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Nano-clays as additives for controlling filtration properties of water–bentonite suspensions

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ABSTRACT

Formation damage is a process that impairs the permeability of a reservoir and consequently decreases the natural flow of fluids from the reservoir into the formation. This phenomenon may occur due to various mechanisms, which reduces the well production. One of the most important factors that cause formation damage is drilling fluid invasion. Hence, designing additives for drilling fluid to minimize filtration into the formation is essential. Prior to the mud cake development, the primary factor involved in nano particles movement through the formation matrix seems to be due to the extra small size of these particles. However, in the case of mud cake creation, the nano particles bridging provides a barrier by which the transport of these tiny materials would be decreased substantially. In this study, the effect of different nano-materials like nano titanium, nano copper oxide, nano alumina, and nano-clay on drilling fluid filtrate is examined. Viscosity, filtration, and rheological properties of the newly designed mud were measured to characterize the formation damage due to mud invasion. Nano clay shows the best performance in controlling filtration and at a concentration of 6% it was able to reduce the filtration rate by about 5% more than conventional additives.

1. Introduction

The invasion of mud fluid into porous, permeable, formations during the process of rotary drilling is unavoidable. Drilling mud is a mixture of clay minerals, and other additives that enhance properties such as density, viscosity, gelation, etc., and a fluid which may be either water or oil. The drilling mud is pumped down to the bit through the drill stem and circulated back to the surface through the annulus between the drill stem and the wall of the wellbore. The density of the mud is adjusted to maintain a pressure difference between the mud and the bottom of the borehole and the fluids in the formation at 1000 MPa (145psi) or more. When a porous formation is penetrated, this pressure difference causes filtration of the liquid portion of the mud (the mud filtrate) into the formation ahead of the bit and into the wall of the borehole. The mud filtrate penetrates the formation radially displacing formation fluids (water and hydrocarbons) ahead of it (Donaldson and Chernoglazov, 1987).

In order to prevent formation fluids from entering the borehole, the hydrostatic pressure of the mud column must be greater than the pressure of the fluids in the pores of the formation. Consequently, mud tends to invade the permeable formations. Massive loss of mud into the formation usually does not occur, because the mud solids are filtered out onto the walls of the hole, forming a cake of relatively low permeability, through which only filtrate can pass. Muds must be treated to keep cake permeability as low as possible in order to maintain a stable borehole and to minimize filtrate invasion of, and damage to, potentially productive horizons. Furthermore, high cake permeabilities result in thick filter cakes, which reduce the effective diameter of the hole and cause various problems, such as excessive torque when rotating the pipe, excessive drag when pulling it, arid high swab and surge pressures. Thick cakes may cause the drill pipe to stick by a mechanism known as differential sticking, which may result in an expensive fishing job. Two types of filtration are involved in drilling an oil well: static filtration, which takes place when the mud is not being circulated, and the filter cake grows undisturbed, and dynamic filtration. When the mud is being circulated the growth of the filter cake is limited by the erosive action of the mud stream. Dynamic filtration rates are much higher than static rates, and most of the filtrate invading subsurface formations does so under dynamic conditions. The filtration properties of drilling fluids are usually evaluated and controlled by the API filter loss test (Caenn et al., 2011).

Laboratory studies (Krueger, 1982; Azam, 1985) indicated that

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Nomenclature

A area, L^2
f_{sc} volume fraction of solids in the cake, L^3
f_{sm} volume fraction of solids in the mud, L^3
h_{mc} height of mud cake, L
k permeability, L^2
t time, T
V_f filtrate volume, L^3
V_m mud volume, L^3
Δp differential pressure, F/L^2
μ viscosity
q_w volume of filtrate, L^3
q_c volume of cake, L^3

operations in a field, such as drilling, completion, workover, production, and stimulation, are potential sources of formation damage. For example, when a drilling mud comes into contact with porous rock, the rock acts as a screen, allowing the fluid and small solids to pass through while retaining the larger solids. The fluid lost to the rock is described as 'filtrate'. The layer of solids deposited on the rock surface is described as 'filter cake'. The quality of mud depends on the volume of filtrate lost to the formation, filter thickness, and strength of the filter cake. The volume of filtrate depends on the magnitude of differential pressure between the drilling fluid and the formation as well as the size of the mud solids making up the filter cake.

