Analysis of Factors Influencing Shut in Pressure Cone in Offshore Strong Bottom Water Reservoir

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Abstract

X oilfield is an offshore strong bottom water reservoir with water cut up to 96% at present, and liquid extraction has become one of the main ways to increase oil production. However, the current liquid production of the oilfield reaches 60,000 m^3/d due to the limitation of offshore platform, well trough and equipment, the oilfield is unable to continue liquid extraction. In order to maximize the oil production of the oilfield, it is necessary to study the strategy of shut in and cone pressure. Through numerical simulation, this paper analyzes the influence of different factors, such as crude oil density, viscosity, reservoir thickness, interlayer, permeability and so on, on the drop height of water cone and the effect of precipitation and oil increase after well shut in. At the same time, the weight of each factor is analyzed by combining the actual dynamic data with the fuzzy mathematics method, and the strategy of well shut in and cone pressure is formulated for the offshore strong bottom water reservoir. It provides the basis and guidance for the reasonable use of shut in pressure cone when the reservoir with strong bottom water meets the bottleneck of liquid volume.

Keywords

Offshore, Strong Bottom Water Reservoir, Shut in Pressure Cone, Precipitation to Increase Oil Production, Fuzzy Mathematics

1. Preface

X oilfield is an offshore strong bottom water reservoir. Due to the particularity of offshore development and exploitation, the oilfield has maintained high-speed development. The strong bottom water reservoir has the characteristics of water cut rising rapidly. At present, the water cut is as high as 96%. In the stage of high

water cut, the oil production is generally increased by liquid extraction to achieve high production. However, limited by offshore conditions, the processing capacity of oilfield liquid has reached its limit. In order to achieve the purpose of increasing oil and stabilizing production, it is necessary to control the liquid production of a single well. Shut in and kill cone is a development method of periodic intermittent production for high water bearing wells in bottom water reservoir. After the high water bearing well is shut in, there is no production pressure difference at the bottom of the well, the oil and water are differentiated under the effect of gravity, the water cone gradually falls back to a certain extent, the production well is reopened for production, the water cut is reduced, and the oil production is increased. Accurate judgment of water cone falling back after shut in can effectively guide the determination of reopening time, so as to improve the development effect of reopening production. At present, there are many single factor analysis on the effect of shut in and cone killing in bottom water reservoir, but there are few analysis on the influence weight of each factor. It is found that Li Chuanliang et al. (Li & Yang, 2006; Liang, Zeng, & Fang, 2012) analyzed the effect of well shut in cone pressure in bottom water reservoir, Pan Zhaocai et al. (Pan, Yuan, Gu et al., 2013) studied the influence of factors such as the scale of remaining recoverable reserves controlled by a single well, the energy of edge and bottom water, and the rising law of bottom water on the effect of well shut in cone pressure, and Nie Bin et al. (Nie, Liu, & Yang, 2012; Li, 1997) studied the interlayer, oil-water viscosity ratio, vertical permeability to horizontal permeability ratio, well spacing, and productivity The influence of liquid quantity and other factors on the water cone take-off and drop law of bottom water reservoir has not been systematically analyzed.

In this paper, numerical simulation method and fuzzy mathematics method are used to study the relationship between the falling height of water cone and shut in time, and the weight of each factor is analyzed to provide effective guidance for shut in and cone killing development mode of bottom water reservoir (Tan, 2019; Cao et al., 2012).

2. Analysis of Factors Affecting Shut in Pressure Cone

The reason of bottom water coning is the pressure drop around the wellbore during the production of oil well, that is to say, during the production process, the formation direction of the lower part of oil layer is close to the vertical pressure gradient. Because the density of water is larger than that of oil, the oil-water interface is conically rising, and the hydrostatic pressure is increasing. However, when the production of oil well exceeds the critical production, the oil-water interface will continue to rise with the production of oil well, and the water coning will become unstable Up to the bottom of the well. **Figure 1** is the schematic diagram of bottom water coning (Zhao & Chen, 2018; Xiong, Li, Zhang et al., 2014; Xiao, Li, & Xiao, 2009).

