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Research Paper

Formation Damage During Drilling and Completion Practices: A Review

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Abstract: Permeability of the reservoir is one of the major characteristics controlling production rate of the wells in which the higher the reservoir permeability, the higher the production rate. Due to some activities such as chemical, mechanical, biological, and thermals the permeability is damaged. The damaged permeability obstacles the natural flow of the well, consequently reducing the production rate. Reduction due to either physical interaction of drilling, completion and stimulation fluids and equipments or changes in reservoir fluid properties is called mechanical formation damage. Fines migration, phase trapping and blocking, external solids entrainment, glazing and mashing, geomechanics and perforation damage are the common mechanical damage mechanisms. The damage induced to the reservoir is called skin, which should be identified using typical well testing methods. The induced skin hinders the flow of hydrocarbon into wellbore and tubing causing reduced flow. Typical methods such as acidizing or hydraulic fracturing should be implemented to restore the original permeability of the reservoir. Gun perforation has been used for more than 40 years for generating a controlled flow channel between oil and gas reservoirs and the bore of an injection or production well. To maximize productivity, perforations must penetrate substantially beyond the zone of drilling damage, and they must be of the highest possible quality but the point is that perforations are never clean and the act of perforating crushes the rock and forces the particles from the hole area into the surrounding formation. Under adverse conditions of too great wellbore pressure and presence of drilling mud or dirty completion fluid, severe additional damage may result.

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Introduction

Any reduction in natural inherent productivity of oil and gas or a reduction in the injectivity of water or gas in injection wells in any life time of well due to drilling, completion, production, stimulation, kill or workover activities is called formation damage which is a result of either the transport of fine solids, chemical reactions or combination of both.

Formation damage fixation is usually difficult and costly; hence formation damage prevention is more preferable than the formation damage fixation. Therefore, the entire process of drilling, cementation, perforation, sand control, production, injection well plugging, workovers, well stimulation, acidizing and fracturing operations as well as the treatment controlling, operating procedure and chemicals selections should be well studied, analyzed and optimized (preplanning, execution and follow up) to prevent any severe damage to the formation.

MECHANISMS OF FORMATION DAMAGE

Mechanical, chemical, biological and thermal damage are the primary mechanisms of formation damage and each of these mechanisms can be further subdivided into sub-mechanisms.

MECHANICAL FORMATION DAMAGE

Permeability

Clay is considering as a common transportable material in clastic formations. As a result of high fluid shear rates and the wetting phase movement in these formations, existing particulates (usually clay) easily migrate and permeability is decreased as a result of fine migration as it is depicted in Fig 1 [2]. Chemical utilization to reduce the mobility of moveable particles, higher density perforation to increase the flow area, interstitial velocity deduction by fracturing and horizontal wells, open hole completion and reducing production rates are some of the applicable treating methods to minimize the fine migration 3,4.

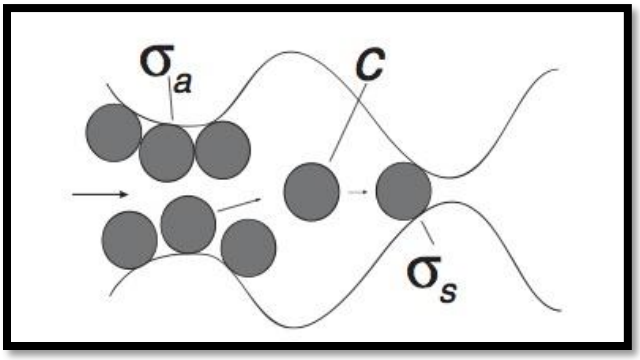

Figure 1. Permeability reduction due to fine migration in a single pore

Phase trapping usually happens in low permeability gas reservoirs. The definition of phase trapping includes the increasing in saturation of the trapped fluid (water, gas or oil) near the wellbore area and consequently reducing the relative permeability of that phase. Depth of invasion, saturation of the trapped phase, reservoir pressure and specific configuration of the relative permeability curve for the rock under consideration are some of the critical factors controlling the magnitude of phase trapping. Invasion of water and oil based fluids, retrograde condensate gas production below the dewpoint pressure, black oil production below bubble point pressure and free gas injection into a fluid saturated zone are the potential options resulting in phase trapping in the reservoirs. Capillary pressure reduction by Surfactants, alcohols and carbon dioxide and etc, miscible gas injection, formation heating and dehydrated gas injection could be used to overcome and extract the trapped phase 5,6,7,8,9,10.

Weighting agents, fluid loss control agents, lost circulating materials and bridging agents as the drilling fluids in overbalanced drilling operations and disposal water in the formation usually contain solid particles which precipitate on the rock matrix near the well bore area and damaging the formation. In case of open hole and uncemented liners the negative effects of the damage is more significant specially for horizontal wells because of the required proper design of low damage overbalanced drill in fluids 11,12.

