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The Effect of Micro and Nona Silica Addition on the Filtration and Mud Cake of Drilling Fluid

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Abstract

The selection of suitable materials as components of the drilling fluid remains the primary concern of the mud engineer. Micro and nanomaterials represent dense and effective complementary additives to the drilling fluid. In this paper, both micro silica and Nano silica were used in order to find the effect of each on the properties of drilling fluid in general and filtration in particular. Where the results showed that each of them has an effective and different role in improving the properties of drilling fluids in general and filtration in particular. although they are one material, but nanotechnology has contributed to making Nano-silica more efficient and effective than micro-silica. Both materials reduce the permeability of the mud cake and reduce the volume of the filtrate, as well as increase the viscosity, yield point and gel strength. As for density and acidity, fine silica had the biggest effect. Where it can be used as a heavy material, as well as the effect of adding micro silica on the PH value has been studied, as the results prove that the proportion is direct. As for Nano silica, it did not have a significant effect on the density or the pH. The results showed that Nano-silica is the most efficient for reducing filtration, followed by CMC, then PAC, then micro-silica It was found that if the percentage of addition was 25%, the filter volume value is as follows: 0.5 cc for Nano silica, 1.9 cc for CMC, 2 cc for PAC and 3 cc for micro silica. The addition of Nano-silica gave a cohesive clay cake with a permeability of 1.84, five times lower than what was provided by PAC for a 25% addition ratio.

Keywords: Mud cake, Bentonite, Filtration, Micro, Nano, Drilling fluid, Rheology.

1. Introduction:

Drilling fluid is one of the most important factors for the success of the drilling process, and it represents the blood circulation of the drilling process**,** as the engineer is looking for an efficient and economic drilling fluid [1]. The fluid loss from the mud as a result of filtration in the well is

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controlled by forming an impermeable mud cake as a result of the deposition of solids and other chemicals such as (CMC, starch) and others [2]. Nanoparticles (NPs) via the nanotechnologies component are taking a huge imminent impact on improving the properties of drilling mud. Nevertheless, the portion of NPs in that arena is still in its infancy and so it has attracted more interest in recent times [3]. The impermeable mud cake is formed by sedimentation of part of the drilling fluid on the wall of the well and its usefulness is to prevent the invasion of the layer by the mud filter. This cake is formed by adding bentonite and adding other filter reducing materials PAC, CMC, and Starch. Also, treating the mud with some chemicals such as Viscosity thinner is useful for improving the properties of slurry cake to ensure solids distribution and diffusion [4]. Silica fume also recognized as micro silica is a by-product of the manufacture procedure of ferrosilicon metallic in electrical arc heaters, that is gained from smoke growing through heater stacks by the compression procedure, and consequently, it is termed from Some authorities recognized Condensed Silica Fume (CSF) [5]. Filtration is the penetration of part of the continuous phase of the drilling fluid into the permeable formations that are penetrated due to the pressure difference between the column of the drilling fluid present in the well and the formation pressure, and is accompanied by the deposition of part of the solids present in the liquid. [6]. The mud filtrate fills the surface pores of the rocks and the area exposed to the liquid, forming what is called a mud cake. The solid parts of the drilling fluid block or bridge the pores of the rocks, forming what is called the inner mud cake, whose thickness is a few millimeters. Then the filtration speed suddenly decreases, and at the same time, the materials begin to settle on the wall of the well, forming an external mud cake. [7]. Filtration sources: pressure rearrangement in the well area, bulge and change in the bastion properties of the rocks, which are fundamental to the unpredictability of drilling, collapse, flaking, and cavity formation by a result within the reservoir, this is called drilling fluid loss [8]. On the wall of the well, the thickness of the mud cake will increase continuously for several hours until reaching the equilibrium thickness, which occurs at the moment when the corrosion forces due to the rotation of the drilling fluid are equal to the forces that lead to the deposition of the solid parts present in the liquid. [9]. The use of a drilling fluid with high filterability, that is, with a high water content, can cause major problems, including the formation of a thick mud cake against the highly permeable layers. Assigning the wall of the well to reduce the occurrence of cavitation in it. Increasing filtration into the layer leads to distort the reservoir properties of the penetrating layers. The tendency to stick the drill

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string partially adherent in the mud cake against the higher permeability layers due to the pressure difference between the drilling fluid shaft and the pressure of the layers. [10].

Silica dust - Silica fume, also known as micro silica - is a pozzolanic material that is added to concrete mixtures, and it is a by-product of the production process of ferrosilicon metal in electric arc furnaces, where it is obtained from smoke rising through the furnace chimneys by the condensation process, and therefore this material has been called condensed silica fume (CSF) by some specialists.

Silicon dioxide makes up about 90% of the composition of micro silica, and its particles are spherical in shape and super fine, so that it is about 100 times finer than the particles of cement. Part of the cement materials used in the concrete mix can be replaced with silica dust in proportions ranging between 7-10% by weight. Micro silica is manufactured in Europe, Egypt, South Africa and India [11]. So, micro silica is basically used with cement as shown above, but what is new in this paper is that it was used as one of the additives to drilling fluid to reduce filtration. One of the most important benefits of using silica dust (micro silica) in clay is as follows: high initial and final resistance, better abrasion resistance, better sulfate resistance, lower permeability and therefore higher durability. Those are one of the most important requirements for a clay cake [12]. The well wall construction and filtration characteristics of the drilling fluid are significant for given that a qualified measure of the quantity of drilling fluid filtrate invasion through a permeable and porous formation. [13].

