Study on the influence of oilfield water injection on casing damage

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Abstract: The casing damage of oil and water wells has seriously affected the normal production of the oilfield. This paper analyzes the high occurrence of casing damage in Saertu oil layer, and finds that there is a contradiction between the water injection production of the wells in Saertu formation and the prevention and control of casing damage. Although the wellhead oil pressure can be guaranteed to be lower than its fracture pressure during production, the injected energy at the wellhead includes pressure potential energy and kinetic energy. Because the fracture pressure of Saertu formation is relatively low, the total injected energy is often higher than its fracture pressure, resulting in water injection at an excess fracture pressure. Unreasonable water injection will lead to the destruction of the underground rock stratum, which acts on the casing and forms casing damage.

1. General situation and statistical law of casing damage in Sabei Development Zone

As of February 2022, there are 2023 casing damaged wells in Sabei Development Zone, including 878 oil wells and 1145 water wells.

1.1 Main types of casing damage

From the perspective of casing damage types, the vast majority of casing damage wells are stagger and deformed, including 796 stagger wells and 880 deformed wells, with a total of 1676 wells accounting for 82.85% of the total casing damage wells. Both dislocation and deformation are expressed in the form of displacement, that is to say, most casing damage is caused by mechanical casing damage caused by the release of formation stress.

1.2 Main layers of casing damage

From the perspective of casing damage horizons, casing damage horizons are mainly concentrated in Nen 2 member and Saer layer system, in which 524 wells in Nen 2 member account for 31.26%, and 935 wells in Saer layer system account for 55.79%.

Table 1 Statistics of Casing Damaged Wells in Sabei Development Zone

Stratigraphy	Number of wells	Proportion (%)
N2	524	31.26
S	935	55.79
P	118	7.04
G	62	3.70
Others	37	2.21

Casing damage of the second segment of the Nenjiang River usually occurs in a certain area and in a relatively short period of time, with concentration in both time and space. The horizontal bedding of oil shale in the standard layer of Nenjiang Formation 2 is developed. When the injected water enters, it will diffuse along the densely superposed paleontological fossil bedding plane, forming a soaking water area, which will crack the mudstone in pieces. When the rock is subjected to shear stress, the stress will be released along the fossil weak surface of the standard layer, leading to casing damage in pieces.

Sal layer is a production layer, and its casing damage is mainly related to water injection. This paper mainly analyzes the relationship between water injection production and casing damage.

2. Water injection and casing damage

The steel grade strength of the casing itself, the consolidation strength of the casing and the rock stratum, and the rock mechanical properties of the rock stratum are the basic factors for casing damage. Generally, these factors are relatively stable, and the casing strength can offset the formation stress, which is the guarantee for normal production. However, in the process of oilfield development, water injection production is required, which will inevitably affect the underground rock stratum. Under low water injection pressure, the rock stratum is generally stable and will not affect the casing. However, once the water injection pressure reaches a certain level, the underground rock stratum will be damaged, causing displacement, and a huge radial force on the casing will cause deformation or dislocation of the casing. In order to prevent casing damage, the injection pressure at the bottom of the well must be lower than the overlying rock

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pressure of the formation. Since only wellhead equipment can be controlled during production, the production site will adjust the oil pressure through the oil pressure gate at the wellhead to ensure that it is lower than the fracture pressure for water injection.

3. Wellhead injection energy analysis

3.1 Wellhead process and principle of water injection well

During production, the water injection pipe network system will maintain a high pressure. At the wellhead end, the high pipe network pressure will be converted into a low injection pressure through an oil pressure gate to achieve constant pressure and quantitative water injection. The pipe network pressure at the wellhead end is called the pump pressure. The injection pressure is called the oil pressure through the pump pressure gauge. The oil pressure gauge shows that between the pump pressure gauge and the oil pressure gauge is the oil pressure gate that regulates the oil pressure. Generally, the pump pressure is more than 2MPa higher than the oil pressure.

