Treatment of ultra high-pressure brine overflow by drainage brine with controlling pressure technology

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Abstract. Overflow of high -pressure brine causes stratification and sedimentation of drilling fluid, which damages the performance of drilling fluid and lead to serious accidents such as sticking. In the face of saltwater overflow, the common practice is to increase the density of drilling fluid to prevent and deal with it. However, increasing the density will lead to serious lost circulation in the thief layer, thus aggravating the saltwater overflow. In order to solve this problem, this paper puts forward a method of drainage brine with controlling pressure to deal with the overflow of high -pressure brine layer. Through laboratory experiments, the pollution capacity limit of high -pressure brine on oil-based drilling fluid was determined, and the drainage brine with controlling pressure technology was systematically proposed. The controlled pressure water drainage treatment technology has been successful applied in 4 Wells drilling in ultra- deep salt paste formation in Tarim Basin.

1. Introduction

The Kuqa piedmont structural block in Tarim basin is a typical ultra deep and ultra-high pressure sub salt oil and gas reservoir[1]. The burial depth of Paleogene giant thick composite salt layer is 1526~7945m, and the thickness varies from tens of meters to hundreds of meters. Many years of research and practice, a relatively perfect safe drilling technology for salt gypsum layer has been basically established. However, with the deepening of exploration and development, the problem of high-pressure brine overflow is inevitable [2.3]. Table 1 shows the statistics of high-pressure saltwater layer encountered during actual drilling in piedmont structural block. The data in the table shows that high-pressure saline water is generally developed in Kuqa piedmont structural block.

Table 1. Complicated accidents caused by high pressure brine overflow in Kuqa piedmont structural area.

No.	Well	Lost circulation times	brine overflows times	Blocking times	Other complex times
1	D5	13	1	42	
2	D206	6	3	17	
3	D303	6	2		
4	D304	22	1	28	2
5	D306	17	4	11	
6	K7	11	1	40	1
7	K2-1-4	1	2	11	
8	K2-1-11	4	1	30	
9	K2-1-18	17	4	15	
10	B101	14	1	44	12

The practical experience shows that high-pressure brine overflow will pollute the drilling fluid, causing drilling fluid stratification, precipitation, and so on, resulting in serious sticking accidents. For high-pressure brine overflow, the current treatment method is to increase the density of drilling fluid to prevent brine overflow. And for the brine overflow that has occurred, kill the well with higher density killing fluid. The drilling fluid density of many wells in Kuqa piedmont structural block is more than 2.45g/cm3, up to 2.59g/cm3, while the

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*corresponding author: liji3211979@163.com kill fluid density has been as high as 2.85g/cm3. Such high density of drilling fluid and killing fluid, on the one hand, makes it difficult to configure and maintain drilling fluid; on the other hand, high fluid injection pressure causes serious leakage in weak formation, which may lead to more serious overflow [4.5]. A lot of wells have suffered great losses due to saltwater overflow and lost circulation, as shown in Table 1. The problem of high pressure and ultra-high pressure brine overflow has become one of the biggest problems in safe drilling of salt gypsum layer.

Faced with the problem of high pressure and ultra-high pressure brine overflow, this paper has carried out a detailed study from the aspects of geological re understanding, the distribution of high-pressure brine layer, and brine pollution to drilling fluid. The geological and technological conditions for the implementation of drainage brine with controlling pressure technology are put forward, the construction scheme of drainage brine with controlling pressure technology is refined, and the implementation effect of drainage brine with controlling pressure technology is improved [6.7]..

2. Laboratory experiments

2.1 Composition analysis of formation brine

When drilling in the well section rich in high-pressure brine, high-pressure brine will inevitably invade the drilling fluid, contaminate the drilling fluid, and make the drilling fluid lose its function. In order to clarify the performance change of drilling fluid after being polluted by salt water, on-site drilling fluid was collected and simulated formation water was prepared for lab test. The effect of high-pressure brine on drilling fluid is tested from the aspects of rheology, water loss, wall building and lubrication of drilling fluid.

Table 2 shows the main ionic composition of the formation brine in the Kuqa piedmont structure block, mainly including Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, etc. $CaCl_2$, KCl, K_2SO_4, $MgCl_2$ and other chemicals are selected and prepared into simulated formation water after multiple deployment.