A numerical model of bottom water reservoir is established, and the influence of crude oil density (ρ_o), crude oil viscosity (μ_o), reservoir thickness, horizontal
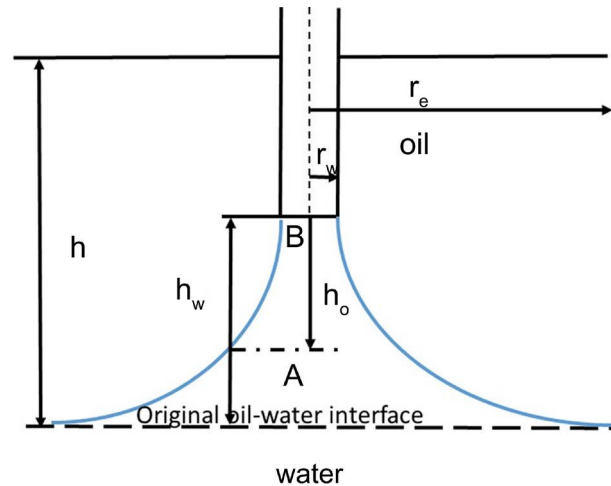
Figure 1. Hint chart of bottom water coning in bottom water reservoir.

permeability, permeability and interlayer on water cone falling ratio $H_D = h_o / h_w$ is simulated and calculated by using single factor analysis method. The relationship between water cone falling height H_D and shut in time (t) under single factor action is obtained

First of all, with the increase of t, H_D increases gradually, but the falling speed of water cone slows down gradually; secondly, ρ_o has obvious influence on the falling of water cone. The smaller ρ_o is, the larger H_D, the faster the falling speed of water cone at the initial stage. This is because ρ_o is the driving force of water cone falling. The smaller ρ_o, the greater the density difference between oil and water, and the more obvious the gravity difference. H_D is significantly affected by μ_o. With the increase of μ_o, H_D decreases, and the falling speed of water cone slows down. The viscosity of crude oil affects the flow capacity of crude oil. The larger μ_o, the worse the flow capacity. With the increase of H_i, H_D increases. The larger the H_i, the higher the water cone height is when the well is shut in, the greater the oil-water gravity potential energy, the faster the water cone falls back, and the higher the falling back height H_w At the same time, it can be seen from the curve that the falling height of water cone has a good positive correlation with reservoir thickness. With the increase of K and H_D, the faster the water cone falls back in the initial stage (see **Figure 2**). K determines the percolation capacity of formation fluid. The larger K is, the stronger the percolation capacity of oil and water, and the faster the differentiation speed of oil and water is under the action of gravity.

Using petrel-re software, a numerical model of bottom water reservoir with one horizontal well is established. The model adopts $40 \times 20 \times 50$ uniform grid system, Carter Tracy water body, grid size 2000 m $\times$ 1000 m $\times$ 50 m, vertically 1 - 15 layers are oil layers, and 15 - 50 layers are water layers.

Other parameters of the basic model are: water oil volume ratio is 100, reservoir thickness (H_i) is 15 m. The porosity is 30% and the horizontal permeability (K_h) is 3000 mD. The vertical permeability (K_v) is 300 mD. The initial oil saturation is 0.75 and the crude oil viscosity (μ_o) is 30 mPa·s. The density of crude
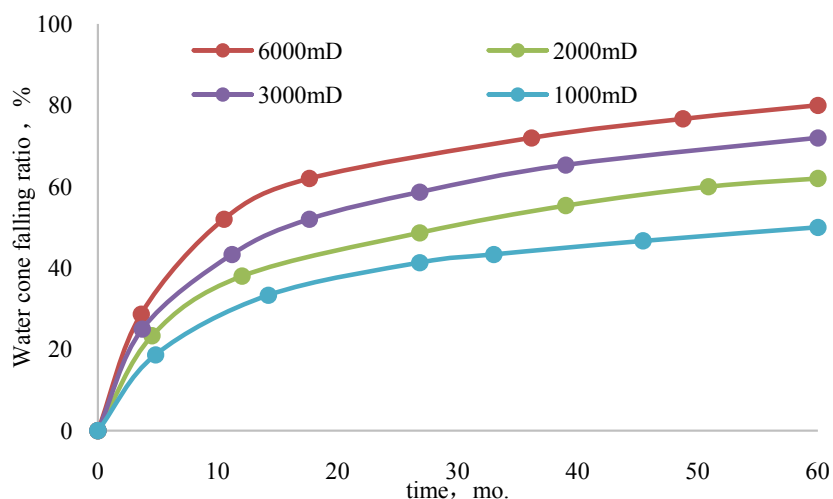
Figure 2. Water cone drop height at different horizontal permeability.