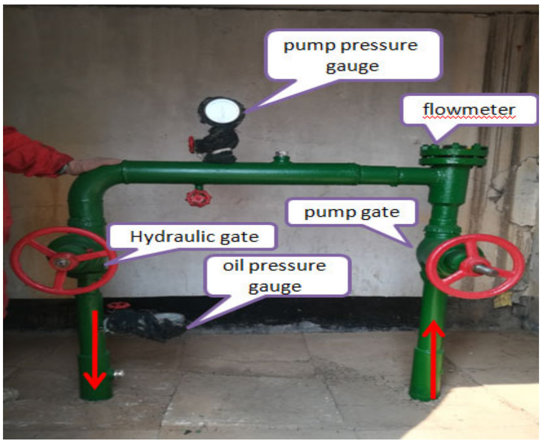

Fig. 1 Flow Chart of Well Head Control System

3.2 Principle of energy conservation in pipe flow system

According to the principle of energy conservation, the pipe flow energy at the oil pressure gauge should be equal to the pipe flow energy at the pump pressure gauge minus the pipe loss between two points. The distance between the pump pressure gauge and the oil pressure gauge is very close, and the pipe loss along the way can be ignored, only the gate pipe loss. The daily injection volume of the water intake well is 100 m3, the pipe diameter R is 0.05 m, the pipe flow velocity can be calculated as 0.6 m/s, the wall roughness of the old steel pipe n is 0.012, and the pipe loss when the gate is only 1/4 open can be calculated.

Calculation of pressure loss per unit length:

$$I = v^2 / \left(\frac{R^{\frac{4}{3}}}{n^2} \right)$$

I —— Pressure loss per unit length
v —— Pipe flow velocity
n —— Pipe wall roughness
R —— caliber

Equivalent length of pipe diameter under different opening degrees of gate:

Table 2 Relation between gate opening degree and equivalent length of pipe loss

Valve opening size	Gate equivalent length (Multiple of pipe diameter)
Fully open	7
3/4	40
1/2	200
1/4	400

It can be seen from the calculation here that when the gate is 1/4 open, the loss is only 0.28P, which can be completely ignored. Generally, when the gate is more than 1/2 open, the pipe loss will be smaller. It can be considered that the pipe flow energy at the pump pressure gauge does not decrease after reaching the oil pressure gauge. The pipe flow energy in front of and behind the oil pressure gate is unchanged, which conforms to the Bernoulli equation of capacity conservation law of the pipe flow system:

$$C = P + \frac{1}{2}\rho v^2 + \rho g h$$

P —— Pressure potential energy
$\frac{1}{2}\rho v^2$ —— kinetic energy
$\rho g h$ —— Gravitational potential energy
C —— Pipe flow energy constant

The sum of pressure potential energy, kinetic energy and gravity potential energy at any point in the pipe flow is constant, and the pipe flow energy at the pump pressure gauge and the oil pressure gauge is equal.

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h$$

P_1 —— Pump pressure
P_2 —— oil pressure
v_1 —— Speed in front of oil pressure gate
v_2 —— Speed behind oil pressure gate

Taking a well with a daily injection of 100 m3 as an example, the flow rate is 0.6m/s, assuming that the pump pressure drops by 2 MPa, the equation is:

v_2 = 63.2m/s

After passing through the oil pressure gate, although there is a pressure loss of 2MPa, the pipe flow speed has changed from 0.6m/s to 63.2m/s, greatly increasing. The oil pressure gate only regulates the pressure. When the injected energy is not reduced, the total energy before and after the oil pressure gate is the same, but the situation is different. The injected energy at the oil pressure gauge includes pressure potential energy and kinetic energy, that is, the sum of oil pressure and kinetic energy at the oil pressure gauge. Therefore, the total injection energy at the wellhead is close to the pump pressure, which is much larger than what we think.

4. Contradiction of water injection well production

4.1 Analysis of water injection before and after pump pressure drop

In oilfield water injection production, the problem of low pump pressure will be encountered. After the pump pressure drops, the injection volume of the well will often drop, and the injection allocation cannot be completed. In this case, the field workers will open the oil pressure gate to increase the oil pressure. At the same time, in order to prevent casing damage, the oil pressure should be lower than the fracture pressure. This method can increase injection volume to a certain extent, but there are still many wells unable to complete injection allocation. Take North 3-But-6 - Lateral 453 of water injection well in North 3rd East Block of Sabei Development Zone as an example:

Table 3 Injection Status before and after Pump Pressure Reduction of B2-D3-CS453

Well name	Rupture pressure (MPa)	Production status	Pump pressure (MPa)	oil pressure (MPa)	Water distribution (m^3)	Injection volume (m^3)
B3-D6-CS453	11.2	normal	13.4	10.5	65	67
		Low pump pressure	12.4	11.1	65	30
		After recovery	14.0	10.4	65	66

