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FORMATION DAMAGE IN HORIZONTAL AND DEVIATED WELLS

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Abstrak. This technical paper discusses the effect of formation damage in horizontal and deviated wells. In general, different drilling environments, such as horizontal drilling and high angle well drilling, will cause different degree of damages which can bring to the reduction of oil productivity. The experimental results revealed 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 minimize this problem, the most suitable measure is to understand the most appropriate differential pressure, annular velocity between the drill pipe and bore hole, and the effect of temperatures.

Keywords: Annular velocity; deviated well; differential pressure; formation damage; horizontal well; reservoir temperature

Abstract. Kertas teknikal ini membincangkan tentang kesan kerosakan formasi dalam telaga mendatar dan tegak. Secara umum, persekitaran penggerudian yang berbeza, misalnya penggerudian mendatar dan sudut besar, akan menyebabkan berlakunya kerosakan formasi dengan pelbagai keterukan sehingga boleh menjejaskan kebolehpengeluaran minyak. Hasil kajian membuktikan bahawa penggerudian telaga mendatar adalah lebih kritikal dan boleh menyebabkan berlakunya kerosakan yang serius kepada formasi. Untuk mengurangkan masalah ini, langkah terbaik adalah dengan melakukan penggerudian menggunakan pembezaan tekanan dan halaju anulus antara paip gerudi dan lubang telaga yang sesuai, serta memahami kesan suhu.

Kata kunci: Halaju anulus; telaga condong; tekanan pembezaan; kerosakan formasi; telaga mendatar; suhu reservoir

1.0 INTRODUCTION

Since the advent of the energy crisis and the Arab embargo, most of the oil companies started to realize and aware of the importance of maximizing well productivity through the prevention of formation damage. Formation damage, sometimes known as wellbore damage, is a process that impairs the permeability of a reservoir and consequently decreases the natural flow of fluids from the reservoir into formation. It can occur in many ways and one of them is during the drilling phase. Laboratory studies [1 – 4] indicated that operations in a field such as drilling, completion, workover, production, and stimulation are the potential sources of formation damage.

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An understanding of mechanisms which can cause and accelerate damage of wellbore is of utmost importance. In general, the reduction of wellbore permeability can occur when particles laden fluids are introduced to the formation under dynamic condition at the different drilling environments. Field experiences[4] 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.

Several researchers [5 – 8] highlighted that under dynamic drilling conditions, dynamic solids and filtrates are directly related to the extent of formation damage caused by drilling fluids. 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 *et al.* [9] in their study 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 occur 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 decreases 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.

2.0 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.

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].

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] 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, 6] have different findings 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]. 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 quickly 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. [12].

3.0 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 potassium 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.

4.0 EXPERIMENTAL SET-UP

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

(i) Circulating system,
(ii) Dynamic filtration cell (Figure 1),
(iii) Filtrate collecting system,
(iv) Pressure measurement system, and
(v) 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 158 °F (70 °C) and the differential pressures were varied from 50 psi to 300 psi.