1.1.Literature review

Shakib (2016) founded that if the solids are existing in a very little percentage the filtration is extraordinary and fast. The filtration rate is related to the concentration of solids in drilling fluid, as when the percentage of solids is increased in the mud, a thick mud cake will form. Consequently, the filtration rate is decreased [14]. Martel et.al (2001) established that the filtration rate also depends on the viscosity of the drilling fluid as they are inversely proportional. The rate of filtration at any given moment is directly proportional to the pressure change through the layer. Nano Clay is engineered by adding nanomaterials to the drilling mud, knowing that the percentages of addition are very low due to the high effectiveness of these materials. [15]. Nanoparticles improve the rheological and thermal properties of drilling fluids as confirmed in recent research. Mahmoud et al. (2016) confirmed on effective performance of drilling fluids

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permeated with silica NPs for use in drilling natural gas wells [16]. He et al. (2021) studied the effect of adding silica NPs as a fluid loss negotiator on drilling mud, they revealed that the addition of Nano silica NPs aided stop water loss and clogging of Nano pores in shale [17]. Guo et al. (2021) founded that micro silica is important in the petroleum industry in many processes and includes foam stabilization in emulsions as well as in reducing water intrusion in formations and controlling filtration and rheology in drilling mud [18]. Abdel-Karim et. al (2021) established that micro silica comprises of glass particles whose size is about 1000 times less than the average size of bentonite particles and this certainly increases the strength and durability of the clay and reduces the permeability of the clay cake [19]. Micro silica is considered an excellent material that the oil industry can benefit from through its applications in improving the rheology of oil wells, more papers are being researched on its economic feasibility and environmental friendliness. This study aims to study the effect of Nano silica and micro silica on drilling mud and the effect of each on the overall properties of the drilling fluid, in order to obtain a final decision on which is better. On the other hand, studying its effectiveness to improve the filtration properties of water-based muds. What is novel in this paper, is the use of micro silica as a filtration reducer, which is a material originally used with concrete mixtures, but in this research it was presented as a filtration reducer and compared its performance with Nano silica and common filtration reducers, the results proved to be successful as a filter reducer.

2. Experimental Work:

2.1 Material and Mixtures:

In this study, bentonite, micro silica, and Nano silica were used in different proportions (Figure 1). The total number of models used was 18 as shown in Table (1).

Table (1) Mixing Quantities.

Sample No.	Water cc	Bentonite gm.	Micro silica%	Nano silica %
1	350	22.5	0	0
2	350	22.5	3.125	non
3	350	22.5	6.25	non
4	350	22.5	12.5	non
5	350	22.5	25	non
6	350	22.5	50	non
7	350	22.5	75	non
8	350	22.5	100	non

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9	350	22.5	non	0.031
10	350	22.5	non	0.063
11	350	22.5	non	0.125
12	350	22.5	non	0.25
13	350	22.5	non	0.5
14	350	22.5	non	0.75
15	350	22.5	non	1
16	350	22.5	12.5	0.125
17	350	22.5	25	0.25
18	350	22.5	50	0.5

Fig. (1) The used materials: a) Micro silica, b) Nano silica, c) bentonite

2.2. The Laboratory Device:

Figure (2) shows the most important laboratory equipment that was used to complete the practical part of this paper. It is worth noting that all measurements were made under laboratory conditions. Below is a simplified explanation of each device and why it was used:

1- **Mixer**: It is used to mix bentonite with water and other additives such as micro and Nano silica. It works with three speeds, low, medium and high
2- **Balance**: It is used to weigh the materials used such as bentonite, micro and Nano silica.
3- **Viscometer:** It is used to find the viscosity, gel force value, yield point, and it has 8 speeds.
4- **pH Paper:** It is used to find the acidity and alkalinity of a drilling fluid
5- **Mud Balance**: It is used to measure the density of drilling fluid. It gives the density in four units, gm/cc, ppg, and lb./ft^3, and a pressure gradient is in psi/1000ft.

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6- **Filter press LTLP:** Standard API filter press, Low Pressure Low Temperature(LTLP), it is used to measure filtration, filtrate size and mud cake thickness and then find mud cake permeability using Darcy equation.