A large invasion zone impairs the natural productivity of the formation. Invasion of the fluid present in the drilling mud into the formation happens because of the filtration of fluid in shale or clay layers or in sandstone or conglomerate reservoirs whose matrix has high amounts of clay. The water present in the drilling mud causes the hydration of active clay minerals or scattering of the clay particles, which closes the rock pores and decreases permeability. Incompatibility of formation water with drilling mud also leads to salt deposition, which is another source of formation damage. The formation of water–oil emulsion is also one of the difficulties arising from filtration invasion. The formation of emulsions around the well increases the viscosity of production fluid and causes formation damage. The water block phenomenon in water-based muds also happens due to the filtration of water into the formation, which decreases the relative permeability to oil or gas. A number of additives are used to create a low permeability filter cake on the formation and to reduce the volume of water loss. These additives include bentonite, emulsified oil, dispersants, biopolymers, carboxymethyl cellulose (CMC), starch, lignite (Gray and Darley, 1980; Nyland et al., 1988; Clark, 1994; Strickland, 1994), and waxy hull-less barley (WHB) (Hamida et al., 2010). These additives also increase the mud viscosity, which decreases the filtration of fluid into the formation.

Nanotechnology can have significant effects in the petroleum industry, allowing high strength materials to be produced, improving the properties of materials and fluids used in operations are including the performance of nano-materials. Properties such as appropriate density and viscosity can be achieved by the use of nano additives. Thus the filtration properties and drilling fluid rheology can be improved in different conditions through the use of these nano-materials. The study presented in this paper deals with the filtration loss characteristics of drilling fluids containing nano-materials. Low pressure/low temperature (LP/LT) tests have been performed to evaluate the feasibility of using nano-clay as a drilling mud additive. By decreasing the size of the supramolecular coordination compounds of polymers to nano size, the surface area is increased. Therefore, their chemical and physical properties are changed (Jin et al., 2001; Weertman and Koch 2002; Jun et al., 2005; Kim et al., 2004; Lv et al., 2007). In nano dimensions, the surface to volume ratio increases and therefore the average properties depend on the surface area and new properties appear. Therefore when a material is in nano dimensions it can be dissolved into a fluid more easily and because of the increase in the cross-section it could be better affected by the environment. This increase of the surface area and reactivity of materials at nano scale can be effective in controlling filtration. Smaller materials block the ducts through the mud filter cake passing through the filter in mud cake. On the other hand, when materials having smaller dimensions are used in the drilling fluid, the permeability of the mud cake decreases. So it seems that nano-materials can have a significant effect in improving the properties of drilling fluid filtration.

We used nano titanium, nano alumina, nano copper oxide, and nano-clay to produce the new mud, and we also used conventional materials as additives for filtration control (CMC was used in this case) to compare the performance of these nano-materials with that of the materials conventionally used in filtration control. To evaluate the performance of these new additives, different tests were done to calculate the mud filtration, mud plastic viscosity, yield point, and gel strength. In this study we used nano-materials with different properties. Nano titanium is very light while nano alumina and nano copper oxide, in contrast, have higher weights and cause almost no reaction or changes in the water. However, compared to the other nano-materials, nano-clay, which had an average weight, showed swelling properties in water and reacted with water.

2. Experiments

Initially, bentonite and distilled water are blended together by a mixer, and the produced mixture is poured in apparatuses' cell. The mud volume should be about 350 ml (the muds surface is 0.25″ beneath the cell's top). Then the cell is sealed and a graduated cylinder is placed beneath the filtrate tube. Just as the container is opened, pressure is applied to the mud for a 30 s period, and a timer is set simultaneously. Measurements begin as the pressure is applied to the cell. Filtrate volume, cumulated in the graduated cylinder, is measured and recorded in specific time steps.

The plastic viscosity or mechanical resistance of fluid is its mechanical friction, which is related to solid particles. Mechanical friction decreases the amount of filtration, as the ability of fluid to flow declines. Plastic viscosity strongly depends on the surface area of the particles in mud. Nano particles affect plastic viscosity due to their large surface to volume ratio. Plastic viscosity is

Table 1
Properties of nano-materials used in tests.

Properties	Nano titanium	Nano copper oxide	Nano alumina	Nano clay
Average particle size	21 nm	23–27 nm	20–30 nm	30–50 nm
Specific surface area	50 m^2/g	45 m^2/g	21.7 m^2/g	46.8 m^2/g
True density	3.84 g/cm^3	4.12 g/cm^3	0.5 g/cm^3	0.9 g/cm^3
Purity	> 99.5%	> 99.5%	> 99.9%	> 99%