A Study of Formation Damage At The Different Drilling Environments

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Abstract

Formation damage sometimes known as wellbore damage can cause serious problem to all drilling programs and should be written in mind of all drilling engineers. An understanding of mechanisms which can cause and accelerate damage of wellbore has led to the knowledge of what can be done to avoid it, is also essential for all drilling engineers. Different drilling environments such as horizontal drilling and high angle well drilling will cause different degree of damage which can bring to the reduction of oil productivity. This paper discusses the results of a study which revealed that drilling in the horizontal environment was the most critical and could cause severe damage to the formation, followed by the high angle well drilling environment. To overcome or minimize this problem, the most suitable measure is to understand the most appropriate drill pipe rotating speed, pressure differential, temperatures, annular velocity between the drill pipe and bore hole.

Introduction

Formation damage is a process that impairs the permeability of a reservoir and consequently decreases the natural flow of fluids from the reservoir into formation.

Laboratory studies [1,2,3,4] indicated that operations in a field such as drilling, completion, workover, production, and stimulation are the potential sources of formation damage. Since the advent of the energy crisis and the Arab embargo, most of the oil companies started to realize and aware of the important of understanding the formation damage should not only focus the prevention of formation damage but also in maximizing well productivity.

Wellbore permeability will be reduced when the particles laden fluids are introduced to the formation under dynamic condition at the different drilling environments. Field experiences [4,6] have proven that drilling at the horizontal environment has a much greater sensitivity of formation damage than deviated wells in the same formation because of the longer contact time with drilling fluids.

Under dynamic drilling conditions, dynamic solids and filtrates are directly related to the extent of formation damage caused by drilling fluids. Several researchers have been dealing with this issues. [5,6,7,8,] The main factors affecting dynamic filtration that can contribute to formation damage are differential pressure, annular velocity, drill pipe rotating speed, rock permeability etc.

Peden found that dynamic filtrate loss was significantly affected by the annular velocity and the permeability of the core. Sharma [7,10] also confirmed the annular velocity was a critical criteria of fines release which could plug the formation and reduces productivity.

Temperature is an important yet often ignored variable in translating laboratory studies on formation damage under the reservoir condition. A severe damage may occurred at higher temperatures.[11] This is due to the thermal degradation of the mud, especially polymer mud system. The ability of fluids to transport the fines decrease with increase in temperatures, as a result this will increase the potential of physical bridging and colloidal trapping, which will lead to the physical damage of the wellbore.

Differential pressure is also another important parameter that can cause formation damage. [7] Generally, higher differential pressure can cause severe damage and the phenomenon is defined as particle plugging.

Damage Mechanisms

During drilling, the formation is exposed to several types of fluids which have high tendencies to reduce and impact productivity. Damage mechanism can seriously reduce the pore throat size and relative permeability. The mechanism that reduces the pore size includes mud solid invasion, clay swelling, filter cake plugging etc. Whereas the damage mechanism that can cause the reduction of relative permeability includes emulsion, fluids saturation and wettability changes etc.

Solids Invasion

The invasion of solid particles into formation has been recognized several years ago and it is also a considerable source of formation damage. Those solids may come directly from a fluid system or from the formation rock itself. The intrusion and deposition of these mobile particles lead to the blockage of pore throat that induce the reduction in permeability of the rock by forming the internal bridges at the pore restriction between internal mineral grains.

To enable the solid particles from drilling fluids entering to the formation, the size of the solid particles must be smaller than pore opening. Solid invasion is not consider a serious problems [1,4] and normally the depth of invasion is from few millimeters to few centimeters.

Invasion of drilling mud particles and their ability to subsequence bridge the pore throats and seal the passages are dependent on the amount of solids particles present in mud and size distribution, the pore size distribution of the invaded formation and the differential pressure between the wellbore and formation.[1]

Fluid invasion

Filtrate invasion is highly potential of damaging rock in the vicinity of a wellbore. The intrusion of potential damaging filtrates into formation can occur during drilling, completion etc. Many researchers [1,4,6,13] found that filtrate from drilling fluids invade reservoir rock much deeper than solids. Permeability damage by mud filtrate may extent from few inches to a few feet. Different researchers [1,3,5,6,7,13] have different finding about the depth of the filtrate invasion. The depth of filtrate invasion mostly depends on initial rock permeability, mud composition, experimental condition, experimental time, and how the experiment is being conducted.