Fig. (2): The used devices: mixer, balance, viscometer, pH paper, mud balance, Filter press LTLP

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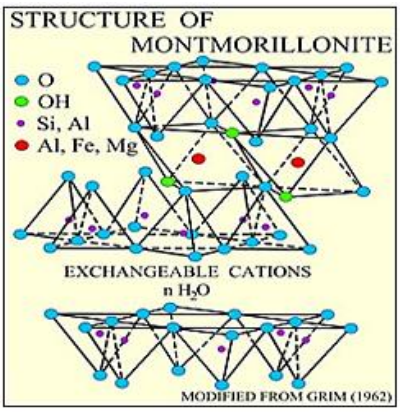
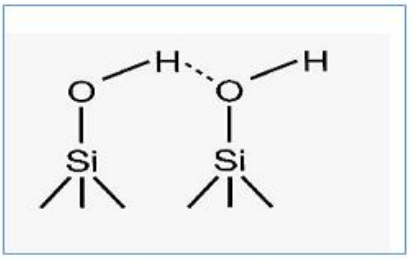
3. Methodology:

The practical part of the paper was accomplished by preparing water-based slurry samples with different concentrations of Nano-silica and micro-silica. The paper includes studying the effect of silica in its Nano and micro states on drilling mud. This requires preparation two types of drilling mud: micro-drilling mud consisting of micro-silica and bentonite, and Nano-drilling mud consisting of Nano-silica and bentonite. Also, drilling mud samples consisting of micro silica, Nano silica and bentonite were prepared and studied in the same model. Figure (3) shows the structure of the used materials.

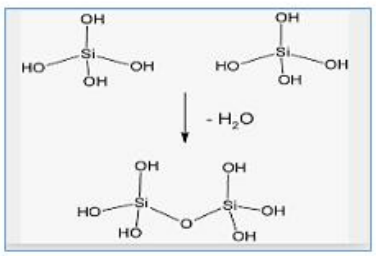
3.1 Bentonite: Bentonite is a class of clay, formed from the weathering of volcanic ash. It is extracted from the mine and ground into fine dust. The preparation of drilling mud depends mainly on bentonite and water, as the preparation according to API consists of 350 ml of water and 22.5 g of bentonite. Since bentonite contains a group of Montmorillonite as a main mineral, this interconnection between its plates is weak, which makes its dispersal in water easy, and it is thus considered a good raw material for the preparation of drilling fluid. The dissimilar categories of the bentonite are: Potassium bentonite, Sodium bentonite, and Calcium bentonite. The bentonite used in this study is potassium based bentonite.



a: bentonite structure



b: silica fume structure



c: Nana silica structure

Fig. (3): The chemical structure of the used materials.

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3.2. Nano particles clays: Nano clays are classified as clays with very little solid content, and this type of clay is characterized by its excellent rheological properties that enable the drilling fluid to perform its functions during drilling. It is also characterized by its low density, and these features are very useful to prepare the drilling fluid required to be pumped during conductor casing drilling (spud mud). Since the rock pieces will be large in size, and in order to carry them out of the well, there is a need for drilling mud with a high viscosity, in addition to a thick mud cake to give stability and support to the well wall. The weight of the drilling fluid should be as small as possible due to the nature of the excavated formations, where the high weight will cause part of the drilling mud to seep into the drilled layer. All of the above requirements are available in Nano-muds, which makes them suitable for being spud mud.

3.3. Micro clay: It consists of silica in different proportions and bentonite. As for silica, its addition to drilling mud makes it have moderate to medium rheological properties in addition to its impact on density. The use of these materials may be an alternative to the use of heavy materials, and thus save costs. Also, one of its advantages is that it gives a cohesive clay cake of medium thickness, and this in turn gives more stability to the walls of the well, especially for some type of formation. It is worth noting that this material was not used before with drilling mud, but rather it is used with cement during cementing operations in order to give the cement more durability. But in this paper it was used with drilling mud, and as proven by the results, it is possible and even better to add it to the drilling mud. Table (1) illustrated the mixing quantities.

4. Results and Discussion:

The fluid loss from the mud as a result of filtration in the well is controlled by the formation of an impermeable mud cake due to the accumulation of a portion of the dispersed phase of the drilling fluid. The fluid loss additives, the most important of which are nanomaterials, are added to the drilling mud to reduce fluid loss on the well wall. In addition to nanomaterials, there are other materials such as: bentonite, fine silica, CMC, PAC. Nanomaterials are newly used additives for mud as they can enhance drilling mud specifications and reduce mud-related problems, thus reducing wasted time and costs. As the results showed, the nanoparticles used in this paper can play an important role in solving drilling fluids problems. Figure (4a) shows that the addition of Nano silica leads to an increase in the viscosity values due to its ability to tap water and accelerate the hydration of bentonite. In the same context, Figure (4b) shows the decrease in the size of the filtrate with the increase in the percentage of addition of Nano-silica,

