Research on Downhole Risk Assessment Method for Production Wells

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Abstract. At present, because of long offshore oil exploitation time, a large amount of adjusting wells and large offshore oil-gas production, downhole risks are difficult to be evaluated, and safety of offshore oil exploitation faces a great challenge. Aiming at the difficulties, reservoir energy is calculated through PHAST software, and overflow capacity of oil wells is analysed. Based on analysis of factors influencing downhole risks of offshore oilfield wells and analysis of reservoir energy and overflow capacity, a qualitative and quantitative assessment method is proposed for downhole risks of production wells. Downhole risk grades are divided according to the method, and corresponding control measures are proposed. This method is applicable to an offshore oilfield, risk grades of more than one hundred wells are divided, and corresponding control measures are proposed for different risk grades, so that downhole risks are reduced, and safety exploration of the oilfield is guaranteed.

1. Introduction

While oil and gas are continuously exploited, offshore well spacing area becomes dense, downhole oil-gas pressure system is complex and safety of offshore oil exploitation becomes worse, the state continuously updates laws and regulations about offshore oil exploration and development and puts forward higher requirements on safety. Risks on offshore oil and gas exploration mainly come from characteristics of formation reservoirs and properties of downhole fluids. At present, accident risks are often overestimated or underestimated if risk grades are simply judged according to one or two indexes. The assessment method defined according to risks, which assesses risks according to the product of accident frequency and accident severity, has some limitations. Therefore, a method for quantitatively dividing downhole risk grades is needed to be created to divide risk grades of different production wells; well-control equipment and tools shall be rationally configured according to risk grades, so as to avoid a great waste of human and material resources.

2. Downhole risk factors of production wells

After research and analysis, there are many factors influencing downhole risks of production wells, and the factors are divided into four classes according to their types as follows: reservoir geologic conditions, equipment and facilities [1], management system, technology and operations of persons [2]-[5]. At present, factors influencing downhole risks mainly include: geologic conditions of reservoirs, such as formation pressure coefficients of reservoirs, oil-gas ratio, well pattern development methods, reservoir temperatures and reservoir depths; equipment and facilitates, such as function failures of well-head assembly, failures of annulus packers of casings, failures of safety instruments, failures of downhole safety valves, failures of through-cable packers and failures of well-control systems. If downhole risks are assessed from the foundational factors, risk statuses of the reservoir itself are needed to be assessed; therefore, main influence factors [6], such as formation
pressure, formation pressure coefficient, oil-gas ratio, gas production rate, reservoir temperature and pressure coefficients of wellbore fluids, shall be considered as main influence factors to quantitatively assess downhole risks.

3. Quantitative assessment of downhole risks
Overflow or artesian flow of oil-gas wells essentially depends on the overflow energy [7] of oil wells. Therefore, downhole risks shall be researched from the reservoir energy. In an ascending process of fluids, reservoir gas inevitably escapes due to reduction of pressure, and gas channelling is one of main factors of blowout accidents; therefore, when factors influencing downhole risks are considered, overflow energy of production wells and reservoir gas energy of oil wells shall be considered as main influence factors to comprehensively assess downhole risks.

3.1. Determination of overflow capacity
Overflow energy is the least energy that well bottom fluids overcome their own gravity and resistance in a flow process while fluids flow to well head from well bottom. Main factors influencing overflow energy are pressure coefficients of reservoirs and pressure coefficients of wellbore fluids. Overflow capacity reflects the difference between the formation pressure coefficient and the fluid pressure coefficient. Formation pressure stabilizes in a certain time; the lower the pressure coefficient of the wellbore fluid, the stronger the overflow capacity. Therefore, the key of research is to calculate the pressure coefficients of wellbore fluids.

In a reservoir exploitation process, the wellbore pressure coefficients vary for flow states and composition of fluids, and the main influence factors are water content, gas-oil ratio, exploitation type and formation pressure [8], [9] in the exploitation process. While exploitation continues, formation pressure is reduced, water content rises, and the wellbore pressure gradient rises correspondingly. The wellbore fluid pressure varies for well depths; therefore, the wellbore fluid pressure shall be collected and sorted to seek the pressure change rules.