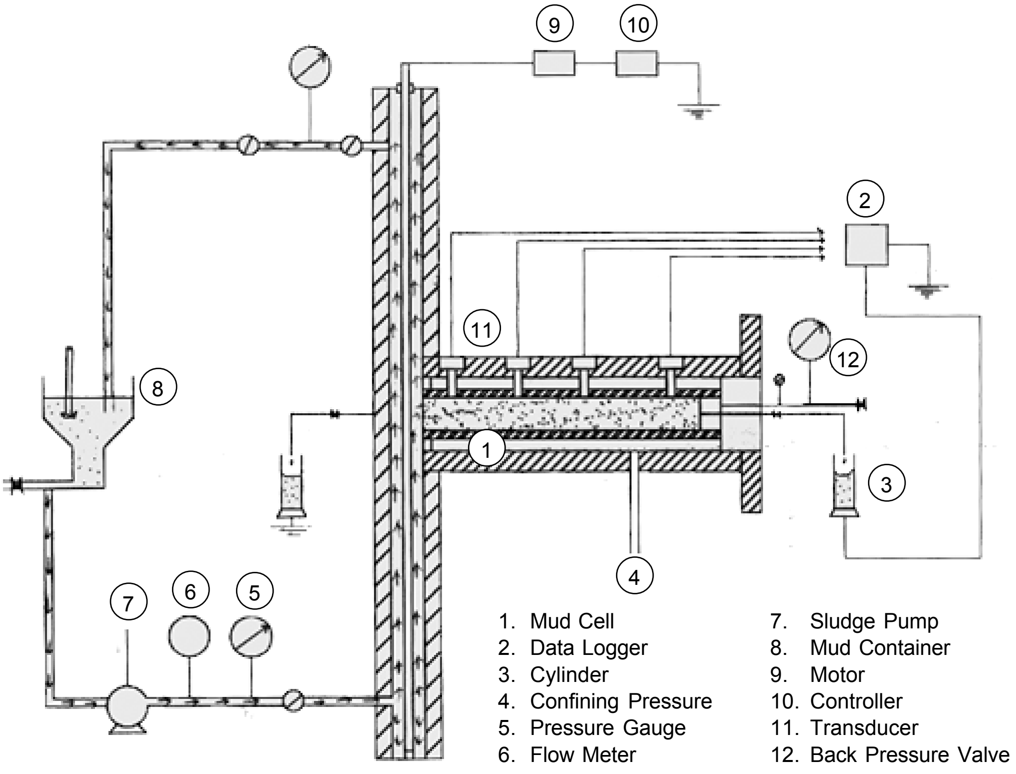

Figure 1 Schematic diagram for the circulation system

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

The Berea core sample used in the experiment was 12 inches long and 2 inches in diameter. It was chosen as test specimen because the matrix of this type of sandstone did not contain any water-sensitive clays.

The core holder was specially designed to allow drilling fluid to be circulated across the face of the core while the mud invading 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.

5.0 EXPERIMENTAL PROCEDURE

The Berea core sandstone was cut into 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 core sandstone. The permeability for the cores was 350 md and the average porosity was 20%. The core sample was placed in the core holder and a confining pressure of 1000 psi was applied to prevent 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 10.5 ppg was used as drilling mud in this study, and the mud properties of the mud, such as yield point, plastic viscosity, gel strength, and fluid loss, were determined, The mud rheological properties were found to be within the field recommended limit. 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 core was determined as the ratio of maximum permeability to oil after backflow to the original permeability to oil.

6.0 RESULTS AND DISCUSSION

The results of the laboratory work were presented in three subsections, namely under the titles influence of differential pressure, influence of annular velocity, and influence of temperature.

6.1 Influence of Differential Pressure

The analysis of Figures 2 and 3 revealed that higher differential pressures would produce greater total fluid loss, thus induced greater damage to the permeability. The experimental results indicated that at higher differential pressures, the rate of