Damages made by fine particles and cuttings as a result of poorly centralized rotating and sliding pipe in a poor hole cleaning situation is called mashing and any direct damage to the wellbore caused by heat and bit interaction is called glazing. Good hole cleaning and utilizing bit lubricators can minimize the impact of these damages to the formation 13.

Well orientation and reservoir stress determine the magnitude of geomechanical stress near the wellbore region. In general near wellbore stresses can be at least two times greater than the far field stresses and it increases with the inclination angle, reservoir depth, and production time. Large permeability reduction as a result of formation damage will happened in soft formations and relatively small permeability reduction for the consolidated formations. In case of the presence of fractures in formation, fractures with wing lengths greater than the damaged region can bypass and overcome the damage 14.

Gun perforation has been used for more than 40 years for generating a controlled flow channel between oil and gas reservoirs and the bore of an injection or production well. To maximize productivity, perforations must penetrate substantially beyond the zone of drilling damage, and they must be of the highest possible quality but the point is that perforations are never clean and the act of perforating crushes the rock and forces the particles from the hole area into the surrounding formation. Under adverse conditions of too great wellbore pressure and presence of drilling mud or dirty completion fluid, severe additional damage may result 15.

CHEMICAL DAMAGE

Any interaction between rock and injected fluid or formation fluid and injected fluid to reduce the formation permeability is called chemical damage. Chemical damage could be a result of clay swelling and deflocculation, chemical adsorption, formation dissolution, paraffins and waxes, emulsions and wettability alteration in the formations.

A type of formation damage in which formation permeability is reduced because of the alteration of clay equilibrium is called clay swelling. It occurs when water-base filtrates from drilling, completion, workover or stimulation fluids enter the formation. The type of substitutions occurring within the clay crystal structure and the exchangeable cations adsorbed on the crystal surface greatly affect clay swelling, a property of primary importance in the drilling fluid industry, clay swelling is a phenomenon in which water molecules surround a clay crystal structure and position themselves to increase the structure thus resulting in an increase in volume. Two types of clay swelling may occur including surface hydration in which water molecules are adsorbed on crystal surface and osmotic swelling in which the concentration of cations between unit layers in a clay minerals is higher than the cation concentration in the surrounding water and consequently water osmotically drawn between the unit layers 16. Figure 2 shows a schematic of clay expansion and permeability reduction by clay swelling 17. Rapid changes in pH and salinity can flocculate the clay and causes reduction of formation permeability by clay deflocculation 18.

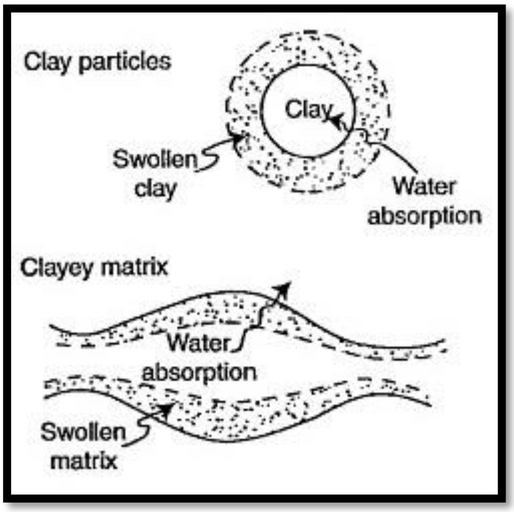

Figure 2. Permeability reduction as a result of clay swelling [18]

Many petroleum engineering operations, such as drilling, well completions, and workover, may cause an alteration in the properties of hydrocarbon-bearing formations, including porosity and permeability. High molecular weight fluids such as polymers have been added to the drilling fluid to improve the rheological control and reduce the fluid loss, however the negative point associated with these kinds of chemicals is the precipitation and adsorption of these materials onto the surface of rock, creating a cake layer and therefore reducing formation permeability 19.

It is a common occurrence worldwide to have hole washouts while drilling with water-based muds. There are several reasons for this and until a concerted effort is taken to address the issue, such holes are bound to develop. There exist some formation types potential for dissolution and washout such as shale and salt formations. Shales that are known to be chemically active, are fine grained sedimentary rocks composed primarily of clays, with parts of silt and in some cases fine sands. Salt formations are encountered in many oil producing regions of the world. These salt zones can be in a variety of forms; salt domes, massive beds and sheets or lenses. The chemistry of salts can vary significantly even in a single bed, from pure sodium chloride to very complex blends of mixed chloride salts. The main salt types are: Halite, Sylvite, Bichofite, Carnalite, Polyhalite, Tachydrite. Performing drilling, completion and workover activities using water based fluids in these formations can increase the possibility of poor gauge hole, formation washout and collapsing 20.

Insoluble organic compound of crude oil with high molecular weight and various homologous series is called paraffin and usually consist of aliphatic and aromatic hydrocarbons, naphtanes, resins and asphaltenes. Waxes are n-alkane based solid hydrocarbons solution in oil. Paraffin and wax deposition in the formation near the well bore area can restrict the oil flow and cause the plugging of pipelines. They can also precipitate in tubing, other pipelines and surface facilities and disturb the production, transportation, and refining processes of crude oil 21.