Table 2. Composition analysis of Kuqa piedmont formation brine and simulated brine

Sampling well	Cl^- mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{2-} mg/L
K13 well@ 7275m	188978	2378	56	150340	3906	256
K 904well@ 7103m	186000	19158	/	91000	3118	7844
Simulated brine	184067	495	210	/	4000	2000

2.2 Effect of high-pressure brine on drilling fluid performance

The drilling fluid used in the experiment is oil-based drilling fluid taken from Well KS2-1-4 with a depth of 5546m. The formula is :0 # diesel oil+ 2%~3% Main emulsifier + 2%~3% Auxiliary emulsifier+0.5%~0.8% organic soil +0.3%~0.6% suspending agent + 1.5%~2.5% DURATONEHT+ Weighting agent.

In the experiment, 5%, 10%, 15%, 20%, 30%, 40%, 50% and 60% brine were used to mix and pollute the oil-based drilling fluid. The oil-based drilling fluid was aged at 150 ℃ for 16h, cooled to 60 ℃, and its properties were determined, as shown in Table 3.

Table 3. Determination of Formation Brine Contaminated Drilling Fluid Performance

Experimental items	Density g/cm³	pH	AV mPa·s	PV mPa·s	YP Pa	Gel10″/10′ Pa/ Pa	HTHP 150°C mL/mm	Lubrication coefficient	Demulsification voltage V
drilling fluid	2.51	9	118.5	114	4.5	3.0/5.5	3.1/1.0	0.075	445
drilling fluid+5%Brine	2.45	9	112	109	3	3.0/6.0	3.4/1.0	0.081	410
drilling fluid+10%Brine	2.40	9	109	107	2	4.0/7.0	3.5/1.5	0.094	380
drilling fluid+15%Brine	2.34	9	104	102	2	3.0/5.5	3.8/1.5	0.125	305
drilling fluid+20%Brine	2.29	9	98	97	1	3.0/6.0	4.4/2.0	0.138	295
drilling fluid+30%Brine	2.21	9	122.5	112	10.5	4.5/6.0	4.5/2.5	0.152	263
drilling fluid+40%Brine	2.13	9	/	/	/	/	5.0/2.5	0.170	225
drilling fluid+50%Brine	2.08	8	/	/	/	/	5.9/3.0	0.191	180
drilling fluid+60%Brine	2.02	8	/	/	/	/	6.6/3.0	0.217	143

The experimental data showing: ①With the increase of brine dosage, the system density gradually decreases; ② With the increase of salt water dosage, the apparent viscosity, plastic viscosity and dynamic shear force decrease first and then increase sharply. The turning point of brine addition was 20%, and the static shear force changed little. ③The HTHP filtration loss increased gradually , but the increase was small. ④The lubricity of drilling fluid becomes worse with the increase of salt water, and the demulsification voltage decreases gradually, which indicates that the stability of the system becomes worse.

The density difference between upper and lower layers of oil-based drilling fluid at room temperature, 120 ℃ and 150 ℃ was tested when 5%~60% salt water was added. This is used to evaluate the settling stability of oil-based drilling fluid after salt-water intrusion. The test results are shown in Figure 1, and the amount of clear water separated from the upper layer is shown in Figure 2.