The consequences of filtrate invasion are numerous and have been identified in many field operations such as drilling, completion, enhance oil recovery etc. [1,6,14] The possible effects of foreign fluid invasion are emulsification with formation fluids, precipitation of solid, and reduction of relative permeability to gas and oil. The most effective way to control the filtrate damage from the water based mud or oil based mud is by having higher concentration of Ca^+ and Mg^+ divalent in the mud system.

Some measures that can be used to reduce/overcome filtrate damage are (1) reduce exposure time of prospective formation; (2) penetrate formation quikly using high bit weight as opposed to high rpm; (3) avoid stabilizer rotation and bits trips past the formation; (4) avoid turbulent and high annular velocities at the formation; (4) Spurt loss and high temperature pressure filtration data should be checked for most mud systems etc.[15]

Formation Damage Prevention

There are many parameters that lead to damage of permeability of a susceptible reservoir during drilling and the key to attaining production efficiency is to prevent damage rather than the use of remedial treatments. The best damage prevention rule is to use the drilling fluids as much like as the formation fluids, look in the detail of the particular jobs which are potentially can damage the formation and understanding operating damage mechanism.

Reed [4]suggested that some measures which are useful in preventing the formation damage such as: (1) maintain an adequate concentration of salt (preferably a potasium salt) in drilling and completion fluids; (2) use the minimum amounts of oil wetting agents and surfactant in oil-based drilling fluids and de-flocculants in water-based drilling fluids; (3) when possible, use fluids with pH below 9.5; (4) drill and complete well with minimum safe overbalance pressure and (5) use clean completion fluids that do not form precipitation when mixed with formation water.

Experimental Apparatus and Procedure

The experimental apparatus used in the study of formation damage at different drilling environments under the dynamic conditions comprised of five major sections:

(a) Circulating system,
(b) Dynamic filtration cell (see Figure 1),
(c) Filtrate collecting system,
(d) Pressure measurement system, and
(e) Two phase reverse injection system.

Continuous mud circulation was maintained with the use of piston reciprocating sludge pump and a close circulation system. The temperature of the circulating mud was maintained at 70°C and the differential pressures were varied from 50psi to300psi.

For the drill pipe rotating speed, it was maintained at 120 rpm, whereas for the annular velocity, it was varied from 100ft/min to 150ft/min. To ensure that the experiment was conducted as close as the reservoir condition, drilling fluids was circulated about 5 hours to achieve the required reservoir temperature.

The berea sample used in the experiment was 12 inches long and had 2 inches in diameter. It was chosen as test specimen because the matrix of this type of sandstone is free from water-sensitive clays in the matrix.

The core holder is specially designed to allow drilling fluid to be circulated across the face of the core while the mud invades the core. It was designed so that a steady shear rate could be applied on to the deposited mud cake. Four evenly-spaced pressures transducers were place along the cell body in order to measure the permeability reduction for the various sections and pressure drops across the different sections.

Flow velocity and annular velocity could be adjusted by varying the pumping rate of the sludge pump. After circulating the mud, mud cake could be physically examined and the initial permeability and return permeability could be measured from different sides of the core holders.

Experimental Procedures

The Berea Sandstone were cut 12 inches long and 2 inches in diameter. In order to get consistent core samples, 30 cores sample were cut from one block of berea sandstone. The permeability for the cores was 350md and the average porosity was 20%. The core samples are placed into the core holder and a confining pressure of 1000psi is applied to prevent the fluid bypass.