Overflow energy of well fluids is mainly calculated according to static pressure test reports, productivity test reports and pressure recovery test results reports. The static pressure test reflects static pressure gradient at different depths of the wellbore, and virtually reflects the static pressure coefficient of the fluid at different well depths via static pressure gradient. Data analysis and calculation steps are shown in figure 1.
Fluid pressure coefficients of oil wells in different areas can be obtained by calculating the overflow energy of some wells in different areas, and the overflow capacity can be measured according to formation pressure coefficients. Taking a well XX as an example, we introduce how to calculate the overflow capacity. The static pressure test data of oil line I of well XX is shown in Table 1.

| Slant depth (m) | Vertical depth (m) | Static pressure (MPa) | Static pressure gradient (MPa/100m) |
|----------------|-------------------|-----------------------|-----------------------------------|
| 1651.5         | 1651.5            | 13.56                 | 0.97                              |
| 1551.7         | 1551.7            | 12.59                 | 0.97                              |
| 1451.5         | 1451.5            | 11.63                 | 0.97                              |
| 1351.5         | 1351.5            | 10.66                 | 0.96                              |
| 1252.8         | 1251.5            | 9.69                  | 0.963                             |
| 1152.7         | 1151.5            | 9.332                 | 0.950                             |
| 1052.3         | 1051.5            | 8.866                 | 0.942                             |
| 952.6          | 951.5             | 8.352                 | 0.932                             |
| 852.9          | 851.5             | 7.784                 | 0.910                             |
| 752.3          | 751.5             | 7.083                 | 0.873                             |
| 652.1          | 651.5             | 6.184                 | 0.855                             |
| 551.9          | 551.5             | 5.287                 | 0.843                             |
| 451.8          | 451.5             | 4.457                 | 0.841                             |
| 351.5          | 351.5             | 3.748                 | 0.834                             |
| 251.5          | 251.5             | 3.119                 | 0.832                             |
| 151.5          | 151.5             | 2.595                 | 0.832                             |
| 51.5           | 51.5              | 2.159                 | 0.811                             |

Table 1 reflects distribution and characteristics of static pressure fluids in oil sections. From data, only static pressure gradients of oil sections are reflected, but pressure gradients at different depths of the whole wellbore cannot be reflected. In order to understand the variation trend of wellbore static pressure gradient, initial data of tests is needed to be sorted, corresponding pressure values shall be sorted per 100m, and the fluid state data of well section 50-1,650m forms according to the initial data of tests. If linear fitting of pressure gradients at different well depths linearly and corresponding well depth is used, change rules of pressure gradients of wellbore fluids can be reflected through a fitting curve as shown in figure 2.

![Figure 2](image)

The formula for fitting curve of pressure gradient and depth is:

\[
y = -0.129x^3 + 0.317x^2 - 0.082x + 0.822 ; \quad R^2 = 0.984
\] (1)
The relative mean pressure coefficient of wellbore fluids can be calculated according to the formula. Because the special well depth corresponds to the relative pressure gradient, the weight pressure coefficient of all wellbore fluids can be obtained by integrating the fitting curve and calculating the ratio of the vertical depth to the pressure of clear water.

\[
\rho = \left[ \int_{H_0}^{H_1} \left(-0.129x^3 + 0.317x^2 - 0.082x + 0.822\right) dx \right] / (H_1 - H_0)
\]  

(2)

Substituting \(H_0=51.5 \times 10^{-3}\) and \(H_1=1651.5 \times 10^{-3}\) into formula (2), we obtain:

\[
\rho = \left[ \int_{0.0515}^{0.6515} \left(-0.129x^3 + 0.317x^2 - 0.082x + 0.822\right) dx \right] / 1.6
\]  

(3)

\[
\rho = \left[ \frac{-0.129}{4} \times (H_1^4 - H_0^4) + \frac{0.317}{3} \times (H_1^3 - H_0^3) - \frac{0.082}{2} \times (H_1^2 - H_0^2) + 0.822(H_1 - H_0) \right] / 1.6
\]  

(4)

\[
\rho = 0.893
\]  

(5)

The pressure coefficient of the wellbore fluid is 0.893, but from reservoir test data, the current formation pressure coefficient is changed between 0.8 and 0.84, and it is lower than the pressure coefficient of the wellbore fluid.

The pressure coefficients of wellbore fluids in a hundred of wells in an oilfield are collected and calculated according to the method, so as to seek the distribution states of pressure coefficients of fluids in the oilfield. After pressure coefficients of wellbore fluids in production wells are calculated and collected, the most wellbore pressure coefficients are within a range of 0.85-0.90, and the lowest wellbore pressure coefficient is 0.8 as shown in figure 3.

![Figure 3. Pressure coefficient chart of production wells in an oilfield.](image)

From calculation results and statistical results of overflow energy of oil wells in the oilfield, the current formation pressure is gradually reduced along with exploitation time, and water content rises gradually in the exploitation process. From analysis of risk principle 20/80, when the formation pressure coefficient of the oil well is lower than 0.80, the oil well has hardly any overflow capacity; when the formation pressure coefficient of the oil well is between 0.8 and 0.905, the oil well has smaller overflow capacity; when the formation pressure coefficient of the oil well is larger than 0.905, the oil well has larger overflow capacity.