An emulsion is a mixture of two or more liquids that are normally immiscible. Oil is usually the continuous phase in the formation and when small bubbles of water disperse in oil phase, then the produced mixture is called emulsion, which is high in viscosity and when the continuous phase is oil and dispersed phase is gas, then the result is foamy oil. The presence of water internal emulsion and foamy oil in the formation increases the viscosity and result in the formation of permeability inhibiting emulsion block 22.

Wettability is defined as the tendency of one fluid to spread on or adhere to a solid surface in the presence of other immiscible fluid. Wettability is a major factor controlling the location, flow, and distribution of fluids in a reservoir. The wettability of originally water-wet reservoir rock can be altered by the adsorption of polar compounds and/or the deposition of organic material that was originally in the crude oil. The presence of oxygen, nitrogen and sulfur in crude oil make the surface active materials to be polar and change the surface wettability to oil wet by the adsorption of the polar end on the rock surface. In this case a semi permeable region will be created in which oil teds to be more immobile than water and water production ratio will be increase that is unfavorable 23. Figure 3 shows the effect of wettability changes on water oil relative permeability near the wellbore 24.

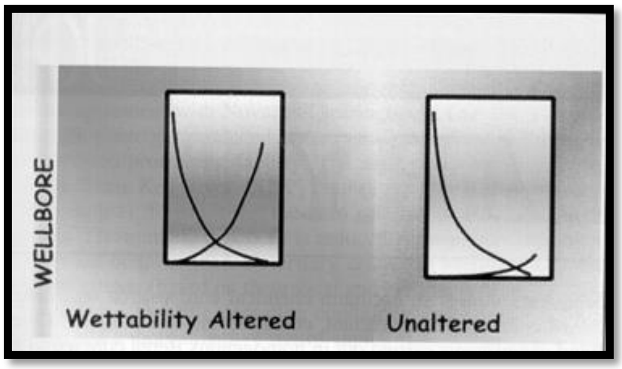

Figure 3. Effect of near wellbore wettability alteration on water oil relative permeability [24]

BIOLOGICAL DAMAGE

Any drilling, completion, workover or stimulation activity that requires the injection of a water base fluid is a potential environment for bacteria to grow. Bacteria usually grow at temperature up to 90 °C, however the temperature of 40 °C would provide the best environment for their maximum growth. Water is consider to be potential source of bacteria and nutrient and injection of a huge volume of water and water based fluids to the formation can reduce the formation temperature and provide a potential area for bacteria to propagate rapidly. Bacteria existence and propagation in the formation causes plugging, corrosion and toxicity issues. Whit the presence of bacteria in the formation, a layer of high molecular weight polyacrylamide polymer will generate in which the injectivity and productivity of the formation will be reduced significantly by formation plugging. Electrochemical cell production that is a result of bacteria and metal surfaces causes a hydrogen reduction reaction and consequently corrosion of tubings and other facilities would be result of this reaction. Toxic hydrogen sulfide gas that is a by-product of sulphate reducing bacteria, is soluble in both water and oil and can be a potential toxic danger for human beings 25.

THERMAL DAMAGE TO THE FORMATION

Mineral transformation and dissolution, wettability alteration and reduction in absolute permeability are the consequences of high temperature operations such as insitu combustion and steam injection on formation. Some of non reactive clay species form swellable hydrate when temperature arises to more than 180 °C during the thermal operations and permeability decreases as a result of mineral transformation. Increasing temperature increases the dissolution rate of minerals in the formation. When temperature is high enough, then dissolution of the species occurs and after that re-precipitation of the particles takes place by moving these particles toward the cool regions of the formation such as production wells. Increasing temperature changes the wettability of the reservoir to water wet, however in some cases switching to oil wet ay occur as well. Grain expansion and pore restriction as well as the thermal stress cracking and manufacturing of mobile and damaging fines are the result of increasing temperature in formation at overburden conditions that lead to the reduction in absolute permeability 25.

CONCLUSION

Petroleum engineering deals with drilling, completion, production, stimulation and work over operations and each of these activities can be inherently a potential risk for the creation of formation damage. Inappropriate design of utilized fluids, lack of studies on rock and fluid properties and unfavorable methodologies can cause sever mechanical, chemical, biological and thermal damages to the formation.

Conclusion

Petroleum engineering deals with drilling, completion, production, stimulation and work over operations and each of these activities can be inherently a potential risk for the creation of formation damage. Inappropriate design of utilized fluids, lack of studies on rock and fluid properties and unfavorable methodologies can cause sever mechanical, chemical, biological and thermal damages to the formation.

Ethical Considerations

Compliance with ethical guidelines

All subjects fulfill the informed consent.

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Authors' contributions

Design and conceptualization, methodology, data analysis and final writing: Amin Azdarpour

Conflicts of interest

The author declared no conflict of interest.

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