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Research Article

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The microcosmic mechanism research on water injection well back washing stratum sand production based on fluid-solid coupling theory

Wang Suling, Bai Nanyang, Zhang Yiming and Zhang Ying

School of Mechanical Science and Engineering, Northeast Petroleum University, Daqing, Heilongjiang, China

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ABSTRACT

Fluid-solid coupling behavior of reservoir rock is the basis of stratum back washing, ABAQUS-6.5 software is used to conduct three-dimensional elastic-plastic concretion numerical simulation for back washing stratum well washing deformation, combined with the technology of water, the deformation process of the reservoir rock is regarded as a coupling process, it's elastic plastic fluid solid coupling. Use Mohr-Coulonb as the yield condition of rock mass to simulate 16 holes per meter of perforating, at the same time, the influence of different crustal stress status, permeability and rock mass mechanical property on oil well sand production was studied. The calculation results show that, when the elasticity modulus of stratum is larger, the rock stratum permeability will be higher, the stratum horizontal crustal stress will be less, the stratum is more difficult to sand product wash pressure can be improved appropriately.

Key words: rock, oil well, back washing well, elastic-plastic, numerical simulation

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INTRODUCTION

Water injection well back washing is the most common well-washing technology to solve well plugging. At the same time, it is also a necessary measure to enhance oil production. As the casing's fluid pressure suddenly drop in the process of injection well back washing, the larger flow pressure difference existing between the bottom of well and stratum, which will cause sand production. The stratum is easy to collapse when the water well sand production is serious.

In recent years, numerous researches are mainly focused on the backwash process impacting on the water well casing strength, but the impacts on the stratum of back washing pressure are rare. A number of basic research on reasonable sanding to improve oil production based on the conventional heavy oil reservoir with loose sandstone were discussed in the literature 1.The fluid-structure interaction problems in underground construction were probed into class in the literature 2. Literature 3 has studied the mathematical model and finite element method of force-hot-flow three field coupling problems. Based on the elasticity-plasticity theory, reference 4 studied the perforation and sediment yield problems under the condition of isotropy horizontal in-situ stress. The influence of principal stress direction on the stability of well hole wall were studied in the literature 5. Reference 6 makes a further study to the horizontal well for adopting the double porosity model.

In this article, use ABAQUS-6.13 to simulate the three-dimensional elastic-plastic finite element solidification for oil reservoir perforation surrounding rock deformation in Daqing oilfield. The oil layer critical sand production criterion was introduced combining with the back washing process, the oillet stability of back washing stratum under different condition is proposed. The main influence factors of sand production was put forward, it provides reasonable theoretical guidance for formulating back washing process.

Back washing stratum mechanical model

Water injection layers of rock are generally located in the range of 800 ~ 3000m underground, the spiral perforations on the length of 1m casing are 16, as the perforation size is small, just 0.0127m, we make water injection layers as the research object, its thickness is 0.1524m, there are four screw holes, fetch 3m in the radial direction, then the injection wells back washing three-dimensional mechanical model is established, it can be shown in fig.1.

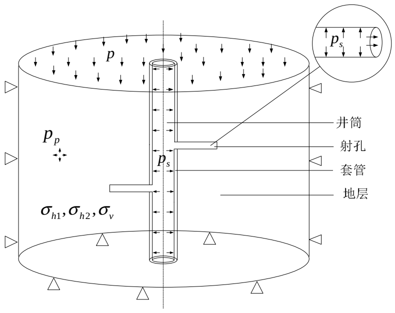


Fig.1 Back washing stratum mechanical model

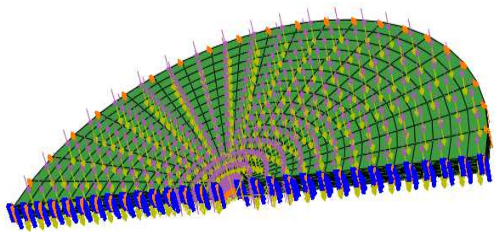


Fig.2 Back washing stratum finite element model

The loads act on the water injection layer and casing are: (1) Overburden pressure- P, (2) Rock weight-G, (3) The stratum original crustal stress are σ_{h1}, σ_{h2}, σ_v, (4) The fluid pressure of flushing fluid- P_s, (5) The pressure of flushing fluid in the wellbore inner wall is P_s.

