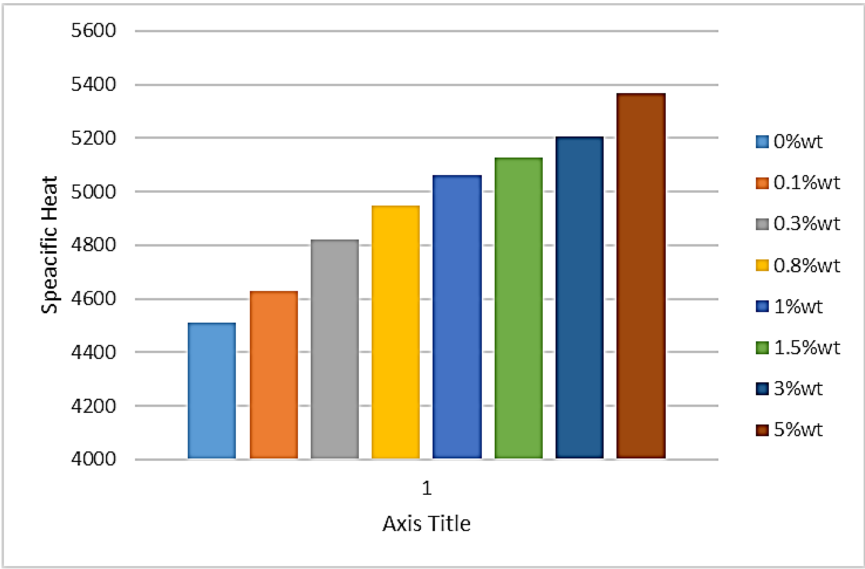


Fig 10: Final change of specific heat capacity for smectite-based drilling mud containing nanoparticles at different concentrations

7. Conclusion

In this research, the effect of nano-silica on the bentonite drilling fluid system of the water base drilling mud with CMC is presented. The purpose of this study is to offer an optimized nanoparticle system that improves the rheology and thermal transfer of drilling mud. Multiple combinations of salt solutions and polymer (CMC and PAC) were tested. By performing numerous experiments, the results show that a mixture of nano-silica with polymeric materials with a specific concentration of composition results in a drilling fluid with a better control over the rheology and an increase in the heat transfer coefficient due to the increase in the Specific heat capacity, and As a result, the drilling fluid's performance improves. In general, the following results are derived from this research.

- Increasing the concentration of nanoparticles increases the rheological properties of bentonite-based and smectite-based drilling muds.
- By increasing the concentration of nanoparticles to a certain extent, the amount of gelatinization properties of the drilling mud decreases and again become incremental from a specific concentration onwards.
- Changes in the amount of gelatinization in the drilling mud are because of changes in the cation exchange capacity due to the negative charge saturation of nanoparticles in the clay plates.
- Increasing nanoparticles to the bentonite-based mud system increases the specific heat coefficient of the fluid up to 4960 j/kgc, which is remarkable per se.
- Increasing nanoparticles to the smectite-based mud system has increased the heat transfer coefficient by 5370.
- Increasing specific heat coefficient itself will increase the heat transfer coefficient and thus improve heat transfer around the drill.

8. Acknowledgements

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9. Highlights

- Investigation of the Effect of Silica oxide Nano on the Improvement of the Performance of the Heat Transfer

Behavior and the Special Thermal Capacity of the Drilling Mud.

- The effect of Silicon oxide Nano on the improvement of rheological properties and viscosity of drilling fluids.

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