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Study of Formation Damage Mechanism Affected by Drilling Fluid Lost During the Drilling Operation by Using Special Additives Materials

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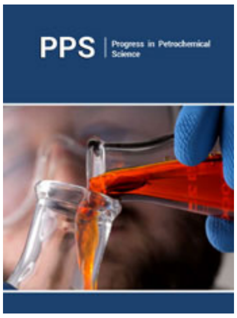

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Abstract

Formation damage is indeed the reduction of the permeability of reservoir rock which is the path that the hydrocarbon will be produced of it. Production rate has a direct relationship with permeability. Therefore, any reduction in permeability will reduce the production rate. The most important factor which will damage the productive formation during the drilling of different types of wells such as development, descriptive, exploratory, repair, and operational shortcoming wells is severe lost circulation. A full understanding of the mechanisms of formation damage, detailed measurements, and its prevention and effective treatments are keys to optimal strategies of production in oil and gas fields. In this study, tried for physical and chemical damage to the formation due to drilling fluid loss during drilling operations was investigated. Studies in this field were reviewed and their results were significantly increased and the main mechanisms associated with damage to oil reservoirs were investigated. The results of this study showed that special drilling fluids NIF, and MMH with high control of loss are the most important material to prevent damage to the formation. Also, the results of studies showed that these Lost Circulation Materials (LCM) have a special chemical structure that has high compatibility with the formation. This material is generally fibrous, which will efficiently bridge over and seal loss zones. Another result of this study is that the removal of these anti-loss materials is very easy and the permeability recovery of the formation is very high in them.

Keywords: Formation damage; Lost circulation materials; Special fluids MMH-NIF; Permeability recovery

Introduction

Due to the demographic and industrial growth of the world in the present era, the need for energy, especially hydrocarbon reserves, is expanding day by day [1]. With rising global oil prices, oil companies have begun to compete closely for petroleum exploration, drilling, and production [2]. The main goal of all operating companies is to maximize the production of the reservoir and the optimal operation of the drilled well. While drilling exploratory, developmental, descriptive, repair, and other operations wells, several mechanisms can be identified and analyzed, and interpreted to help diagnose and assess the extent of the damage [3]. This research has tried to study the main mechanisms related to the damage of the formation in hydrocarbon reservoirs and also to review the global studies and research, to provide ways to eliminate or reduce the damage of the reservoir. Damage to the formation or reduced permeability of the production formation can reduce the efficiency of a production well [4]. Therefore, this issue is very important, because every oil company aims to increase the efficiency of production wells. Drilling in the fractured reservoir is very difficult [5]. Because in such reservoirs, the presence of high-pressure and low-pressure parts in the formation complicates the operation [6]. To overcome the problem of well stability, the hydrostatic pressure must be kept high, which leads to loss, stuck pipe, and damage to the formation. On the other hand, this reservoir is full of fractures and as it is known, most of the production takes place through these fractures, and if these fractures are damaged by their factors and their permeability is reduced, the efficiency of the well will decrease. Therefore, in this study, we try to identify the mechanisms that damage the reservoir, analyze it and, by summarizing the research, provide appropriate solutions to reduce the amount of damage.

The first well drilled in a reservoir is unknown and risky. In exploration drilling to better identify the reservoir and field, the possibility of severe loss and damage to the formation is also high, because it is not possible to predict the behaviors of the reservoir before drilling the well and the reservoir has unknown conditions [7]. Therefore, drilling wells should be drilled with a high level of safety, to minimize the risks of unknown reservoir behavior, including fire and the blowouts of the well, which may lead to the launch of the Derick and well facilities with big force. For this reason, high-weight drilling fluids are used, which will cause a complete loss of drilling mud as soon as it enters a pay ozone layer. This can cause financial and human risks and severe damage to the production layer. In addition to the studies used in the main part of the study, some other studies are also mentioned. In 2017, a study modeled fluid loss for reservoir areas using the Gustafson-Kessel method. The results of this study showed that the use of this method has a key role in determining the predictable loss volume in each part of the reservoir [8]. In 2017, a study Conducted with the aim of experimental and field analysis to control drilling fluid loss. With the introduction of an additive, its test results showed that this compound has been very effective in controlling critical and heavy loss and has a better performance [9]. In 2017, a study was conducted using the index kriging method to estimate sectors with critical loss. The estimated results show that the fluid loss has high variability in formation and critical loss points are located in northwest parts and southeast parts, especially dispersed in deeper zones [10]. In 2020, another study conducted a study on the effect of bentonite mud contents on fluid loss. The results of the study showed that fluid filtration is 2.5 to 4 times the standard limit. The Vipulanandan model was compared with the API model and its results showed that the Vipulanandan method predicts maximum filtration, short-term and long-term loss model well [11]. In 2021, Conducted a dynamic study of drilling fluid loss. The results of this study showed that changes with increasing overbalanced pressure, the dynamic fluid loss decreases due to the formation of mud cake on the well wall [12].