The model is adopted hexahedral element to divide, the stratum rocks are adopted pore pressure element C3D8RP, the casing elements are adopted membrane element M3D4, then we can get finite element model, it can be shown in fig.2. In order to reduce calculated amount, the symmetrical model is used to analyze in the middle of symmetry plane, the displacement in Y direction is zero, the horizontal displacement in the outer limit is zero, the displacement on the bottom surface in Z direction is zero, it is uniform distribution pressure on the upper surface. The initial conditions are: the initial porosity ratio is 0.25, the initial pore pressure is $p = 10MPa$, the initial crustal stress are $\sigma_H = 29MPa$, $\sigma_h = 25MPa$, $\sigma_v = 22MPa$, the shear stress component is zero. The pore pressure on the outer boundary is $p = 10MPa$, the symmetry plane is set to impervious boundary. The rock elastic modulus is 7GPa. Poisson's ratio is 0.22, the strength parameters are respectively: Internal friction angle- $\varphi = 25^\circ$, dilation angle- $\theta = 10^\circ$, bonding strength- $c = 5\times10^5 Pa$.

Stratum sand production criterion

The stratum will produce distortion under the combined effect of original ground stress, pore pressure and the pressure of well bore fluid, when the deformation exceeds rock elastic deformation limitation, it will turn to the stage of plastic deformation. Different rocks have different abilities to produce plastic deformation, and the range of critical equivalent plastic strain is (0.3-0.8)%. When the equivalent plastic strain exceed critical value, the cementation between rock sand will be disconnected, and the rocks will become free sand. The equivalent plastic strain ε_p can be expressed by the following formula:

$$\varepsilon_p=\sqrt{\frac{2}{3}\left(\varepsilon_{p1}^2+\varepsilon_{p2}^2+\varepsilon_{p3}^2\right)}$$

In the formula, $\varepsilon_{p1}^2,\varepsilon_{p2}^2,\varepsilon_{p3}^2$ respectively represent the equivalent plastic strain of the three principal stress orientation. The criterion of sand production prediction can be expressed by the following formula:

$\varepsilon_p < \varepsilon_0$, No sand producing

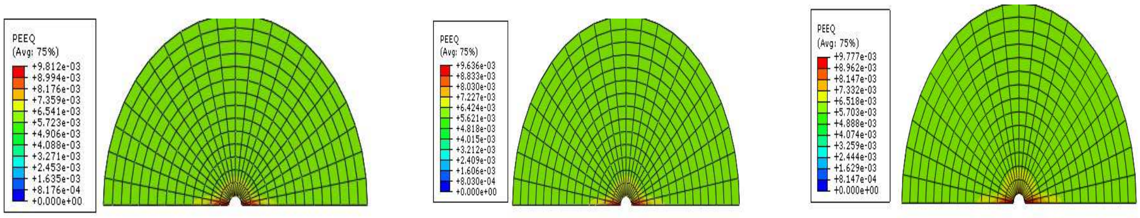
$\varepsilon_p \geq \varepsilon_0$, Sand producing

In the formula, ε_0 is the critical plastic strain value of the rock stratum. Because of the rocks in different strata have different mechanical properties and deformation features. According to the geological conditions and test in Daqing oilfield, the condition of rock mass sand producing was determined that is the maximum equivalent plastic strain value, which is greater than 1%.

RESULT AND DISCUSSION

Analysis on the influence of the ground stress on sand production

In order to investigate the influence of ground stress on stratum sand production, the change of the horizontal crustal stress was adopted to calculate. Fig.3 shows that under different horizontal crustal stress the distribution of rock mass equivalent plastic strain. Fig.3 shows when reaching the critical equivalent plastic strain, the comparison of unloading pressure difference.