3.2. Determination of reservoir gas energy

While fluid pressure is reduced, gas in production wells escapes gradually. Gas itself has compressibility, and has huge destructive power in the exploitation process. Gas is also one of the main factors causing well-control damage. Therefore, we should calculate the reservoir gas energy. From the sorted production data, oil production rate and gas production rate of current oil wells are reduced gradually, and oil-water ratio becomes higher and higher. Therefore, only the maximum data of daily gas production rate in recent years not only represents the maximum amount of gas, but also represents the maximum damage risk of gas in recent years.

Pressure, temperature, oil production rate, gas production rate of the oilfield, sizes of casings and other parameters are entered in software PHAST to calculate the gas energy via a leakage model; kinetic
energy of gas blowout of the oil well can be calculated according to parameters of various oil wells. The kinetic energy reflects the damage capability of the gas in oil wells. Energy of gas in oil wells is mainly related to reservoir pressure, gas production rate and temperatures of oil wells, leakage size and other parameters, and the acting energy can be calculated through quantitative calculation software PHAST. If the change section of the acting energy of gas in production wells is \((7,956.55, 215,954.57)\) MJ, according to requirements of risk principle of 20/80 and requirements of risk grade division, the gas energy of oil wells is low if less than 26,000 MJ, medium if between 26,000 MJ and 50,000 MJ, and high if more than 50,000 MJ.

4. Distinction of downhole risks

Downhole risks of oil wells shall be assessed according to intrinsic safety factors of well control, namely formation energy of oil wells. Downhole well-control risks shall be comprehensively assessed by calculating overflow capacity and reservoir gas energy of oil wells. Based on overflow energy, a risk matrix is created according to the acting energy of the reservoir gas to divide the downhole risk grades of production wells. Downhole well-control risk assessment matrix diagram is shown in Figure 4-1. The red area represents high risk, the yellow area represents medium risk, and the green area represents low risk.

| Reservoir gas energy | Formation pressure coefficients |
|----------------------|--------------------------------|
| Risk grades          | P<0.80 | 0.80-0.905 | >0.905 |
| 0-26000MJ            |        |          |        |
| 26000-50000MJ        |        |          |        |
| >50000MJ             |        |          |        |

**Figure 4.** Risk matrix diagram.

According to requirements of the risk matrix diagram, formation pressure coefficient and acting energy of reservoir gas of oil wells containing gas can be calculated through the method, and the downhole well-control risk grades of production wells can be comprehensively assessed according to the risk matrix principle. An offshore oilfield has a hundred of production wells, and downhole risk grades are divided. A statistical analysis shall be made according to high, medium and low grades: 1) oilfield wells with high downhole risks are accounted for 24%; 2) oilfield wells with medium downhole risks are accounted for 47%; 3) oilfield wells with low downhole risks are accounted for 29%, as shown in figure 5.

**Figure 5.** Risk grade scale.
5. Measures and suggestions
(1) For wells with high risks, enterprises shall highly input, list critical focus wells in daily production, regularly monitor and record well bottom pressure, well head pressure, temperature and other production parameters. If parameters fluctuate severely, enterprises shall reduce the monitoring period, and master the well bottom pressure, annulus under-pressure statuses and trend to make sure that the aboveground and downhole well-control equipment is in good conditions.
(2) For wells with medium and low risks, enterprises shall understand well bottom pressure and trend, monitor and record well bottom pressure, well head pressure, temperature and other production parameters. Well head equipment, safety instruments, downhole safety valves and other well-control facilities shall be timely maintained or replaced if having any failure.

6. Conclusion
(1) This paper analyses various factors influencing downhole risks of production wells, and creates a downhole risk analysis and assessment method for production wells based on essential safety;
(2) A downhole risk assessment and grading model is created for production wells according to the proposed assessment method and such factors as formation pressure coefficients, gas-oil ratio of reservoirs, oil production rate and gas production rate.
(3) The acting energy of downhole gas is calculated through the model via quantitative software PHAST. Downhole risk situations are obtained from essential safety according to overflow capacity of oil-gas wells, and the grades of the risks are divided: More than 100 production wells in XX Oil Field are assessed with 24% of high risk wells, 47% of medium risk wells and 29% for low risk wells.
(4) The next step will carry out the well integrity analysis of high risk wells, further quantify the downhole risk, and put forward immediate corrective measures for the high risk wells that have been assessed.

7. References
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