Materials and Methods

Formation damage in hydrocarbon reservoirs

Damage to the hydrocarbon formation due to loss is a common problem in field operations, which is the biggest factor in reducing the efficiency of production wells because it reduces the permeability of the radius around the well. Permeability reduces or its reduction in hydrocarbon formations can occur through various processes. In 2006, Mr. Civan summarized the seven main mechanisms of damage in hydrocarbon reservoirs as follows [13] (Table 1).

Table 1: Risk assessment of formation in different operations (Byrne).

Significance (%)	Damage Removal (1-5)	Total Formation Damage (%)	Operation
75	2	25	Drilling
65	3	25	Well Completion
65	4	15	Stimulation
45	3	15	Production
40	4	10	Internal factors of wells
20	2	10	Injection

a) Fluid and fluid incompatibility and emulsions formed between filtrate oil-based mud and water formation.

b) Incompatibility of rock, fluid, and severe permeability reduction due to swelling and nodules of smectite and kaolinite clays with water.

c) Invasion of solid particles for example invasion of weight gain particles or drilling cutting

d) Fuzzy blockage or entrapment, for example, invasion of water-based mud around wells in a gas well.

e) Chemical adsorption and permeability alterations due to emulsifier adsorption and changes in fluid flow characteristics in a formation.

f) Migration of fine particles by movement within the rock pore causes plug and bridge in the pore throat.

g) Biological activities with the entry of bacteria into the formation during drilling and production of polysaccharide polymer strips and reduction of permeability [14] (Table 2).

Table 2: The source of damage to the formation during various operations [16].

Process	Source of Damage
Drilling	1- Invasion of drilling mud filtration 2- Invasion of foreign solid particles 3. Water sensitivity (swelling and particle migration)
Production	1- Inorganic sediments (calcium carbonate, barium sulfate, calcium sulfate) 2- Organic sediments (asphaltene, paraffin) 3- Particle migration
Water Flooding	1- Iron deposition 2- Production of iron corrosion 3- Injected solid particles 4- Swelling and migration of particles
Stimulation A. Acid injection	1- Deposition of iron compounds 2- Release of sand grains
B. Alkaline flooding is a source of damage	1- Carbonate deposition 2- Hydroxyde depositions 3- Silicate sediment
C. Surfactant injection	1- Sulfonate precipitate

Mud loss and damage to the formation during drilling operations

During drilling, to prevent the blowout of the fluid in the formation, the drilling mud should be designed in such a way that the pressure caused by the drilling fluid is higher than the formation pressure. Due to this pressure difference, the formation is invaded. In this way, particles with a diameter smaller than the diameter of the fractures of the formation can penetrate the formation. They can plug the porous space around the well and create a so-called inner mud cake. Larger particles can also form a mud cake on the surface of the formation or remain suspended inside the mud due to shear forces from the mud circulation. If a low permeability mud cake is formed on the surface of the formation, it is possible to prevent further penetration of mud particles into the formation. But the mud filtrate penetration cannot be prevented. While the drilling mud filtrate passes through the mud cake, the thickness of the mud cake increases due to the remaining mud particles until a dynamic overbalance is established. Under this overbalance, the deposition rate of the mud cake particles and its erosion rate due to the mud circulation will be equalized and the thickness of the mud cake will be a constant value. The plugging of the fractures of the formation around the well and the completion of the mud cake on the wall will eventually limit the mud filtrate invasion of the mud. mud particles and mud that enter the production during drilling operations and can cause damage to the formation. mud particles can reduce the permeability of the formation by plugging and filling fractures. Filtration can sometimes create deposits by moving fine particles, causing damage by altering the permeability and wettability of the rock. Water-based muds contain various particles and chemicals that can react with the reservoir fluid, resulting in sediment deposition. oil-based mud and emulsion mud containing surfactants and emulsifiers can change their wettability to oil-friendly, which can reduce the effective oil phase permeability. mud filtrate can move fine particles from the surfaces of fractures by colloidal and hydrodynamic forces. These fine particles are trapped on the surface of other fractures or deposited on the surface of other fractures, causing damage to the formation.