oil (ρ_o) is 950 kg/m³, and the apparent viscosity of formation water (μ_w) is 0.45 mPa·s, formation water density (ρ_w) is 1000 kg/m³. In the model, when the water cut of production well reaches 95%, shut in the well and press the water cone to simulate the water cone falling process of horizontal well in bottom water reservoir.

The interlayer blocks the fall of water cone (see **Figure 3**). Through analysis, it is concluded that the closer the interlayer is to the well, the slower the falling speed of the water cone is, and the lower the falling height H_w (see **Figure 4**).

3. Grey Relation Analysis

By analyzing the similarity or dissimilarity of the development trend of each factor, the grey relational analysis method measures and describes the degree of correlation between them. Compared with the statistical methods such as regression analysis, this method needs less data and requires less data. In the process of analysis, there will be no inconsistency between quantitative and qualitative analysis results. It is a simple and practical statistical analysis method. The steps include the determination of the original sequence, the processing of the original data, the calculation of the correlation coefficient, the calculation and sorting of the correlation degree, etc.

3.1. Original Sequence Determination

First of all, the qualitative analysis of the problem is carried out, and the original sequence is determined on this basis. The sequence consists of one dependent variable and several independent variables. Among them, the dependent variable factors reflect the behavior characteristics of the system, and the multiple sample data values of the factors constitute the reference sequence; the independent variable factors are the factors that affect the behavior characteristics of the system, and the multiple sample data values of each factor can form a comparison sequence (Nie, Zhou, Guo et al., 2013). The sequence is expressed as:
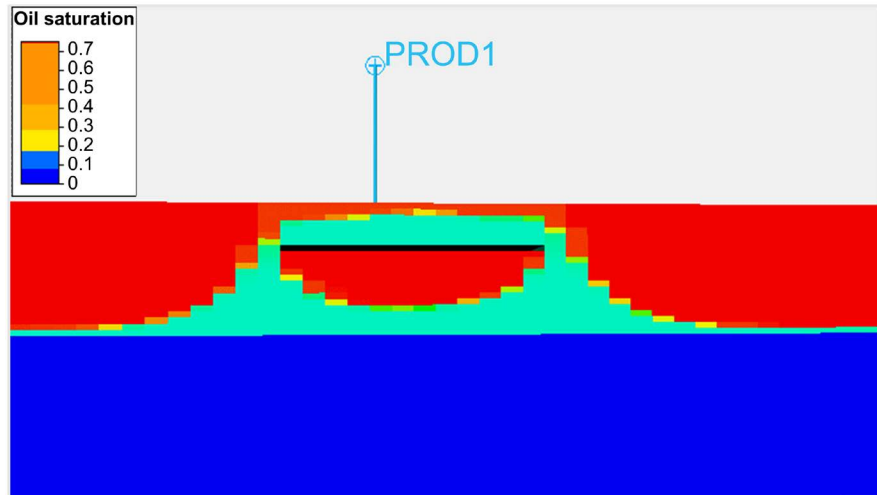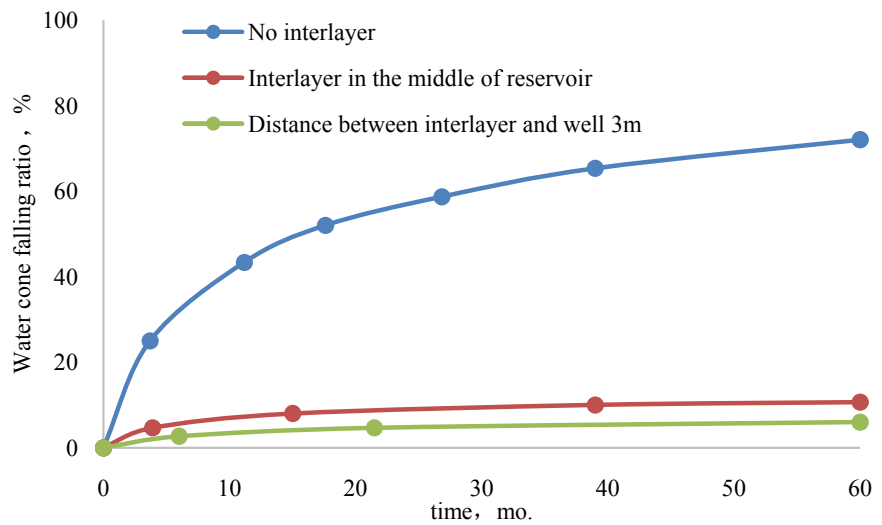
Figure 3. Effect of interlayer on water cone fall.