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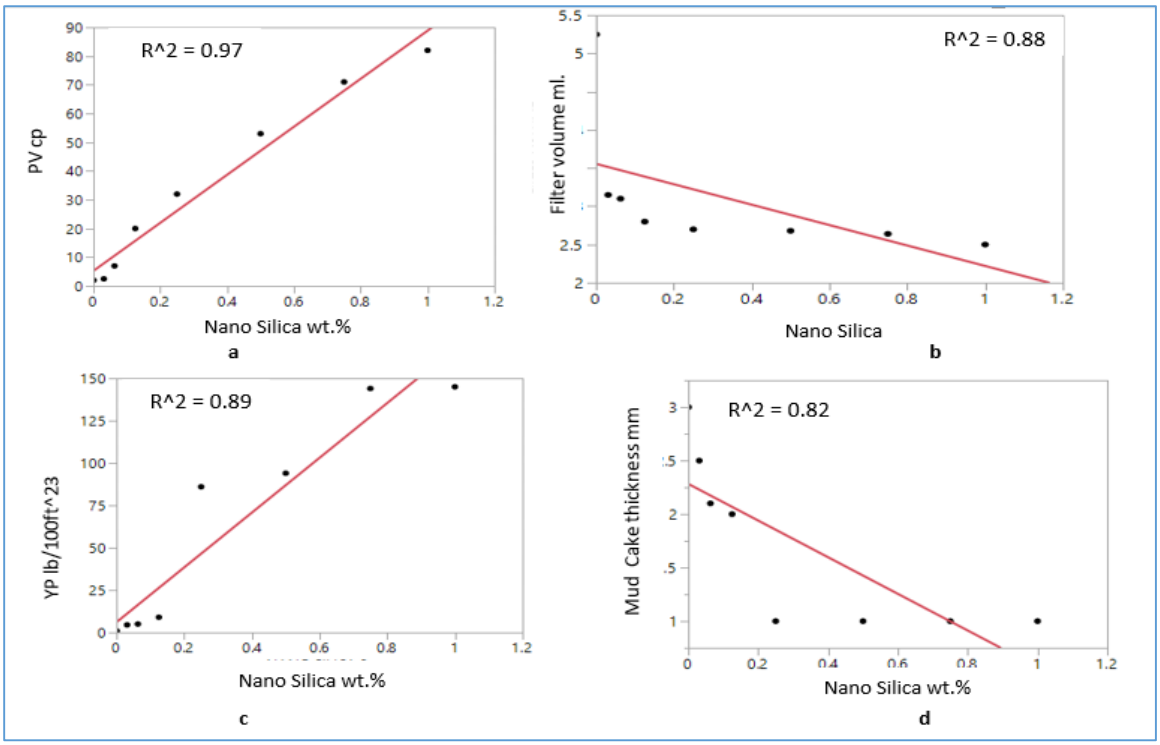
due to increased viscosity. Nano-silica can affect the physical and chemical properties of the drilling fluid, which in turn affects its behavior and stability. The addition of Nano silica increases the stimulation of attraction and bonding between molecules, and thus increases Yp. Whereas, the Nano-sizes of the material can be used as a catalyst for chemical processes, and it works to accelerate chemical reactions very quickly as illustrated in Figure (4c). From field experience, the thickness of the mud cake during constant filtration conditions is preferably about 5 mm. The clay cakes can grow up to 4 mm under static pressure conditions, which is better for well wall stability, and this is evident to us from the additions of Nano-silica to the prepared models. Figure (4d) shows that the thickness of the clay paste (obtained from the fluid loss lab work) for the different clay samples significantly decreased with increasing Nano silica weight percentages. Figures (4) (e, f, g, and h) show that the performance of micro-silica will not differ from that of Nano-silica. The only difference is how much is added, in other words, that is, the amount of nanoparticles required is 100% less than when fine silica is added to achieve the same result.



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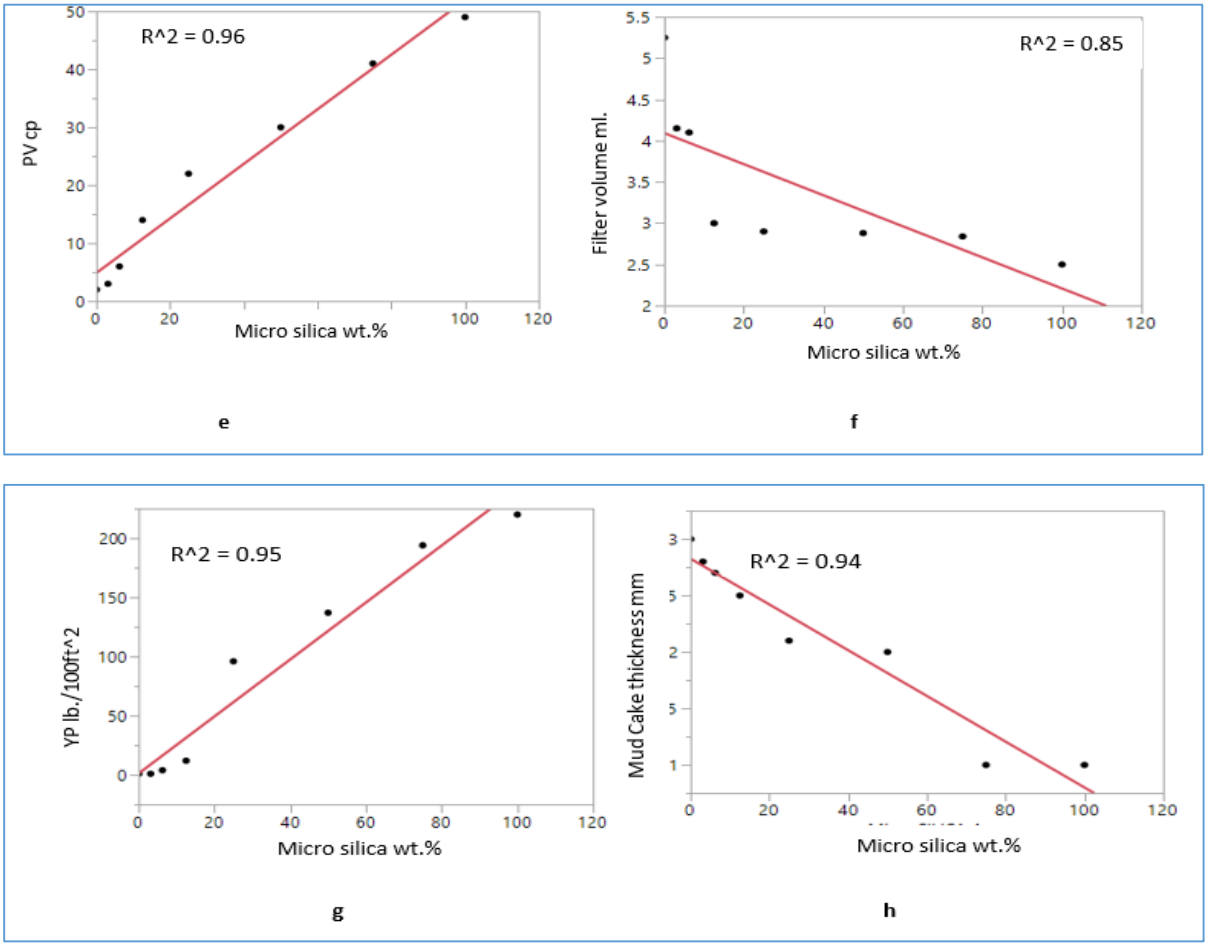