Drilling mud filtration invasion

Mud filtrate invasions have a high potential for rock damage near wells. mud filtrate penetration into the formation can occur during drilling or repair and completion. Many researchers have shown that the penetration depth of mud filtrate is much greater than the penetration depth of solid mud particles. Therefore, permeability reduction due to mud filtration can extend from several inches to several feet. The depth of filtration invasion depends more on the following parameters.

a) Well and time conditions.

b) Primary permeability of the rock.

c) Mud composition and how to perform operations.

Gradually, with the formation of the mud cake and its compaction, the amount of filtrate penetration into the formation is reduced. Effects that may have on mud or any external fluid include (Figure 1) [15].

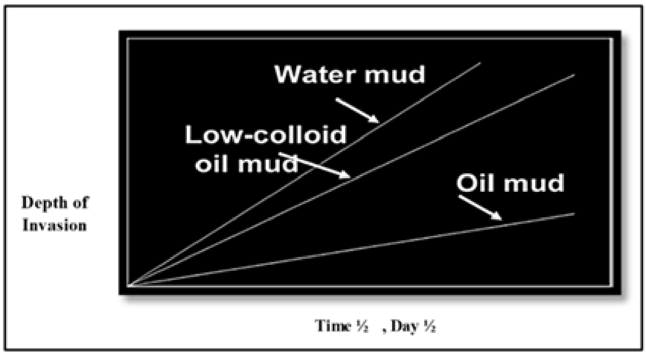

Figure 1: Filtrate penetration in different muds [15].

i. Sediment deposition.

ii. Development of emulsion with formation fluid.

iii. Wettability alteration and decrease in relative oil and gas permeability.

The liquid phase filtration of the drilling fluids into the formation can change the relative permeability of the formation rock and cause the formation to plug. Sometimes some fluids can reduce the relative permeability by up to 80%.

Invasion of external solid particles

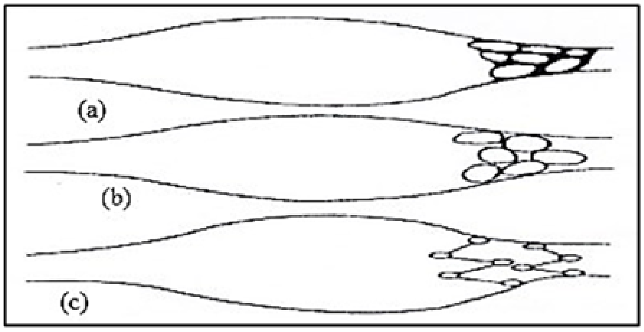

Figure 2: Mechanisms of fine particle migration and throat damage [15].

Due to the positive pressure difference between the drilling fluid and the hydrocarbon formation, it causes severe loss (above 200bbl/h), intermediate loss (between 20-200bbl/h), and normal loss (between 1-20bbl/h). These conditions cause some of the drilling fluid to penetrate the formation, and this continues until an impermeable mud cake is formed on the wall. In fractured reservoirs, due to the diameter of the fissure, larger amounts of mud and its filtration particles penetrate the formation. These particles are absorbed, stored, and deposited within the formation. The invasion of solid particles due to the loss of drilling mud causes damage to the throat of the pores within the formation, the mechanisms of which are as follows (Figure 2) [15].

a. Plugging and flooding.

b. Restricting the flow.

c. Bridging.

Water sensitivity (swelling and particle migration)

Clay is sensitive to water and the volume of the clay can change as a result of changing the salinity of the fluid that passes through them and the porosity of the porous medium is reduced. The mud filtrate penetration of the drilling fluid into the formation reduces the salinity of the formation water and causes swellings to clay, which can block the pores and throats in the production formation. The permeability changes of the formation are due to the change of clays due to the amount, position, and type of clay minerals in the formation. Common clays that are prone to swelling are compounds of smectite. Smectite causes swelling by absorbing water into its structure. They can increase their volume by up to 600%. Which can be an important factor in reducing permeability. If smectite clays occupy only the throats of pores and smaller pathways, the problem will not be so serious. But if they have filled large pores, they can create almost an impermeable barrier to the flow.