NaCl with a concentration of 30,000 ppm was injected to measure the initial permeability. KCl polymer mud with the mud weight of 10.5ppg has been used as the drilling fluid and the mud properties such as yield point, plastic viscosity, gel strength, filtrate loss and etc had been determined and all are in the accepted limit before used it as the drilling fluid. The drilling mud was then circulated across the face of core for 5 hours. After circulating the mud, mud cake at the core face was removed and the same concentration of NaCl was used to measure the return permeability of the core. Damage to the cores was determined as the ratio of maximum permeability to oil after backflow to the original permeability to oil.

Results and Discussion

An investigation of Figures 2 and3 concluded that higher differential pressures would produce greater total fluid loss, thus induced greater damage to the permeability.

Influence of differential pressure

Test results indicate that at higher differential pressures, the rate of the permeability reduction was found to increase as well and it is more severe to the horizontal drilling compared to the high angle drilling environment (Figure 4). The differential pressures are important for the mud cake compaction and once the cake is formed. Due to the lack of the external cake because of the unfavorable increase in differential pressure, the infiltration of mud solid and cause the damage to the cores.

Higher differential pressure led to severe formation damage only for the first two inches of the core length and this was due to the invasion of mud filtrate. The dependence of differential pressure also depends on annular velocity, temperature, mud types, etc.

Influence of annular velocity

The influence of annular velocity is presented in Figures 5 and 6 .As expected, higher annular velocity would higher filtration rates thus leads to higher formation damage. The damage ratio for the horizontal drilling lower than the deviated drilling environment because of the tendency of mud solid particle settling down to the formation. When the annular velocity increase from 120ft/min to 150ft/min, this particle tends to invade into the formation due to the thermodynamic force accumulate at the solid particle .

Influence of temperature

The influence of temperature is presented in Figure 7 when temperature exceeds 158°F (70°C), a drastic increase in damage as indicated by sharp reduction of damage ratio, probably because of thermal degradation of polymer used in the drilling fluids. It is more severe for the horizontal drilling compared to the deviated drilling environment.

Conclusions

The following conclusions could be drawn from the experiment conducted in this study :

1. Horizontal drilling environment causes more severe damage to the formation compared to the deviated/high angle drilling environment. Formation damage at different environments always depends parameters such as differential pressures, annular velocity temperature etc.
2. Understanding of the physical mechanisms which contribute to the formation damage is vital in order to maximise productivity of a reservoir. Drilling fluid with low filtration loss, low solid contains thermally must be used to minimize formation damage.

References

1. Krueger, R.F. " An Overview of Formation Damage and Well Productivity In Oil Field Operations" paper SPE 10029,1982.
2. Abu Azam Md. Yassin.1985. "Formation Damage During Drilling and Completion Practises". *A Review*.1985.
3. Records, L .R. 1976. "Drilling Practice That Affect Formation Damage" paper *SPE 5714* presented at AIME Symposium of Formation Damage, Housten, Jan 29-30,1976.
4. Reed, M. G. " Formation damage Prevention During Drilling and Completion" paper SPE 20149 presented at Centennial Symposium Petroleum Technology, Mexico,Oct 15-19,1989.
5. Nowak, T.J. and Krueger, R.F. " The Effect of Mud Filtrate and Mud Particles Upon the Permeabilities of Cores" API Drilling and Production Practice.(1951) 164.