Fig. (4): The laboratory results of Nano silica (a - d) and micro silica (e - h).

As for the XRF analysis, it can be seen from Figure (5) that the addition of micro-silica led to a significant increase in the proportion of silica in bentonite. It was also noted that there was an increase in the proportion of aluminum and iron due to the addition of micro silica to bentonite. Figure (6) shows the effect of adding Nano-silica on clay, Whereas the XRF results showed that although the percentage of Nano silica addition decreased, adding it led to an increase in the percentage of silicon, in addition to a very slight increase in the percentage of aluminum. As for the effect of adding both materials to bentonite, the XRF analysis showed that there is a substantial increase in the proportion of silicon and a slight increase in the proportion of aluminum as shown in Figure (7). Figure (8) shows part of the experimental work and laboratory results for the studied clay models. Table (2) shows the XRF results for micro and Nano mud samples.

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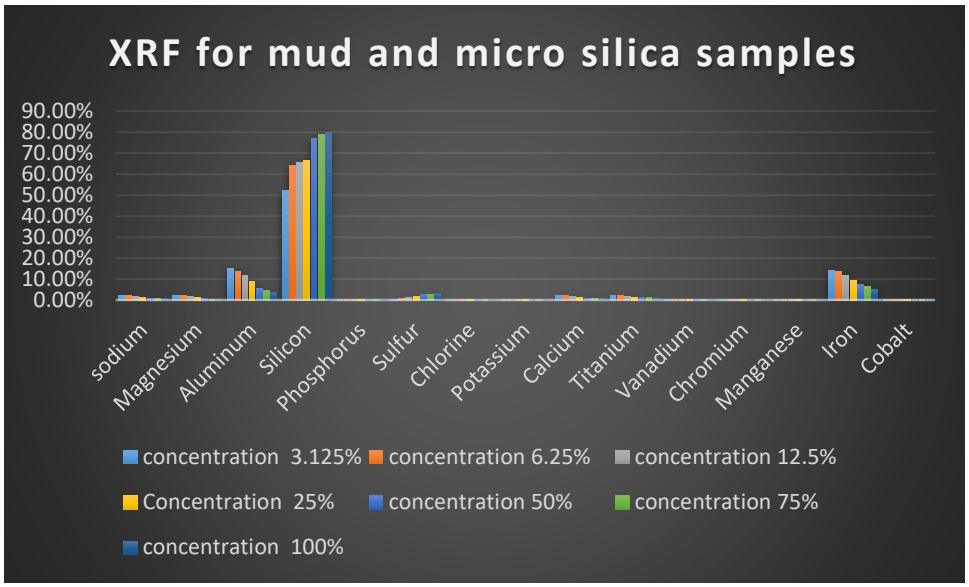

Fig. (5): The laboratory results of XRF for mud and Micro silica samples.