Ways to deal with drilling fluid loss and damage

In the drilling of the affected formation, due to the difference between the pressure of the drilling fluid and the formation, in the most optimistic case, low mud loss will occur. Therefore, to prevent this unpleasant event that causes damage to the productive layers and reduces productivity, you must think of a solution. One of the ways to deal with this problem is the use of Non-Invasive Fluid (NIF) and low-damage Mixed Metal Hydroxide (MMH), which have passed the test and very good results have been obtained from them.

Ideal conditions for a special drilling fluid for an oil reservoir

a. The fluid should be able to bridge the throat cavity in a wide range without altering the formulation.

b. Bridging should be done very quickly and not be damaged.

c. From the point of completion of the well and the production process the damage created on the formation should be easily removed

d. The formed barrier must be able to continue to perform well in the high overbalance of its tasks. In fact, with increasing weight, they still do not allow the transfer of pressure from the well to the discharged formation.

e. The fluid must be able to be effective in different ranges of density, temperature, and bottom well pressures.

f. The same conditions can be established in different muds, and fluid preparation can be done easily.

g. Additives are non-toxic and HSE-approved.

Thus, of course, there can be no claim of non-aggression, but the term NIF is used to distinguish it from other drilling muds.

This mud has undergone various laboratory tests before using field operations and has had positive results.

Use of non-invasive fluid (NIF)

The heart of the NIF system is a mixture of polymers with a range of solubility in water and oil. When added to a water-based polymer fluid, it forms a micelle, a group of molecules that form spheres, plates, and microscopic cylinders in solution. At overbalanced pressure, the fluid begins to penetrate the permeable rock, and these micelles form a low permeable surface on the throat that prevents a further fluid invasion. Because the micelles are deformable within the layer. Therefore, with increasing pressure, the compaction and permeability of the mud cake further reduces the barrier (Figure 3), [16]. The following is a schematic of the modified polymers and the formation of micelles in the solution. The formation of micelles causes low permeability and in the very early stages of mud filtration prevents deformation at the rock surface. The following figure shows the reduction of the depth of invasion using this fluid in laboratory samples (Figure 4), [16].

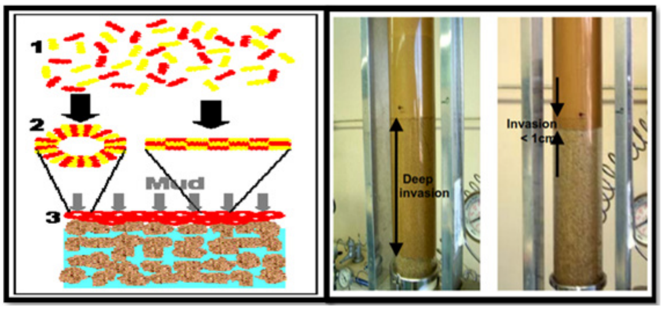

Figure 3: The left shows a deep invasion of a field of oil-based mud on a layer of sandstone; On the right, it shows mud similar to 5ppb of micelle additives (NIF) that has an invasion of less than 1cm [17].

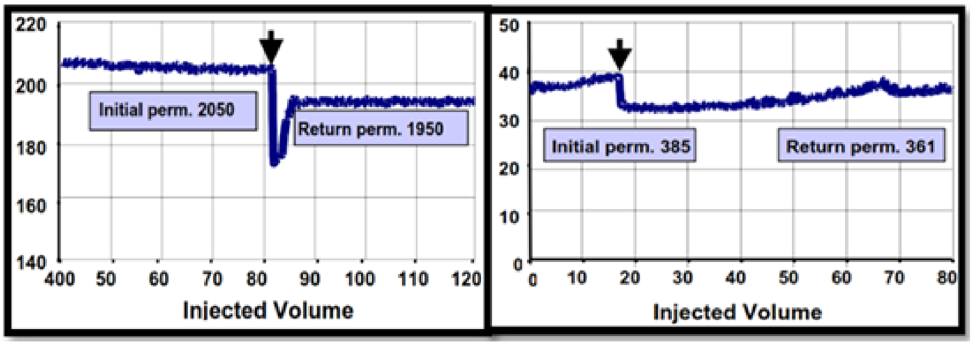

Figure 4: 95% and 93% permeability returns using a water-based mud to which 6ppb and 8ppb micelles were added (both experiments were performed on a well in South America) [17].