6. Krueger, R.F. and Vogel, L.C. " Damage To Sandstone Cores by Particles From Drilling Fluids" API Drilling and Production Practice.(1954) 158.
7. Marx, C and Rahman, S.S. " Evaluation of Formation Damage Cause by Drilling Fluids Specially in Pressure Reduces Formation" paper SPE 12494 presented at the 1984 Formation Damage Control Symposium, Bakersfield, Feb. 13-14.
8. Hydrodynamic Detachment of Particles From Surfaces" in Press Coll. Interface SCI Hassen.B.R."New Technique Estimate Drilling Filtration Invasion" paper SPE 8791 presented at the Fourth Symposium on Formation Damage in Bakersfield, California, Jan 28-29, 1980.
9. Gray,G.R. and Darley,H.C.H. " Composition and Properties od Oil Well Drilling Fluids", Fourth Edition, Gulf Publishing Company, Houston, Texas(1981) 277.
10. Sharma, M.M., Chamoun, H. Sarma, S.R. and Schecter, R. " Factors Controlling the Hydrodynamic Detactment of particles from Surfaces" in press,J.Coll. Interface Sci.(1991).
11. Peden, J.M., Avalos, M.R. and Arthur, K.G. " The Analysis of the Dynamic Filtration and Permeability Impairment Characteristics of Inhibited Water Based Muds" paper SPE 10655 presented at SPE Formation Damage Control Symposium, Latayette, LA, March 24-25, 1982.
12. Guota, A and Civan, F. " Temperature Sensitivity of Formation Damage in Petroleum Reservoirs" paper SPE 27368 presented at SPE Formation Damage Control Symposium, Latayette, LA, Feb 7-10, 1994.
13. Jiao, Di and Sharma, M.M. " Formation damage Due to Static and Dynamic Filtration of Water-Based Muds" paper SPE 23823 presented at the SPE International Symposium on Formation Damage Control ,Lafayette, Louisiana, February 26-27,1992.
14. Dairymple, E.D., McFatridge, D.G., and Zeltman, T.A. " Field evaluation of New Treatment Technique to Remove Permeability Damage by Polymeric Material" paper SPE 20117, presented at the Permian Basin Oil & Gas Recovery Symposium, Midland, TX. March 8-9,1990.
15. Hassen, B.R. " New Technique Estimate Drilling Filtrate Invasion" paper SPE 8791 presented at the Fourth Symposium on Formation Damage in Bakersfield, California, Jan 28-29, 1980.