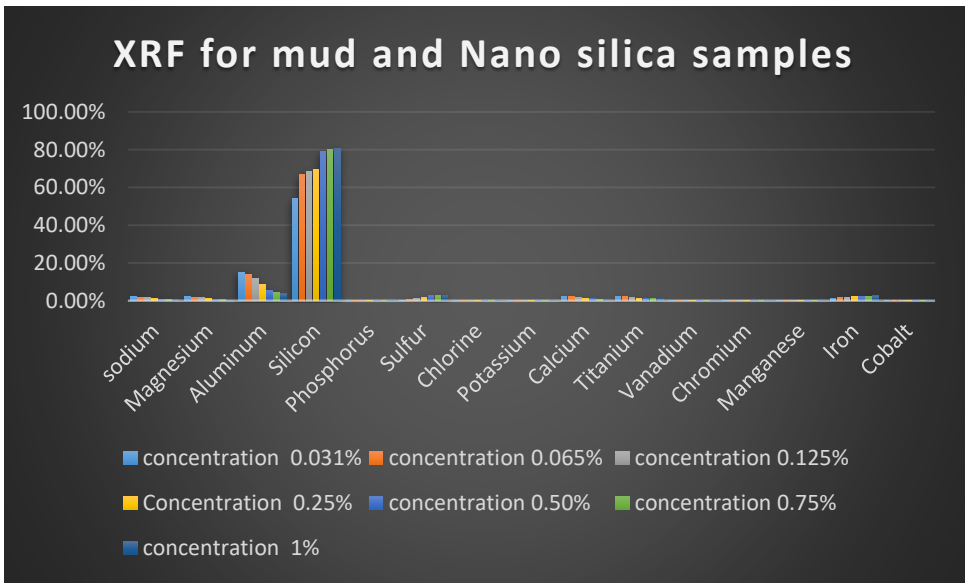

Fig. (6): The laboratory results of XRF for mud and Nano silica samples.

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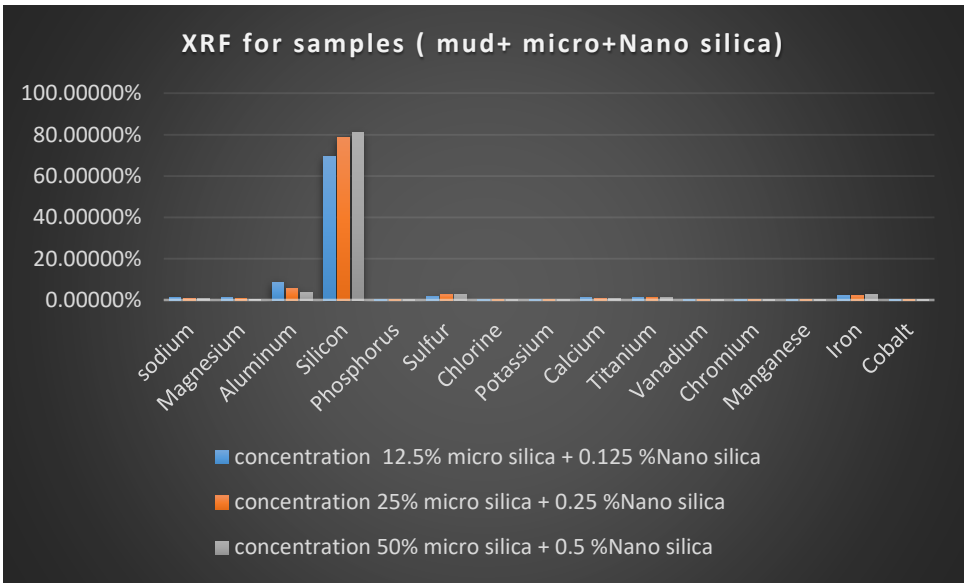

Fig. (7): The laboratory results of XRF for (mud and Micro + Nano silica) samples.

Table (2) The laboratory results for micro and Nano mud samples.

sample No.	Micro silica%	Nano silica%	Bentonite gm	Filter volume ml.	Mud cake thickness mm
sample 1	0	0	22.5	4.5	2
sample 2	12.5	0.125	22.5	3	1.7
sample 3	25	0.25	22.5	2.5	1
sample 4	50	0.5	22.5	0.75	1

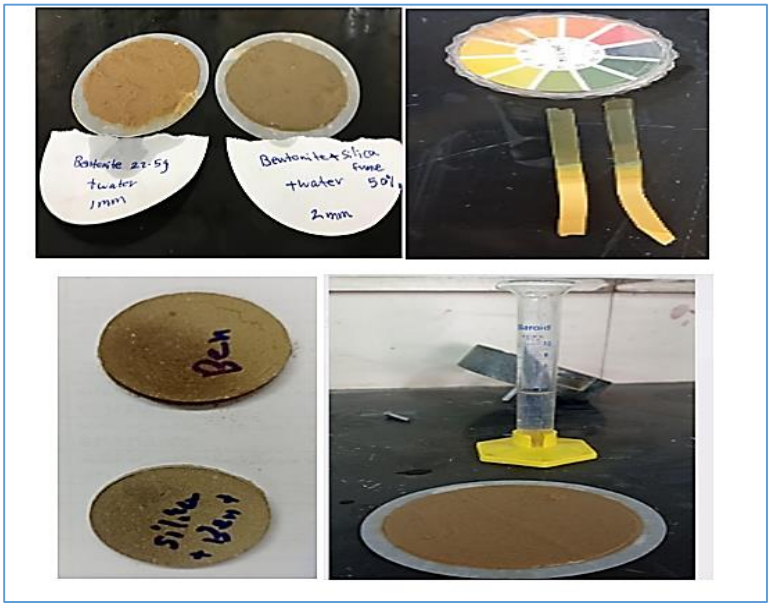

Fig. (8): The laboratory results for the used mud samples.