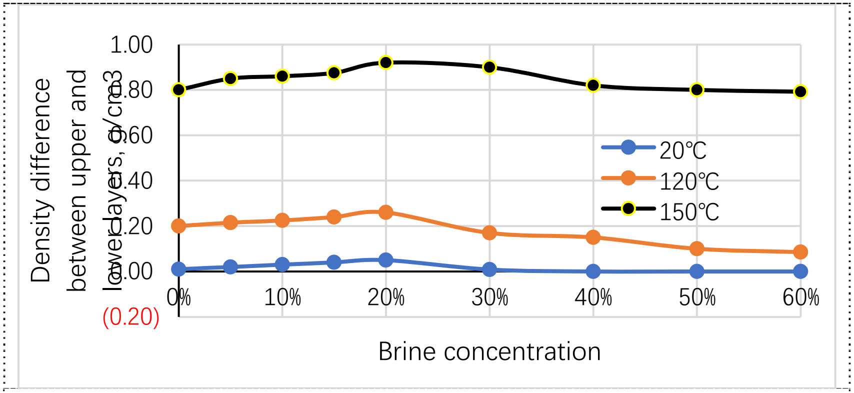

Figure 1. Effect of brine dosage on density difference at different temperatures

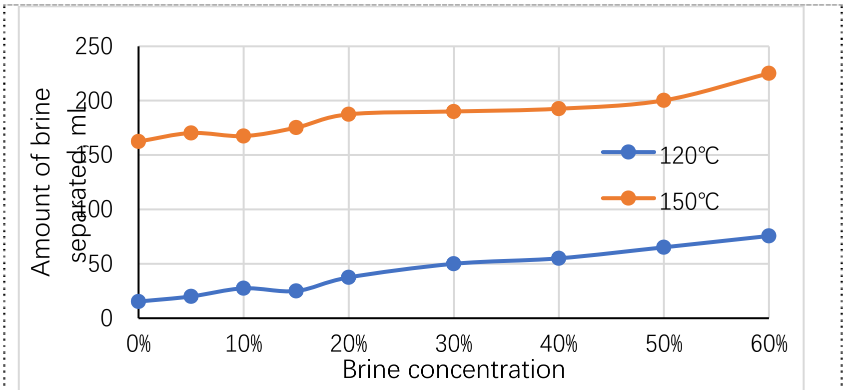

Figure 2. Effect of brine dosage on water precipitation at different temperatures

2.3 Analysis on the Mechanism of Salt-Water Pollution

Through comprehensive analysis of the influence of brine dosage on the rheological property, sedimentation stability, filtration loss, demulsification voltage, filter cake and lubricity of oil-based drilling fluid system, it is found that: ① When a small amount of salt water (≤ 20%) is mixed to pollute oil-based drilling fluid, its viscosity drops slowly, and the system still has a high demulsification voltage, indicating that the immersed salt water and the rich emulsifier in the system form a relatively stable emulsion; ②When a large amount of salt water (>20%) is mixed to pollute the oil-based drilling fluid, the system rich emulsifier has been consumed, and the increasing water phase content has a great impact on the viscosity and stability of the emulsion, which directly leads to the poor performance of the drilling fluid;③ When the intrusion of saline water (60%) continues to increase, the system still maintains the emulsion state, and no emulsion stratification is found.④ When the amount of salt water is increased to 600%, the system is still not demulsified after fully stirring and standing, but more clear liquid is separated from the upper layer, indicating that too much salt water does not participate in emulsification, as shown in the experimental photo in Figure 3.

The above experiments show that oil-based drilling fluid has a strong anti-pollution ability to brine. It will not demulsify after being polluted by brine. The capacity limit of the brine used in the system is 20%, and the contaminated drilling fluid needs to be released after more than 20% brine is leached.

Figure 3. 600% brine contaminated oil-based drilling fluid

3. Drilling site implementation processt

The technology of drainage brine with controlling pressure is to reduce the density of drilling fluid and meet the requirements of subsequent drilling by controlling the release of an appropriate amount of salt water when drilling in salt gypsum layer and encountering salt-water layer with insufficient formation energy supplement or poor connectivity. The drainage brine with controlling pressure operation is conducted in multiple cycles, each cycle mainly includes four steps: Shut in and observation, throttling and drainage, throttling and circulating well killing, and discharging contaminated drilling fluid. See Figure 4 for the Procedure.

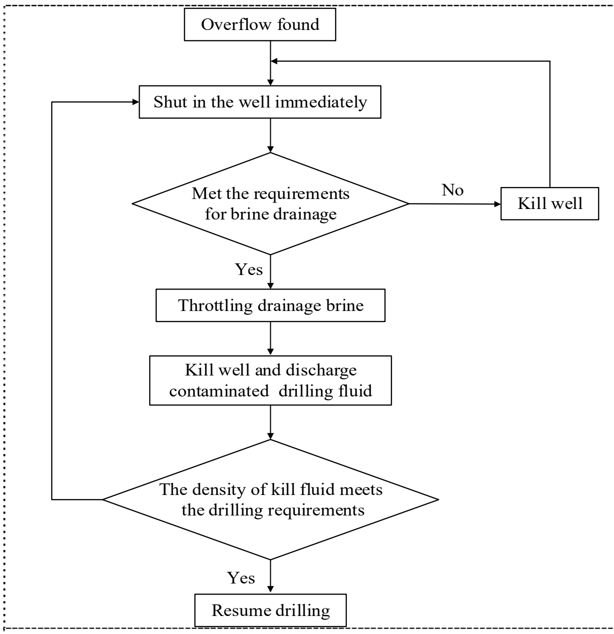

Figure 4. Procedure of drainage brine with controlling pressure

3.1 Shut in and observation

In case of salt-water overflow, shut in the well immediately and record the riser pressure and casing pressure. Calculate the density of kill fluid through the vertical pressure (Formula 1). If the calculated kill fluid density meets the requirements of subsequent drilling, and the circulating equivalent density does not exceed the equivalent density of formation fracture pressure during drilling, without causing leakage and other complex situations, then continue drilling after killing the well. If the density of kill fluid cannot meet the requirements of subsequent drilling, pressure control and water drainage shall be carried out to reduce the density of drilling fluid.