Figure 4. The drop height of shut-in water cone at different interlayer locations.

$$X_o = \left\{ X_o(1), X_o(2), X_o(3), \cdots, X_o(n) \right\} \tag{1}$$

$$X_i = \left\{ X_i(1), X_i(2), X_i(3), \cdots, X_i(n) \right\} (i = 1, 2, 3, \cdots, m) \tag{2}$$

where, X_o is reference sequence, X_i is Comparative sequence, i is Sequence number of comparison sequence, m is number of independent variable factors, n is Number of data samples in the series.

3.2. Raw Data Processing

Due to the different measurement units of each factor in the original sequence, the value size and change range of each original data are also different. If the original data is directly used for calculation and comparison, it is difficult to draw reasonable conclusions; therefore, the original data needs to be dimensionless processing. The commonly used dimensionless methods are initial value method and mean value method, and the calculation formulas are respectively:

$$Y_i(k) = \frac{X_i(k)}{X_i'} \tag{3}$$

$$Y_i(k) = \frac{X_i(k)}{\frac{1}{n}\sum_{k=1}^{n} X_i(k)} \tag{4}$$

where, $Y_i(k)$ is Dimensionless data, X_i' is Initialization reference value optimized according to a certain principle, k is Serial number of data sample in the series, $k = 1, 2, 3, \cdots, n$.

3.3. Calculation of Correlation Coefficient

Calculate the absolute difference between the reference sequence and the comparison sequence after dimensionless, and record the absolute difference between each sample value in the ith comparison sequence and the corresponding sample value in the reference sequence as:

$$\Delta_{0i}(k) = |Y_i(k) - Y_0(k)| \tag{5}$$

The maximum and minimum values of the absolute difference of each sample data in all comparison series are expressed as:

$$\Delta_{\max} = \max_{i=1,2,\cdots,m} \max_{k=1,2,\cdots,n} \left(\Delta_{0i}(k)\right) \tag{6}$$

$$\Delta_{\min} = \min_{i=1,2,\cdots,m} \min_{k=1,2,\cdots,n} \left(\Delta_{0i}(k)\right) \tag{7}$$

where, $\Delta_{\max}$ is Maximum absolute difference, $\Delta_{\min}$ is Minimum absolute difference.

The correlation coefficient between the ith comparison sequence and the reference sequence in the k-th sample is expressed as:

$$\xi_{0i}(k) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(k) + \rho\Delta_{\min}} \tag{8}$$

where, ρ is Resolution coefficient $\rho \in (0,1)$ usually take 0.5.

The role of ρ is to improve the significance of the difference between the correlation coefficients. The smaller the ρ value, the higher the difference between the correlation coefficients.

3.4. Correlation Calculation

If n correlation coefficients are simply used to reflect the correlation degree between the comparison sequence and the reference sequence, it is not easy to compare them as a whole due to the scattered correlation information; therefore, the correlation information is processed in a centralized way, and the average value of all sample correlation coefficients is used to quantitatively reflect the correlation degree between the sequence. The calculation formula is:

$$r_{0i} = \frac{1}{n}\sum_{k=1}^{n} \xi_{0i}(k) \tag{9}$$

where, r_{0i} is correlation between the i-th comparison sequence and the refer-

ence sequence.