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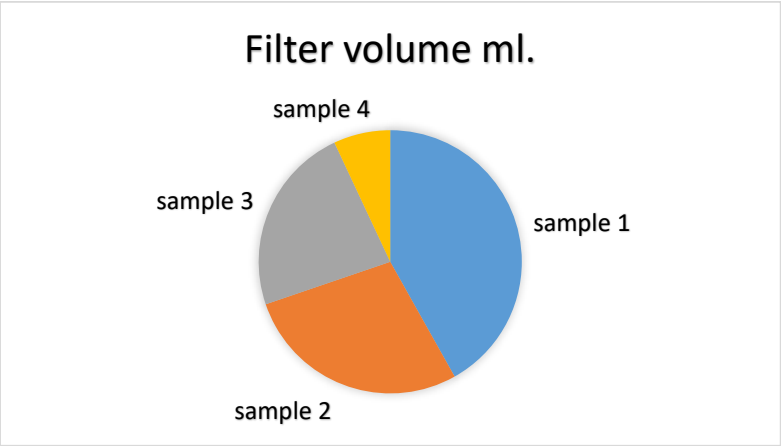

Fig. (9): The results for the filter volume for micro and Nano mud samples.

A mud cake is a layer of mud formed by drilling fluids leaching onto the well wall during the drilling process. The occurrence of the filtration process for drilling mud is associated with the occurrence of the drilling process under certain conditions called balanced conditions, which means that the pressure of the used mud is slightly higher than the formation pressure. Mud cake permeability can be calculated using Darcy's.

$$Q = \frac{K}{\mu} * \frac{\Delta p}{L} \quad \text{.....(1)}$$

where:

Q= flowrate cc/sec

k= mud cake permeability md

μ= viscosity, cp

p= pressure, psi

L= mud cake thickness at time t, mm

Figure (10) shows the effect of adding Nano and micro silica on the permeability of the mud cake. It is clear that both materials have reduced the permeability, but Nano silica had the most effective.

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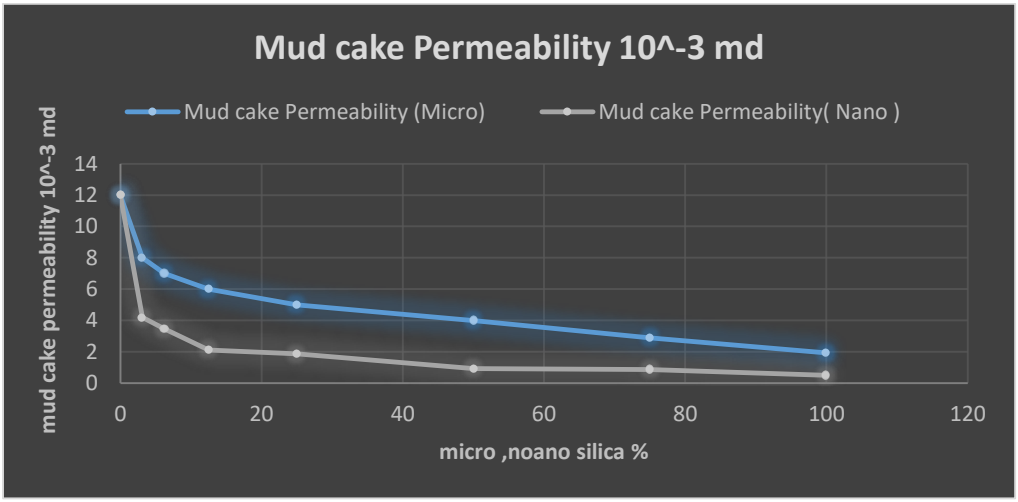

Fig. (10): The effect of micro and Nano mud additives on mud cake permeability.

Figure (11) illustrates the relationship between the filtration time and the permeability of the mud cake, where it is clear that the proportion is direct. The mud cake features are tightly regulated by clay type, properties and additives. The drilling fluid is often required to leave a small, low-permeability paste on the well wall in order to support it. The goal is to reduce the entire amount of mud flowing into the formation and stop the loss of circulation, which causes many of the problems associated with drilling fluid. Figure (12) shows the relationship between the filtration time and the thickness of the mud cake, where an increase in the filtration time leads to an increase in the thickness of the mud cake. The greater the filtration time, the greater the accumulation of solids, and thus the increase in the thickness of the mud cake.

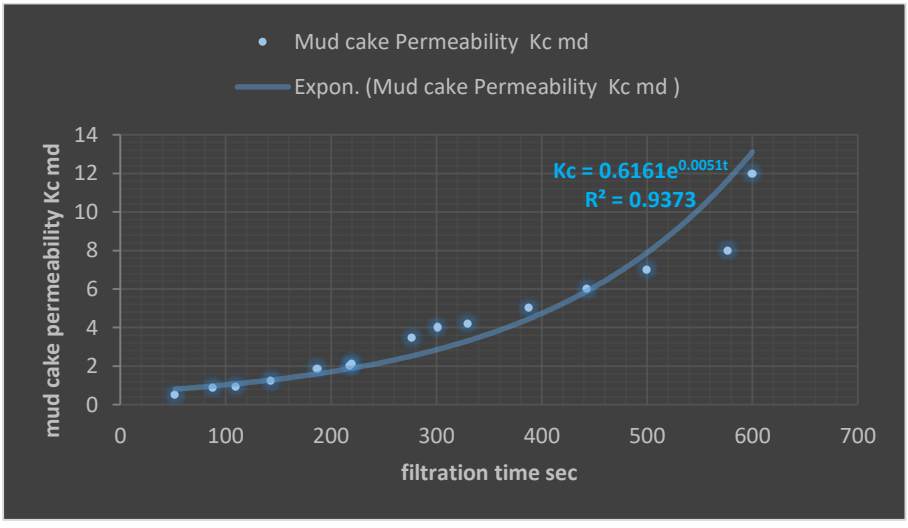

Fig. (11): The effect of filtration time on mud cake permeability.