During normal production, the pump pressure is 13.4 MPa, and the oil pressure is 10.5 MPa, which can complete the injection allocation. When the pump pressure drops to 12.4 MPa, even if the oil pressure is increased to 11.1 MPa, the injection allocation cannot be completed. Under the condition that all parameters of the same well remain unchanged, the water injection rate is proportional to the injection energy, and the decrease of water injection rate indicates that the injection energy is reduced at this time. Before the oil pressure gate, the pipe flow speed is very slow, and the injected energy here only includes the pressure potential energy, that is, the pump pressure. After passing the oil pressure gate, the pipe flow speed is greatly increased, and the front and rear pressure differences are converted into the kinetic energy of the pipe flow. The pipe flow energy here includes the pressure potential energy and the kinetic energy. After the pump pressure decreases, the total injected energy decreases. Although the pressure potential energy at the oil pressure gauge remains unchanged or even increases, the kinetic energy decreases significantly. The total injected energy can no longer meet the water injection requirements, resulting in a decrease in water injection volume.

4.2 Comparison of injected energy and fracture pressure

The pressure difference between pump pressure and oil pressure will be converted into kinetic energy and retained in the pipe flow system. That is to say, in addition to the 11.1 MPa pressure potential energy, 1.3 MPa kinetic energy will exist in the pipe flow system after the pump pressure of Well Bei 3-Ding 6-Skew 453 decreases. When this energy enters the formation through the downhole string, it will be converted into pressure potential energy again (conversion efficiency is unknown). The pressure potential energy of 11.1MPa is already the top fracture pressure. With the kinetic energy of 1.3MPa, the total action energy on the formation must exceed the fracture pressure by 11.2MPa. After the well pump pressure drops, water injection cannot be completed at the top fracture pressure. It can be inferred that the injection energy at this time is lower than that in normal production. Although the injection pressure is only 10.5MPa, much lower than the fracture pressure of 11.2MPa, in fact, in addition to the 10.5MPa pressure potential energy, there is also 2.9MPa kinetic energy. The total injection energy is much higher than the fracture pressure.

4.3 Overbreak pressure water injection of the system wells in Saer Formation

This phenomenon of water injection under super fracture pressure is common in the wells of the Sal layer system. The Sal layer system is shallowly developed with low fracture pressure, which is obviously different from the other two layers. At present, the water injection pipe network system is the same for the water wells of the three development strata, and the injection energy is similar. The average pressure at the wellhead of the pipe network system in Sabei Development Zone is about 14.5MPa, while the average fracture pressure of the Sal Formation is only 12.4MPa, and the average injection energy is 2.3MPa higher than the fracture pressure. This high-energy water injection method of super rock formation fracture pressure will inevitably cause certain damage to the underground rock strata.

Table 4 Comparison of Injection Pressure Status of Stratified Systems and Number of Casing Damaged Wells in Sabei Development Area

Stratigraphy	Pump pressure (MPa)	Rupture pressure (MPa)	Pressure Difference (MPa)	Number of wells with damaged casing	Proportion (%)
S	14.7	12.4	2.3	935	83.86
P	14.6	14.0	0.6	118	10.58
G	14.5	14.9	-0.4	62	5.56

Statistically, it is found that the injection energy of the Sal layer system exceeds the average fracture pressure of the layer system by 2.3MPa, and the casing damage rate is particularly high, accounting for 83.86% of the casing damage wells in the oil layer; The injection energy of

Putaohua Formation is 0.6 MPa higher than its average fracture pressure, and its casing damage rate is greatly reduced compared with that of Sal Formation, accounting for only 10.58% of the casing damage wells in the oil layer; The injection energy of Gaotai sublayer is 0.4MPa lower than its average fracture pressure, and its casing damage rate is less. It can be seen that the casing damage occurrence rate of a set of layers is closely related to the difference between its injection energy and fracture pressure. The more the injection energy exceeds the fracture pressure, the easier it is to damage the formation and cause casing damage. It also confirms the correlation between the degree of the super fracture pressure of the water injection well and the number of wells where casing damage occurs. Therefore, the main reason for the high casing damage occurrence rate of the Sal layer system is its unreasonable injection status.

5. Conclusion

(1) Casing damage in production horizon is mainly concentrated in Sal layer system, and most of the casing damage types are stagger and deformation. The main reason for casing damage is that there is extrusion and shearing of rock stratum to casing at the bottom of Sal layer system.

(2) The oil pressure at the wellhead of a water well does not represent the injected energy. The total injected energy includes pressure potential energy and kinetic energy, which are much larger than what is generally believed.

(3) Overbreak pressure water injection is a common phenomenon in the system wells of Sa'er Formation, and the main reason for the high casing damage is the unreasonable injection condition.

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