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THE EXPERIMENTAL STUDY OF FORMATION DAMAGE DURING UNDERBALANCED DRILLING CAUSED BY SPONTANEOUS IMBIBITION IN FRACTURED RESERVOIRS

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ПОВРЕЖДЕНИЙ В ТРЕЩИНОВАТЫХ КОЛЛЕКТОРАХ (ОБУСЛОВЛЕННЫХ САМОПРОИЗВОЛЬНЫМ НАБУХАНИЕМ) ПРИ БУРЕНИИ НА ДЕПРЕССИИ

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Abstract. In conventional drilling, high mud weight can create a large overbalance pressure between the wellbore and reservoir. This overbalance can result in the invasion of mud filtrate, drilled solids and foreign fluids into the formation. Subsequently, this overbalance causes significant formation damage, and reduced productivity, thus requiring further costly stimulation operation such as acidizing and hydraulic fracturing.

Underbalanced drilling (UBD) is a drilling operation in which the circulating drilling fluid pressure is less than formation pore pressure. Underbalanced technology may be very successful in decreasing or eliminating formation damage if properly executed. However, the advantage of underbalanced drilling can be lost in case of short pulse overbalanced conditions or in case of spontaneous imbibition.

During a UBD operation, due to existence of capillary forces and wettability characteristic, especially in low permeable zones, the drilling fluid imbibes into the reservoir rocks in opposite direction due to the reservoir fluids and consequently formation damage can occur. Several parameters, e.g. pressure difference or exposure time, can affect the severity and magnitude of this kind of damage.

The main goal of this study's determining the saturation profile of imbibed drilling fluid and consequently evaluating the magnitude of formation damage which occurs in underbalanced drilling. Four sandstone plugs with a single longitudinal fracture with open ends were used in experiments. The plugs were exposed to different experimental conditions to measure the effect of various parameters, e.g. exposure time and overburden pressure, on the severity of the damage. In the next step, the actual saturation profile of imbibed water was determined by the X-ray computed tomography (CT scan) technique. It is shown that for lower underbalanced differential pressure, higher exposure time and lower drilling fluid viscosity, fluid invasion will increase.

Аннотация. При обычном бурении, высокая плотность бурового раствора может создать большое давление между стволом скважины и пластом. Это приводит к попаданию бурового шлама и других жидкостей, в фильтрат бурового раствора, что вызывает повреждения пласта, и понижает производительность труда. Для того, чтобы исправить эти недостатки, необходимы дорогостоящие операции, такие как кислотная обработка и гидроразрыв пласта.

Бурение на депрессии (UBD) является операцией бурения, при которой давление жидкости меньше пластового давления поры. На депрессии пласта технология может быть очень успешной только в случае уменьшения или устранения повреждения пласта. Однако преимущества бурения на депрессии могут быть потеряны в случае короткого импульса репрессии и в случае спонтанного набухания.

В UBD работы в условиях низкой проницаемости зон, буровой раствор (из-за существования капиллярных сил) впитывается в пласт породы в противоположном направлении (особенно в связи с пластовыми флюидами) и, следовательно, может произойти повреждение пласта. Некоторые параметры, например перепад давления или время эксперимента, могут повлиять на тяжесть и величину повреждения пласта.

Основная цель этого исследования определить степень насыщения профиля набухания бурового раствора и, следовательно, оценить величину ущерба, причиняемого в ходе бурения на депрессии. В экспериментах были использованы четыре песчаника зажигания с одной продольной перелома и открытыми концами. Пробки подвергались воздействию в различных экспериментальных условиях. Так, чтобы избежать серьезных повреждений пласта, во время опыта измерялось давление горной выработки. На следующем этапе рентгеновской компьютерной томографией (КТ) определялся, фактический профиль насыщения впитывания воды. Показано, что в случае перепада или при снижении давления депрессии, выше или ниже, воздействие жидкости на вязкость бурового раствора, будет увеличиваться.

Keywords: formation damage, fractured reservoirs, counter-current spontaneous imbibition, underbalanced drilling; X-ray computed tomography.

Ключевые слова: повреждение пласта, трещиноватые коллекторы, противоток, спонтанное набухание бурение скважин, рентгеновская компьютерная томография.