Results and Discussion

In a series of wells drilled in a development field in the Far East with an average loss of 0.91 and 0.41 barrels per foot for two different well sections over two years in 2001, after treatment by a special drilling fluid the loss reached 0.06 and 0.21 barrels per foot, which reduced the formation damage. The mud loss occurred during the repair operation of a series of wells in the Far East in 2002. The mud loss occurred inside the reservoir fractures, which were stopped with 40 barrels of special drilling fluid, and after 3 hours, the well was drilled. The pressure of 1000 psi remained without loss, which was an effective step in reducing the damage of the formation. In drilling operations in the United States in the last 5 years, these special drilling fluids have been used to treat massive loss in carbonate reservoirs with natural fractures and weak sandstones. The target wells were selected with carbonate fractures drilled with oil-based mud and added 40-60 barrels of special drilling fluid, which reduced loss by 80% -90%, and by adding only a small amount of drilling fluid loss, it reached zero.

Use of low-damaging drilling fluid MMH (Mix Metal Hydroxide)

Table 3: Compatibility between the low-damage drilling fluid and core plug [18].

Weight of Core (g)			
Core Number	Before Being Contaminated	After Being Contaminated	Recovery Percent (%)
1	39.76	39.56	99.5
2	40.15	39.86	99.3
Average			99.4

Mix metal hydroxide is a colloidal drilling fluid that can protect the formation can perform tasks such as reducing the invasion of clay particles (Table 3), [17]. Preventing hydration and swelling of clays, high collapse rate, and high permeability recovery. These fluids are generally composed of transparent cleaning additives (such as fiber and calcium carbonate in different formations), soft particles such as oil-soluble resin, and additives for forming the film on fractures with different widths. In the MMH drilling fluid system, bentonite can react with MMH particles and water to form a spatial network structure (Table 4), [17]. MMH-modified, low-damage drilling fluid not only has excellent compatibility with rock and brine from the target formations but also has good rheological properties, low filtration rate, and high permeability return. MMH low-damage drilling fluid is multifunctional, minimizing the depth of solid particle invasion, effectively inhibiting clay hydration and swelling, reducing salt sensitivity, high drainage rate, and high permeability due to the formation of lattice structure by clay particles, water molecules, and MMH colloidal particles, Therefore, MMH-modified low-damage drilling fluid can be used to protect slotted carbonate reservoirs during drilling (Table 5), [17].

Table 4: Recovered permeability of core contaminated with low-damage drilling fluid [18].

Core Number	Initial Permeability K, 10^{-3} μm^2	Permeability After Being Exposed to Drilling Fluid K, 10^{-3}μm^2	Return Permeability (%)
1	5.36	4.68	87.3
2	7.12	6.29	88.3
Average			87.8

Table 5: The recovered permeability of the sample from a depth of 5585m [18].

Core Number	Initial Permeability K, 10^{-3}μm^2	Permeability after being exposed to drilling fluid K, 10^{-3} μm^2	Return Permeability (%)
3	9.38	8.41	86.8
4	8.41	7.2	85.6
Average			86.2

Summary and Conclusions

a. The results of this study showed that to deal with the loss that is the main cause of damage to the formation during drilling operations, fluids should be used that, in addition to performing their usual duties well in terms of damage to the formation, also have a good justification in using they exist [18].

b. The results of these studies showed that the use of special drilling fluids NIF and MMH in drilling fractured and discharged reservoirs that are in the second half of their life seems necessary. Reservoirs that have been reduced in pressure during production are more likely to be a loss. According to the results of the data obtained from the use of special drilling fluids, it can be concluded that the use of these fluids can play a very important role in reducing damage to hydrocarbon reservoirs. The fluids used were the best compatibility with the formation fluids, the sharp reduction of loss, and most importantly the recovery of permeability after their use.

c. Carbonated and fractured hydrocarbon reservoirs have a high-pressure drop due to decades of production. Therefore, according to the existing conditions, the use of these special fluids with high efficiency is recommended. The results of using these fluids significantly reduced the damage of the formation, and the permeability recovery after their use was very high. Due to the significant permeability recovery in the use of these fluids, especially in carbonate reservoirs with a high risk of loss, compared to other methods and techniques of loss prevention are used. Reducing damage and increasing the recovery factor and efficiency of reservoirs are important goals of using this technique.

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