The greater the degree of correlation, the more consistent the change between the comparison sequence and the reference sequence.

3.5. Weight Calculation

In order to more easily see the relative size of the correlation degree of each comparison sequence, the correlation degree is normalized to get the weight W_i of each comparison sequence, and the order of the weight is the same as that of the correlation degree.

$$W_i = \frac{r_{0i}}{\sum_{i=1}^{m} r_{0i}} \quad (10)$$

3.6. Relevance Ranking

The correlation degree or weight is arranged in a column according to the order of size to form the correlation order, reflecting the "primary and secondary" relationship between each comparison sequence and the reference sequence.

4. Grey Relation Analysis

The oilfield is a typical bottom water reservoir, with water cut of 96% and liquid production of 60,000 m^3/d limited by offshore platforms, well slots and equipment, the oilfield is unable to continue to extract liquid. In order to maximize the oil production of the oilfield, it is necessary to carry out the research on the strategy of high water content shut in pressure cone to let the liquid supply to low water bearing wells. The oil field is divided into more than 20 sand bodies from top to bottom, and the fluid properties and reservoir physical properties change greatly. Permeability is 1000 mD - 10,000 mD, crude oil viscosity is 3 - 325 cp, crude oil density is 800 - 980 kg/m^3, reservoir thickness is 10 - 25 m (Table 1). According to these factors, a total of $4 \times 4 = 16$ schemes can be formed.

Through the grey relation method, the weight of each factor is obtained (see Table 2).

Reservoir thickness and crude oil viscosity are the main factors affecting the effect of bottom water pressure cone (see Figure 5 and Table 2).

Considering that the purpose of well shut in pressure cone is to increase oil production, under the influence of different factors, the water cone is reduced by

Table 1. Values of different influencing factors in X Oilfield.

Factor	Crude oil density kg/m^3	Viscosity of crude oil mPa·s	effective thickness m	Permeability mD
1	980	325	10	1000
2	950	90	15	2000
3	900	30	20	3000
4	800	3	25	6000

Table 2. Influence weight of each influencing factor on shut in pressure cone.

Factor	Crude oil density kg/m³	Viscosity of crude oil mPa·s	effective thickness m	Permeability mD
Weight	0.223	0.257	0.275	0.245
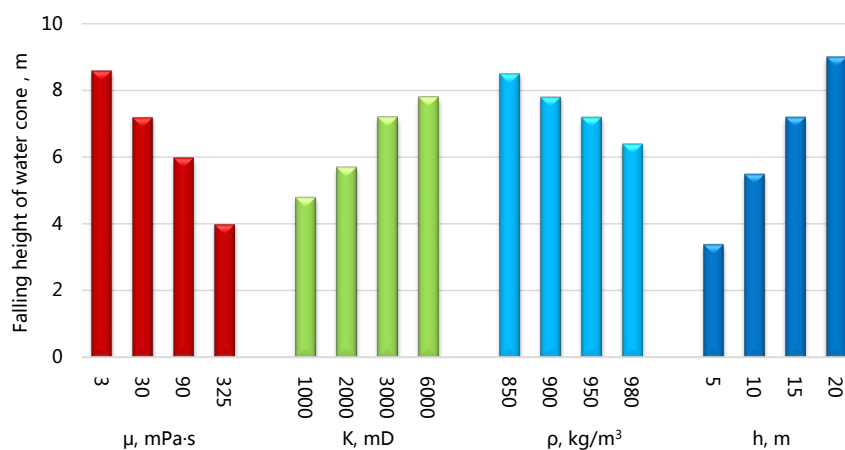
Figure 5. The influence of various factors on the falling height of water cone.
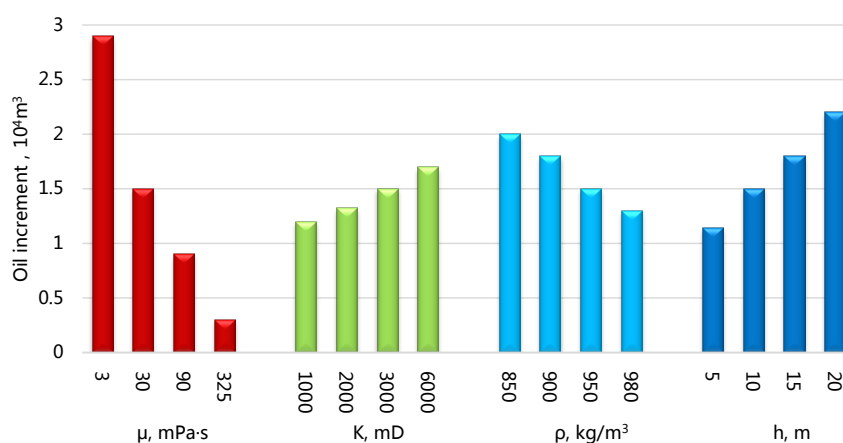
Figure 6. The influence of various factors on oil production.