(a) PEEQ distribution under 20Mpa **(b) PEEQ distribution under 30Mpa** **(c) PEEQ distribution under 40Mpa**

Fig.3 The distribution of rock mass equivalent plastic strain under different horizontal crustal stress

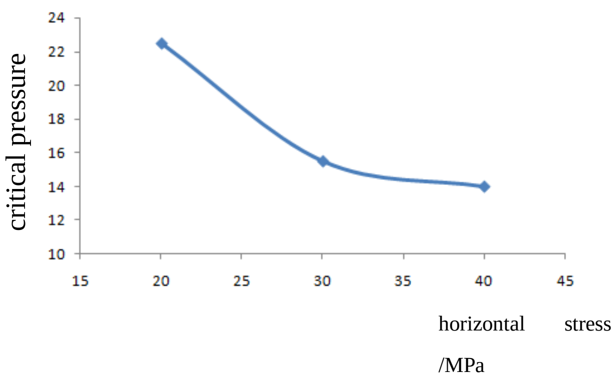


Fig.4 The comparison on stratum sand production Critical pressure under different vertical stress

We can conclude that from fig.3 and fig.4 under different horizontal crustal stress, the distribution of stratum rock mass critical equivalent plastic strain is same. With the increasing of the maximum horizontal principal stress, the unloading pressure of stratum will decrease. This is because of when the ground stress value is greater under water flooding disturbance condition, the deformation of stratum will increase.

The influence analysis of formation permeability on the stratum sand production

Permeability is an important factor influencing stratum stress changes when the water injection well back washing. The initial permeability of rock and pore ratio is given, the void ratio changing along with the permeability is determined by experiment, the unloading pressure is 20MPa, Table 1 is the change rules of different stratum pore pressure and the equivalent plastic strain with the change of permeability.

Table 1: Stratum pore pressure and equivalent plastic strain along with the change of permeability

Permeability / mD	5	50	500
Stratum POR/ MPa	33.14021	32.53	31.1391
Stratum PEEQ/%	1.20	1.05	0.89

It can be seen from table 1, when the formation permeability is higher, the formation pore ratio will be greater and the equivalent plastic strain PEEQ can be smaller, perforating will be harder to sand production, and it can withstand the maximum unloading pressure will be more larger.

The influence analysis of stratum mechanical property on sand production

Keep other parameters constant, the stratum elastic modulus E is respectively 7 GPa, 12 GPa, 17 GPa, 20 GPa, the

Poisson's ratio is 0.22, the initial porosity is 0.25, unloading pressure is 20MPa, from fig.4 we can see the change rule of stratum equivalent plastic strain under different modulus of elasticity.

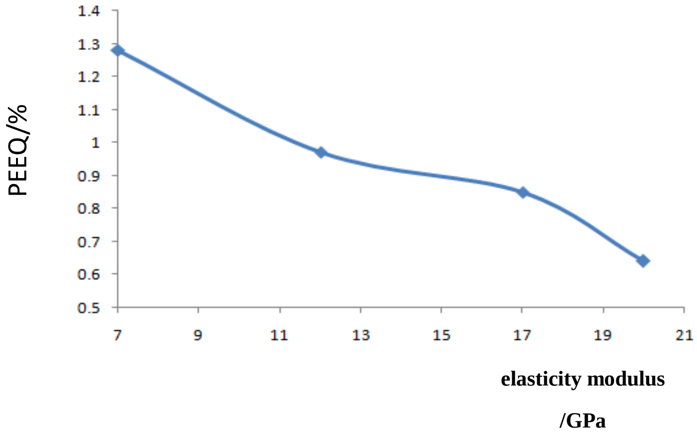


Fig.5 The change of stratum equivalent plastic strain under different modulus of elasticity

It can be seen from fig.5, in the same conditions, the equivalent plastic strain of stratum rock mass decreases with the increasing of elastic modulus. It shows that stratum unloading pressure will gradually increase with the increasing of elastic modulus, this is because the larger of the modulus of elasticity, the ability of the elastic deformation of stratum is stronger, it’s more difficult to take off the sand.

CONCLUSION

1. According to rock mechanics, seepage mechanics and elastic-plastic mechanics, using finite element analysis software ABAQUS in consideration of fluid-solid coupling dynamic effect and rock material plastic deformation, the water injection well back washing stratum fluid-solid coupling mechanical model is established, then the stratum stress change rule and distribution status in the process of water injection well back washing are obtained.

2. Calculation shows that, when the elasticity modulus of stratum is larger and the rock stratum permeability is higher, it will be more difficult to produce sand. Vertical principal stress has little impact on the stratum sand production ability, the stratum load capacity and horizontal crustal stress are inverse ratio. It's more easily to produce sand when the well washing unloading pressure difference is larger.

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