$$\rho_{MK} = \rho_M + \frac{P_S}{0.00981 \times H} + \rho_E \qquad (1)$$

Where:

ρ_{MK}-Kill fluid density, g/cm^3 ; ρ_M-Drilling fluid density when overflow occurs, g/cm^3 ; P_S-riser pressure when shutting in , MPa; H-Vertical depth of salt water overflow stratum, m; ρ_E-Density added value， g/cm^3

3.2 Drainage brine with controlling pressure

Throttling and drainage operation shall be carried out after well shut in observation. By adjusting the opening of throttle valve, the casing pressure shall be controlled to be less than the maximum shut in pressure (and a certain safety range shall be reserved), so that the formation brine can invade a certain volume in the wellbore at a certain speed. The speed is calculated by Formula 2.:

$$Q = K\frac{A}{\mu}\frac{\Delta P}{\Delta L} \qquad (2)$$

Where:

the speed of drainage brine with controlling pressure, cm^3/s; K -Permeability of saline rock, μm^2 ; A-Cross sectional area of brine seepage, cm^2; μ-Brine viscosity, mPa · s; ΔP -pressure difference, MPa; ΔL -Salt water seepage distance, cm.

The speed of brine drainage is critical. If the water is discharged too fast, the formation will be activated, which will cause the speed of brine intrusion into the wellbore to be out of control, causing the shut in casing pressure to exceed the maximum shut in pressure; If it is too slow, the drainage time will be extended, and economic input will be increased. During the implementation, the shut in casing pressure and drainage time after each drainage can be observed to determine whether the formation is activated. When the shut in casing pressure is significantly higher than the previous shut-in casing pressure, or the drainage time of each cubic meter of brine is continuously reduced, the formation may be activated. If the formation is activated, the casing pressure should be increased to reduce the drainage rate. If the casing pressure continues to increase, the well shall be killed again to increase the density of kill fluid in the wellbore. Only after the casing pressure is reduced can the pressure control and water drainage operation continue.

The single salt-water intrusion shall be controlled in the throttling and water discharge link, otherwise the pressure in the wellbore will not be controlled. For the single drainage volume, it is better not to produce salt crystals to block the well bore. As the excessive salt water will precipitate salt crystals with the decrease of temperature during the up-flow period, the well bore will be blocked, resulting in unsuccessful drainage

3.3 Throttling and circulating well killing and discharging contaminated drilling fluid

After throttling and drainage, the formation brine enters the wellbore under controlled conditions. At this time, the brine in the wellbore and the drilling fluid contaminated by brine needs to be drained out of the wellbore. This process is called circulating well killing and blowdown. This process shall be carried out according to the conventional choke and kill operation procedure. According to the analysis on the pollution mechanism of drilling fluid, the invasion of a small amount of salt water will not change the performance of drilling fluid dramatically, and it is enough to add base fluid to maintain the normal performance. However, it is also necessary to consider the preparation capacity of the on-site base fluid.

The contaminated drilling fluid that exceeds the on-site maintenance capacity should be discharged from the circulating system..

4. Field application

A well in piedmont structural zone has overflowed 0.5m when drilling to the depth of 7187.6m3, after 28 hours of shut in, the shut in vertical pressure is 13MPa, and the shut in casing pressure is 15.2MPa. The overflow layer is salt rock section. According to the vertical pressure and casing pressure recovery curves after well shut in, the formation is judged to be high pressure and low permeability formation. See Table 4 for the drilling fluid properties when overflow occurs

Table 4. Drilling Fluid Performance in Case of Overflow

Experimental items	Test value	Experimental items	Test value
Density, g/cm^3	2.40	HTHP 150℃, mL/mm	2.20/1.0
FV, s	86	Solid content, %	47
PV, mPa·s	73	water content, %	8
YP, Pa	6	oil content, %	45
Gel10″/10′, Pa/Pa	3.5/5	Cl-, mg/L	21000
Demulsification voltage，V	660	Alkalinity of drilling fluid	2.10

After overflow, the kill fluid density is 2.59g/cm3 according to the shut in vertical pressure. According to the actual drilling of adjacent wells, when drilling to the weak dolomite layer of the same open hole section in the later stage, this density is prone to lost circulation. In order to meet the later drilling requirements, the density of drilling fluid should be reduced as much as possible. Therefore, the pressure control and brine drainage operation should be carried out to release the pressure of the salt-water layer, so as to reduce the density of drilling fluid and increase the safe density window of drilling fluid.