1. Introduction

Most formations are drilled in overbalanced condition which the drilling mud creates a downhole pressure which is greater than the in-situ formation pressure. If the exposed formation is permeable, the circulating fluid and its solids can invade into the formation and cause formation damage. In underbalanced drilling, the wellbore pressure is less than the formation pressure and it prevents the invasion of the drilling fluids into the reservoir rocks and reduces the formation damage. Overbalanced pulses, especially in bit changing and tripping times and consequently severe mud invasions due to the absence of mud cake on the wellbore, are inevitable in underbalanced drilling. Furthermore, due to counter-current spontaneous imbibition (COUCSI) process, the potential of damage exists.

In COUCSI process, the capillary forces draw the wetting fluid a couple of meters up into the exposed formation specifically in situation where the original saturation in the reservoir(either hydrocarbon or water), is less than the irreducible saturation of the phase utilized in drilling mud (Bennion and Thomas, 1994).

The main objective of this work is evaluating of the effecting parameters such as exposure time, amount of pressure difference etc. on COUCSI in underbalanced drilling in fractured reservoirs.

In previous works, many researchers made different studies for modeling of COUCSI phenomena in porous media. An analytical one dimensional solution for linear, cylindrical and radial flow of COUCSI was derived by Kashchiev and Firoozabadi (2003). Naziri Khansari (2009) presented a modeling methodology including using a commercial reservoir simulator and a developed simulation tool to model the spontaneous imbibition process. Naseri (2012) modeled COUCSI for a vertical and horizontal well in a conventional reservoir which was drilled using water based mud system in an underbalanced mode to investigate the effects of some factors such as exposure time and underbalanced differential pressure. The differential form of the governing equations was derived from mass balance and Darcy's equations for two phase (water and oil)flow model in radial coordinate system.

A series of experimental studies was done to evaluate spontaneous imbibition. Bennion and Thomas (1994) investigated the effect of various parameters, e.g. initial water saturation, underbalanced pressure, time and absolute permeability, on spontaneous imbibition phenomenon in underbalanced drilling in water-wet plugs. They presented results by flow initiation pressure during flowback which is mostly controlled by solids and filtrate invasion. Salimi et al. (2008) evaluated the effect of both over balanced pressure pulse and spontaneous imbibition experimentally in fractured carbonate rocks.

In the present study, the effects of some parameters such as exposure time and viscosity of drilling fluid on COUCSI were investigated. At the end of all experiments, X-ray computed tomography (CT scan) technique was used to determine the exact saturation profile of imbibed fluid.

Wellington and Vinegar (1987) used X-ray CT scan technique to study CO_2 displacementin cores. Others studies have used the same method for in-situ saturation determination while imbibition process experiments, both for air/water imbibition (Schembre et al. 1998) and water/oil imbibition (Akin et al. 1999).

2. Methodology

2.1. COUCSI experiments

We used an underbalanced core flooding apparatus (shown in Figure 1) to create underbalanced conditions. It consists of a core holder and three cylinders. The left side cylinder is used to simulate the reservoir and keep a specified oil pressure at core face. In order to circulate the drilling mud at the other face of the plug at a pressure less than the reservoir pressure the right side cylinder is used. The third cylinder which is equipped with a back pressure regulator is applied to collect the returned drilling fluid and to maintain the circulation pressure at any desirable value, too.

Four water-wet sandstone plugs with a single longitudinal fracture with open ends were used in experiments.Table1 describes the physical properties of these plugs. Porosity and permeability of plugs are given in Table 2.In the first step, the plugs were saturated with water and a CT scanner was used to take images every 1mm from cross section of plugs. The CT values were obtained for each slice. The average saturation of each slice can be obtained from these CT values as described later. In the second step, the plugs were saturated with kerosene and CT values were recorded, again. In the next step, the plugs were exposed to experiment conditions to let the COUCSI process to occur and the CT values were recorded to measure the extent of COUCSI.

As it is shown in Table 3, each plug is nominated for investigating the effect of a specific parameter on severity of COUCSI process. In order to investigate the effect of each parameter, three experiments with different values were done while the other parameters were held at constant value.