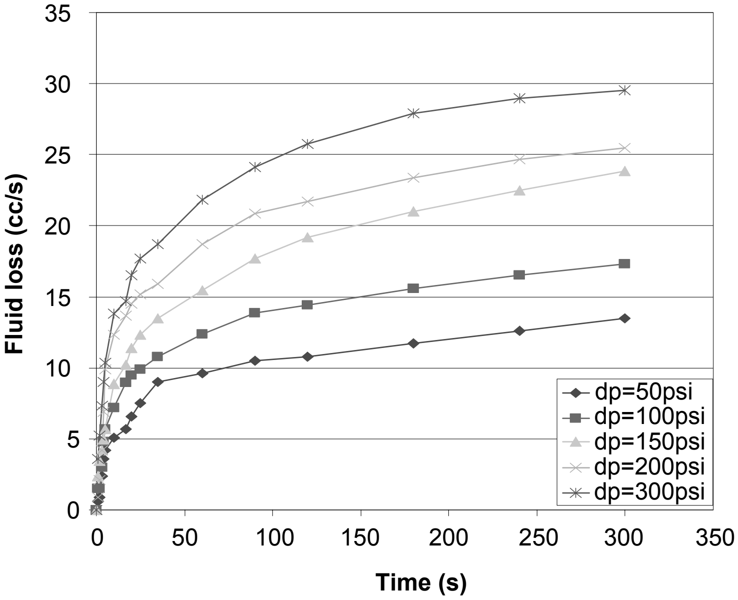

Figure 2 Fluid loss versus time as a function of ▲P for deviated well

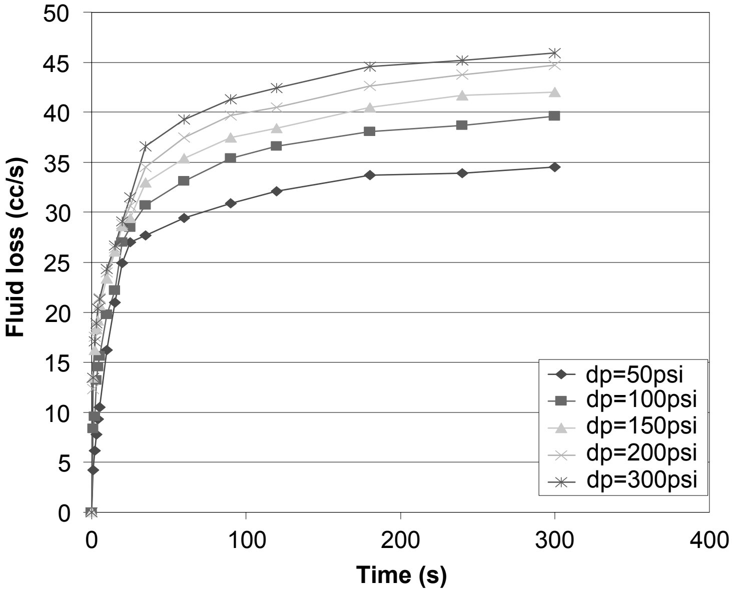

Figure 3 Fluid loss versus time as a function of ▲P for horizontal well

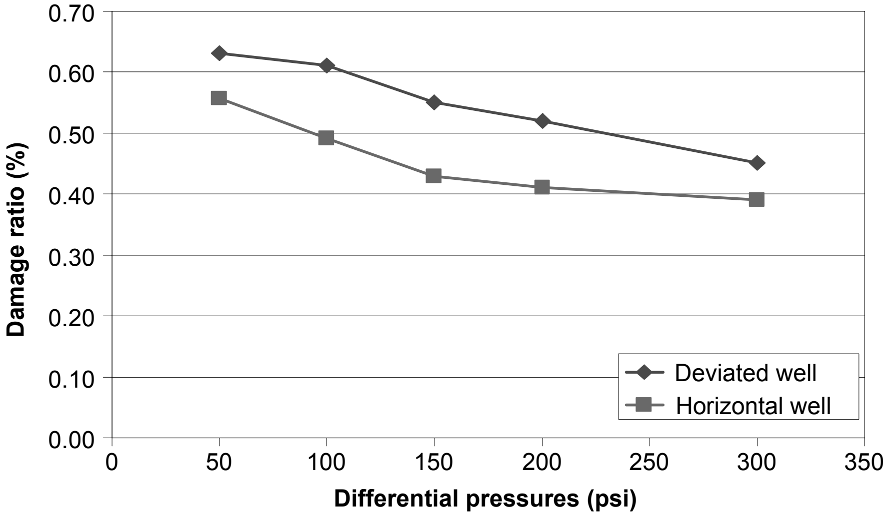

Figure 4 Damage ratio as a function of “P

the permeability reduction was found to increase as well and it was more severe in the horizontal drilling as compared to the high angle drilling environment (Figure 4). In general, differential pressures are important for the mud cake compaction and during the formation of the cake. Due to the poor quality of external cake (the presence of unfavorable increase in differential pressure), the infiltration of mud solid was found to have caused the damage to the cores. It was found that only the first two inches of the core experienced severe formation damage.

6.2 Influence of Annular Velocity

The influence of annular velocity was given in Figures 5 and 6. As expected, higher annular velocity would cause higher filtration rates thus induced greater formation damage. The damage ratio for the horizontal drilling was lower than the deviated drilling environment due to the settling of mud solid particles onto the surface of the formation. When the annular velocity increased from 120 ft/min to 150 ft/min, these particles were forced to invade into the formation due to the thermodynamic force accumulated at the solid particles.

6.3 Influence of Temperature

Figure 7 revealed that temperature plays a role in inflicting damage to formation. When temperature exceeds 158°F (70°C), a drastic increase in damage was experienced as indicated by sharp reduction of damage ratio. This was due to the thermal degradation of polymer used in the drilling mud. The degraded mud failed to form a compact and less permeable mud cake. This phenomenon was more