Figure 5 shows the bottom hole difference after each brine drainage, and Figure 6 shows the discharge of 1m3 under different annular densities.

It can be seen from Figure 5 that the converted bottom hole pressure generally shows a downward trend with the increase of the cumulative amount of brine drainage. And this indicates that the formation energy is attenuated, and the high-pressure energy of brine is effectively released. It can be seen from Figure 6 that in a single brine discharge operation, the time for brine discharge generally decreases with the increase of cumulative brine discharge.

The well discharges 235.58m3 of saline water through drainage brine with controlling pressure technology. After that, the density of drilling fluid is 2.59g/cm3 drop to 2.37g/cm3, and the Drilling continued, which effectively reduced the density of drilling fluid. The purpose of treating high-pressure brine overflow with drainage brine with controlling pressure technology is achieved.

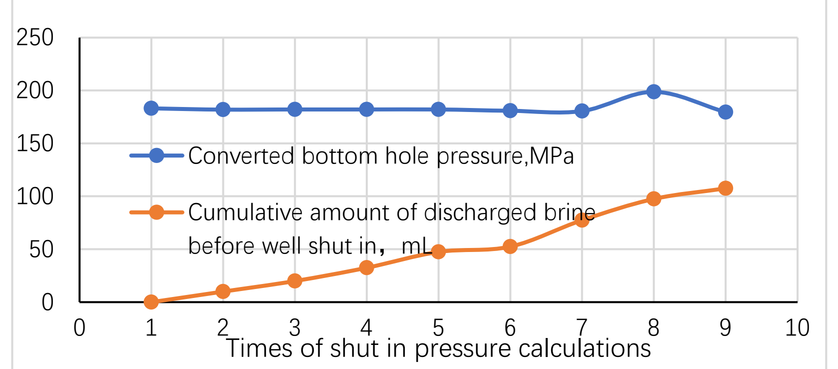

Figure 5. Calculated bottom hole pressure difference after multiple brine drainage operations

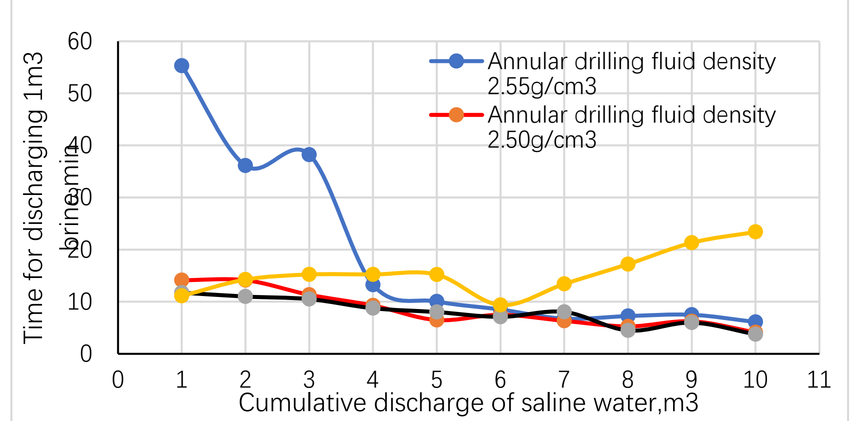

Figure 6. Comparison of Time for Discharge of 1.0 m3 Brine under Different Annulus Density

5. Conclusion

1)For a small closed (lenticular) high-pressure brine reservoir; the drainage brine with controlling pressure technology operation can effectively release the energy of high-pressure brine in the formation, reduce the density of drilling fluid, and thus increase the safe density window of drilling fluid.

2) The process of drainage brine with controlling pressure technology is to calculate the control casing pressure based on the vertical pressure obtained by shutting in the well and discharge the overflow high-pressure brine in the well step by step in a manner that does not activate the reservoir brine, thus reducing the pressure of the brine layer.

3）The successful application of drainage brine with controlling pressure technology in the drilling site of Kuqa piedmont structural belt in the Tarim Basin has confirmed the feasibility of the technology. The formation pressure has been reduced through the discharge of brine, and the problems and risks caused using Ultra High Density killing have been avoided.

Acknowledgments

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