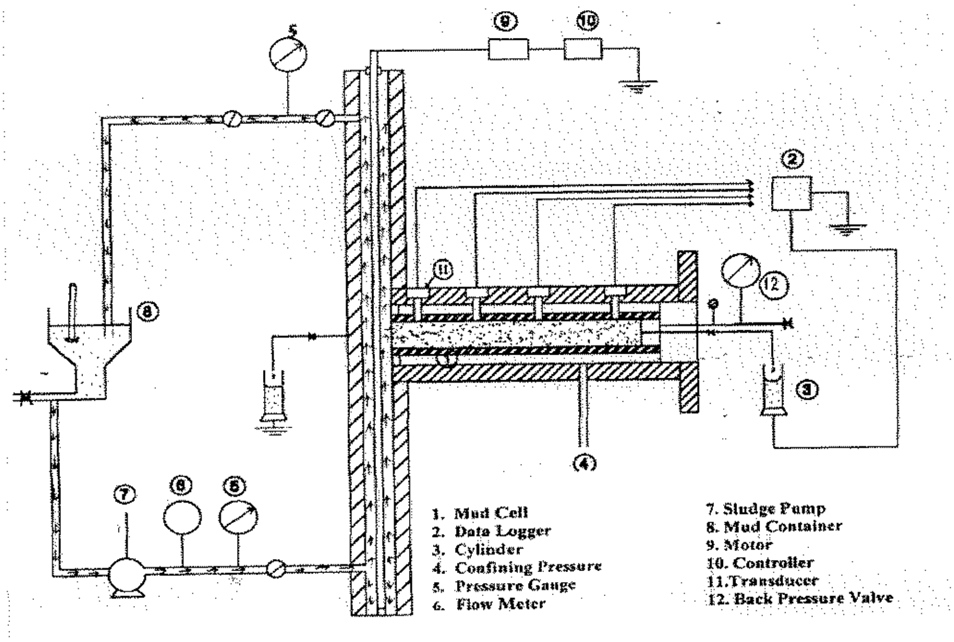

Fig 1. Schematic diagram for the circulation system

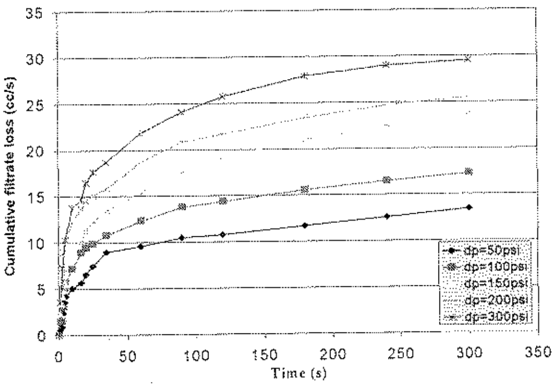

Fig.2 Filtrate loss versus time as a function of ΔP for deviated well

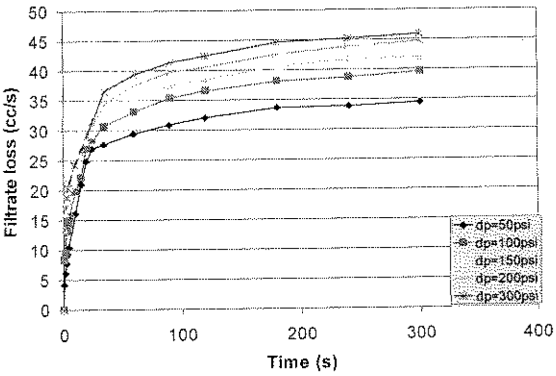

Fig.3 Filtrate loss versus time as a function of ΔP for horizontal well

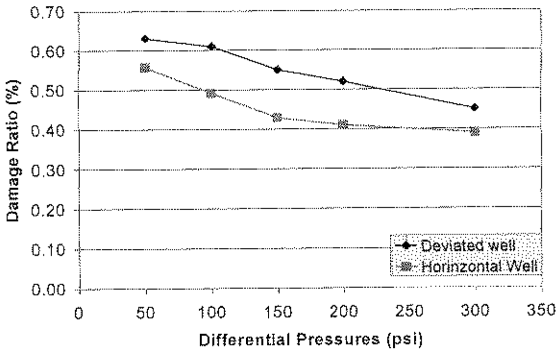

Fig.4 Damage ratio as a function of ΔP

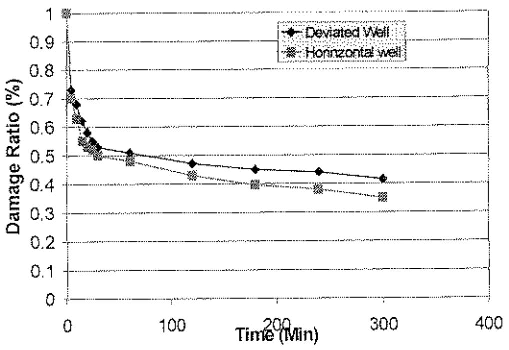

Fig 5 Damage ratio versus time for annular velocity (120ft/min)

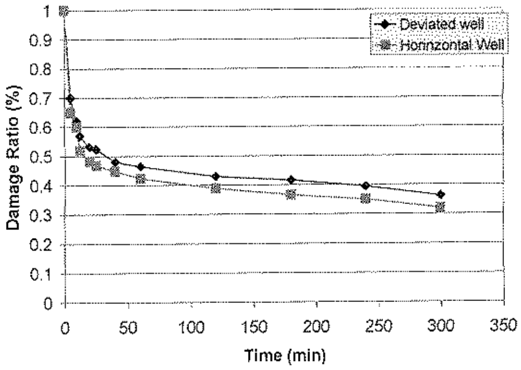

Fig.6 Damage ratio versus time for annular velocity (150ft/min)

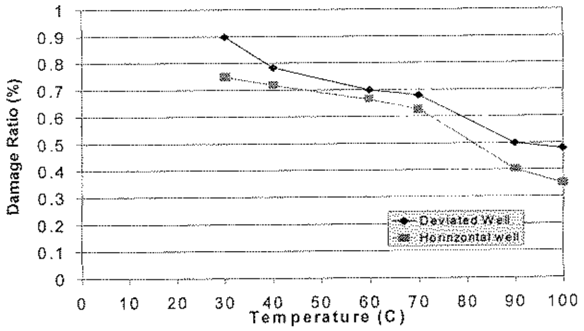

Fig.7 Damage ratio as a function of