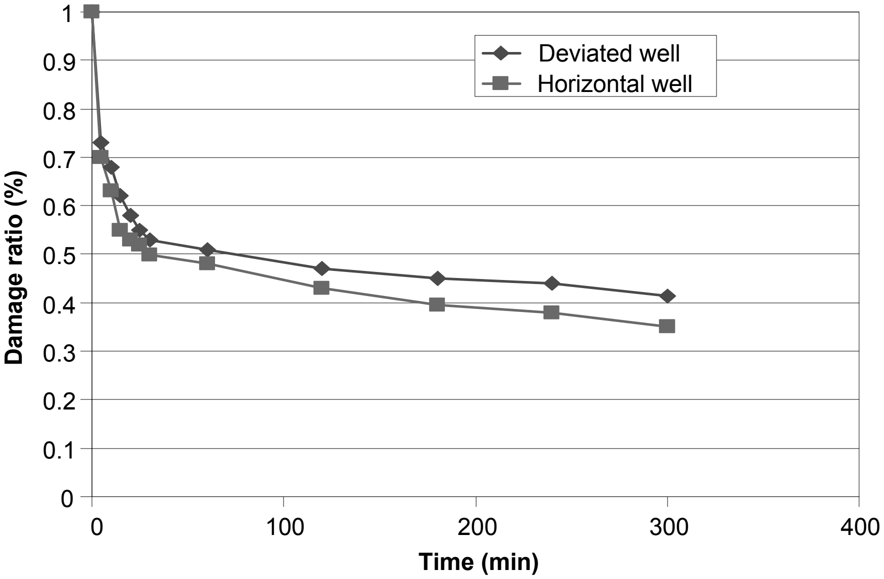

Figure 5 Damage ratio versus time for annular velocity (120 ft/min)

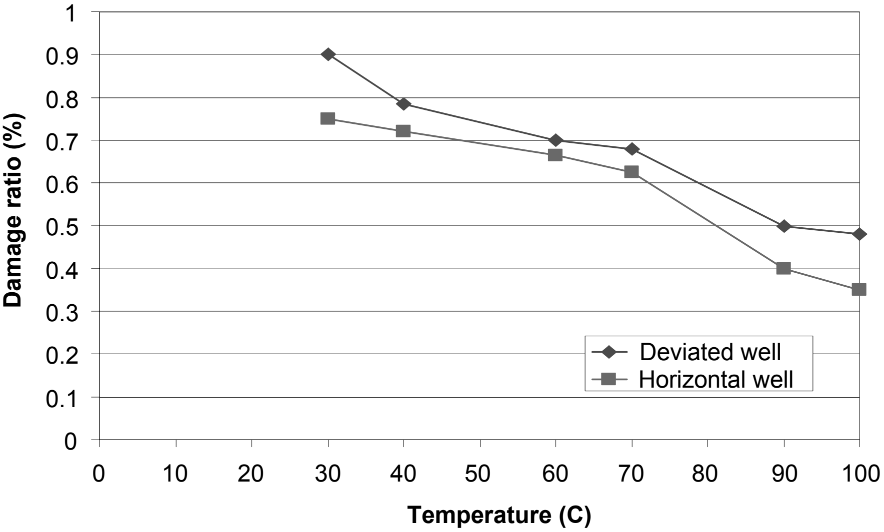

Figure 6 Damage ratio versus time for annular velocity (150 ft/min)

severe in horizontal drilling as compared to the deviated drilling environment due to anisotropic flow and gravity effect in horizontal condition.

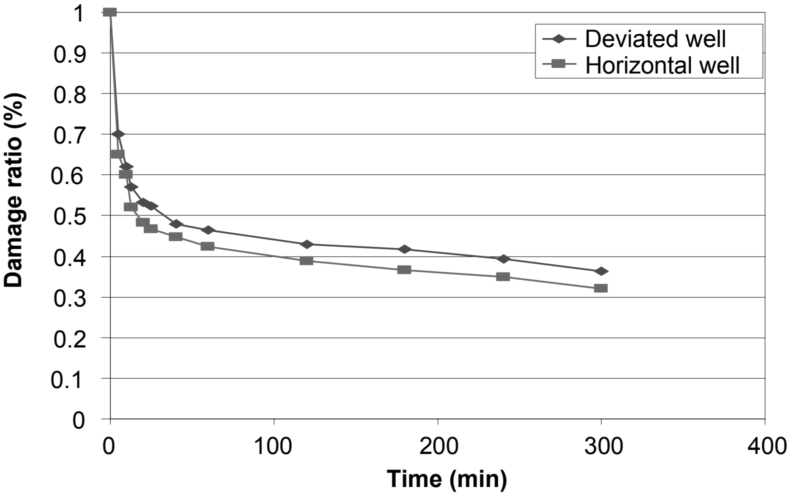

Figure 7 Damage ratio as a function of temperature

7.0 CONCLUSIONS

The following conclusions were derived from this research work:

(1) Higher differential pressures cause severe formation damage. In general, the migration of solid particles into core samples increases with differential pressure.
(2) Horizontal drilling environments cause severe damage to the formation as compared to deviated/high angle environments. This is due to the anisotropic flow and gravity effect in horizontal condition.
(3) Higher annular velocity causes severe formation damage due to the thermodynamic force accumulated at the solid particles.
(4) Higher temperatures cause severe formation damage due to the thermal degradation of polymer used in drilling mud.

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