2.2. Measurement of saturation profile (CT scan)

CT number is defined as follows:

$$CT_{obj}(Hounsfield) = \frac{\gamma_{obj} - \gamma_{water}}{\gamma_{water}} \times 1000 \qquad (1)$$

In the above formula,γ is attenuation coefficient of X-ray in a specific media. In addition, CT is a numerical value (Hounsfield unit) converted from the X-ray attenuation coefficients. The CT numbers are normalized values relative to the linear absorption coefficient of water. The following equation can be applied to calculate imbibed water saturation (Akin et al. 1999):

$$S_w = \frac{CT_{exp} - CT_{oil}^{sat}}{CT_{water}^{sat} - CT_{oil}^{sat}} (2)$$

In equation (2),CT_{water}^{sat} is CT number of a core 100% saturated with water, CT_{oil}^{sat} is CT number of a core 100% saturated with oil or kerosene and CT_{exp} is CT number of a core after any specific COUCSI experiment.

3. Results and discussion

To investigate the effect of some parameters, e.g. drilling time and drilling fluid viscosity, different condition are considered. In each experiment, all parameters are held at a constant value, except the one which is being to be studied.

Effect of overburden pressure: Sandstone No. 1 was assigned for investigating the effect of overburden pressure on COUCSI process. Table 4 describes parameters which were assumed for these tests.

CT scan results of the experiments are shown in Figures 2, 3 and 4.Water imbibition profile can be calculated by equation 2. Figure5, 6 and 7show the saturation profile after conducting experiments. The varying parameter in these experiments was overburden pressure. As it is shown in figures, increasing the overburden pressure has a little effect on the saturation profile of invaded fluid in sandstone No. 1.Water front positions for each experiment are given in Table 5.

Effect of exposure time (drilling time): Sandstone No. 2 was assigned for investigating the effect of exposure time on COUCSI process. **Ошибка! Источник ссылки не найден.**Table 6 describes parameters which were assumed for these tests.

CT scan results and saturation profile are shown in Figure 8through Figure 13. It is shown that the exposure time of underbalanced drilling operation implies a direct effect on the extent of COUCSI process in fractured reservoirs, i.e., more COUCSI happens at long exposure times. Water front positions for each experiment are given in Table 7.

Effect of drilling fluid viscosity: Sandstone No. 3 was assigned for investigating the effect of circulating fluid viscosity on the severity of COUCSI process. Table 8 describes parameters which were assumed for these tests.

CT scan results and saturation profile are shown in Figure 14 through Figure 19.The degree of permeability impairment due to imbibition was found to increase with decreasing the drilling fluid viscosity, i.e., less drilling fluid viscosity causes more COUCSI and formation damage. Water front positions for each experiment are given in Table 9.

Effect of underbalanced differential pressure: Sandstone No. 4 was assigned for investigating the effect of underbalanced differential pressure on COUCSI phenomenon. Table 10 describes parameters which were assumed for these tests.

CT scan results and saturation profile are shown in Figure 20 through Figure 25.The degree of underbalanced pressure has a reverse effect on permeability impairment due to imbibition, i.e. increasing the underbalanced differential pressure causes the reduction of formation damage. Water front positions for each experiment are given in Table 11.

4. Conclusions and recommendations

A summary of experimental results presented in this work reveal that:

1. Countercurrent spontaneous imbibition (COUCSI) of water based filtrates has been illustrated to be potentially damaging even if totally underbalanced conditions are continuously maintained. This shows the counter-current spontaneous imbibition process is an important damage mechanism in underbalanced drilling in fractured reservoirs.
2. The overburden pressure has a little effect on COUCSI process in fractured reservoirs.
3. It is shown that the exposure time of underbalanced drilling operation implies a direct effect on the extent of COUCSI process in fractured reservoirs, i.e., more COUCSI happens at long exposure times.
4. The degree of permeability impairment due to imbibition was found to increase with decreasing the drilling fluid viscosity, i.e., less drilling fluid viscosity causes more COUCSI and formation damage.
5. The degree of underbalanced differential pressure has a reverse and strong effect on COUCSI process in fractured reservoirs, i.e. the more pressure difference leads to reduction of COUCSI and fluid invasion, too.
6. Using the CT scan apparatus to find the saturation profile of imbibed fluid in the rock exactly is a useful method to evaluate the extent of damage caused by COUCSI during UBD.

5. Nomenclature

P_{ov}: Overburden pressure (psi)
ΔP: Underbalanced pressure difference (psi)
ΔT: Exposure time (min)
S_w: Water saturation (dimensionless)
CT: CT number from X-ray scan (Hounsfield)
γ: X-ray attenuation coefficients (dimensionless)
$x/$L: Dimensionless position

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