5 m, the well is reopened to produce at a constant liquid output of 1000 m³/d, and the water cut is calculated to reach 98% of the corresponding oil production. Through the analysis, it is concluded that the fluid property is the main control factor (see Figure 6) that affects the effect of shut in coning pressure increasing oil production. When selecting the shut in coning pressure measures, the well with good fluid property is preferred.

5. Practical Examples

X oilfield is a typical oilfield with strong bottom water. The viscosity of formation crude oil is 40 mPa·s, the thickness of oil layer is 10 m, and the density of crude oil is 0.93 kg/m³. Well A1 has been shut in several times in history, and the water cut has decreased to varying degrees (Figure 7). From the surrounding
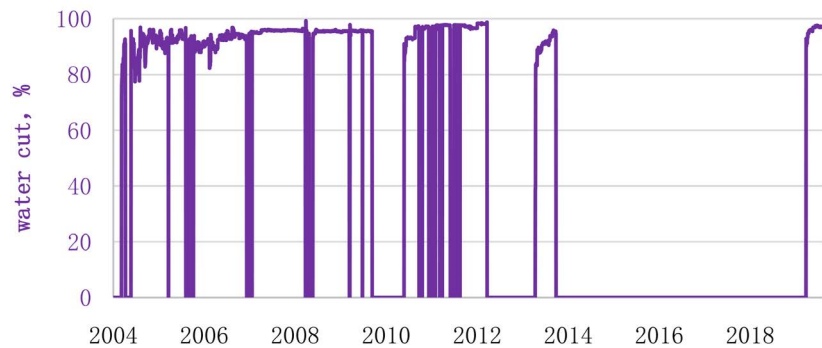
Figure 7. Water cut curve of well A1.

passing wells, the oil-water interface rises slightly during well opening, but falls back again after well closing.

6. Conclusion

Through numerical simulation, this paper analyzes the influence of different factors on the falling height of water cone, as well as the influence of precipitation and oil production after well shut in. At the same time, combined with the actual dynamic data, the fuzzy mathematics method is used to analyze the weight of each factor. The following conclusions are drawn:

1) The shut in pressure cone has the effect of increasing oil by precipitation, and has the characteristics of good initial effect and slow down later.

2) The well shut in period is more than 3 months, which has obvious effect of increasing oil by precipitation, but the effect of increasing oil by further precipitation is limited with the extension of shut in time.

3) For wells with different crude oil properties and reservoir physical properties, the effect of shut in pressure cone is obviously different: the smaller the crude oil density is, the better the effect of shut in pressure cone is; the smaller the crude oil viscosity is, the better the effect of shut in pressure cone is; the thicker the reservoir is, the better the effect of shut in pressure cone is, but the smaller the recovery ratio is; the greater the permeability is, the better the effect of shut in pressure cone is; The interlayer has a very strong barrier effect on the well shut in pressure cone, and the effect of the well shut in pressure cone is poor, and the fluid physical properties have a greater impact on the well shut in pressure cone effect. The reservoir with high density of crude oil, low viscosity, good permeability and large thickness should be selected.

This study provides the basis and guidance for the rational use of shut in pressure cone in the case of limited fluid volume.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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