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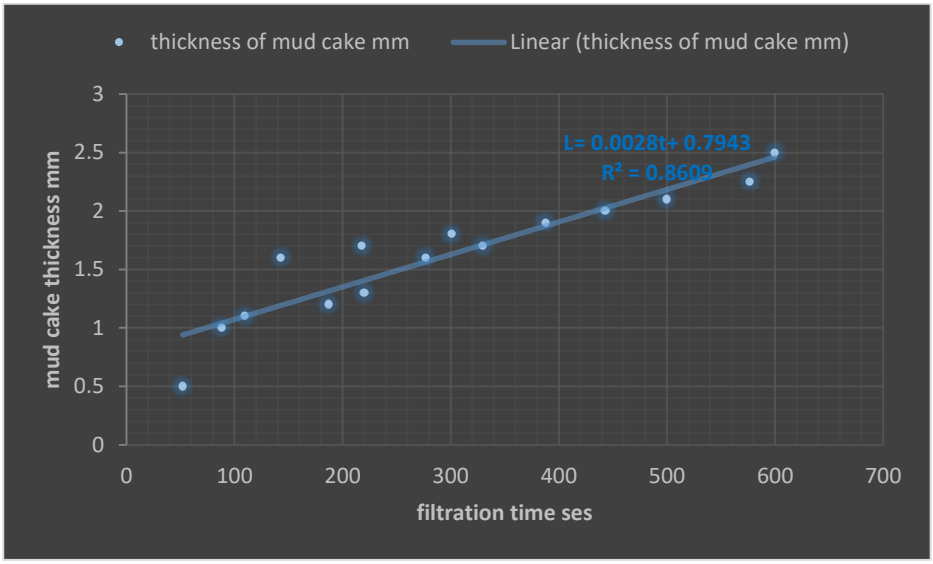

Fig. (12): The effect of filtration time on mud cake thickness.

Since carboxyl methyl cellulose CMC and polyconic cellulose PAC are among the most popular materials used as filtration agitators, they were added to drilling mud and their results were compared with the results obtained from micro and Nano. As shown in Tables (3) and (4), Nano-silica was the most effective, followed by CMC, then PAC, while micro silica was the least effective. Based on the results that have been reached, it is recommended to use Nano silica as a filter reducer because it gave excellent and encouraging results such as reducing the size of the filter and reducing the permeability of the mud cake in addition to its effect on increasing the viscosity.

Table (3) The Filtration results for micro, Nano, CMC, and PAC mud samples.

Additives %	Filter volume ml. Micro silica	Filter volume ml. Nano silica	Filter volume ml. CMC	Filter volume ml. PAC
0	4.5	4.5	4.5	4.5
0.031	4.25	3	4	4.2
0.063	3.5	2.5	3	3.5
0.125	3.25	0.75	2	2.75
0.25	3	0.5	1.9	2

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Table (4) The mud cake permeability results for micro and Nano, CMC and PAC mud samples.

Additives %	Mud cake Permeability $*10^{-3}$ (micro silica)	Mud cake Permeability $*10^{-3}$ (Nano silica)	Mud cake Permeability $*10^{-3}$ (CMC)	Mud cake Permeability $*10^{-3}$ (PAC)
0	12	12	12	12
0.031	8	4.1968	7.2	9
0.063	7	3.455	7	8.8
0.125	6	2.12	5	7
0.25	5	1.864	4	6

5. Conclusions:

1- The results proved that Nano silica is more effective than fine silica, and its effect is limited only to viscosity and filtration. On the other hand, fine silica has an effect on density, filtration, viscosity and pH.

2- The relationship between the weight ratios w% of silica (micro or Nano) and PV, YP is a direct relationship, meaning that the viscosity and yield point increase with the increase in the addition ratios.

3- The results showed that adding micro silica or Nano silica contributed to reducing the size of the mud filtrate and reducing the permeability of the mud cake.

4- Giving a cohesive mud cake with a low permeability was one of the advantages of adding silica to the drilling mud, and this was shown by the results of this paper.

5- After comparing the results of Nano silica with the results of other studied materials, it was proved that Nano silica can be considered as the best filter reducer.

List of Symbols:

CMC: Carboxyl Methyl Cellulose

PAC: Polyconic Cellulose

XRF: X-Ray Fluorescence

LPLT: Low Pressure Low Temperature

Y_P: Yield Point

NPs: Nano Particle

CSF: Condensed Silica Fume

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