Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2019, 7, 18-25
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Adjustment of Liquid Production in Reservoir with Handling Capacity Constraints

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How to cite this paper: Tan, J., Zhang, D., Yang, D. D., Mou, S. R., & Peng, Q. (2019). Adjustment of Liquid Production in Reservoir with Handling Capacity Constraints. *Journal of Geoscience and Environment Protection, 7,* 18-25.
https://doi.org/10.4236/gep.2019.74002

Received: March 16, 2019
Accepted: April 7, 2019
Published: April 10, 2019

Abstract

A oilfield was an oil reservoir with strong bottom water in offshore, the water cut was as high as 96%. In the high water cut stage, the most effective way of increasing oil production was to extract liquid and increase oil. The processing capacity of oilfield fluid was limited by the conditions. By using Petrel-RE-2017 software, combining reservoir engineering and percolation mechanics methods, this paper analyzes the effect of large-scale liquid pumping, expand coverage and shut-in coning in oil reservoirs with bottom water, and formulates the adjustment strategy of single well production structure of the whole oilfield. It was confirmed that large-scale liquid production can expand coverage and shutting down well can reduce water cut. It can provide reference and guidance for oil field with strong bottom water when it encounters bottleneck of liquid treatment capacity.

Keywords

Strong Bottom Water Reservoir, High Water Cut, Liquid Production Structure Adjustment, Maximum Liquid Production Capacity, Maximum Reasonable Pressure, Bottom Water Coning

1. Introduction

Usually, oil wells had been abandoned in the case of high water cut. So for oilfields with super high water cut and limited fluid, there was little research on what measures should be taken to increase oil production.

At the same time, existing studies had shown that under normal circumstances, a large amount of liquid extraction will cause water content to rise. And Liang Dan and others also analyzed that the increase in oil produced by shut-in cone killing was less than that produced by open-hole production, that is, shut-in cone killing was not conducive to oil increase, Liang, Zeng, & Fang (2012).

In this paper, through reservoir engineering and seepage mechanics combined with field technology and reasonable production system research, a reasonable allocation strategy was obtained for single well fluid production in offshore strong bottom water reservoirs. At the same time, through field experiments, it could achieve the effect of increasing oil.

2. Analysis of Maximum Fluid Production Capacity

In order to adjust the fluid production structure, firstly, it was analyzed whether a single well can increase the liquid production and the ability of extracting the liquid. The maximum liquid productivity of a single well was mainly affected by two aspects. One was the maximum reasonable differential pressure in a single underground well, the other was the limitation of pumps and ground equipment.

2.1. Analysis of Maximum Reasonable Pressure Analysis

Sand production will cause blockage in oil wells, seriously affecting the normal production of oil wells, so the differential pressure of oil wells should not exceed the critical sand production pressure. Mohr-Coulomb criterion, Zhou (2009):

$$\tau = C + \sigma \mathrm{tg}\theta \tag{1}$$

Minimum bottom hole pressure and critical bottom hole flowing pressure for sand production in oil wells P_{wcr} is:

$$P_{wcr} = \frac{\dfrac{2\sigma_{ZO}\mu_d + \left(1-2\mu_d\right)\beta P_e \sin\theta}{1-\mu_d} + 2C\cos\theta}{\dfrac{1-2\mu_d}{1-\mu_d}\beta - 2 + \dfrac{\sin\theta}{1-\mu_d}\beta} - \frac{\dfrac{2\sigma_{ZO}\mu_d}{1-\mu_d} + \dfrac{1-2\mu_d}{1-\mu_d}\beta P_e}{\dfrac{1-2\mu_d}{1-\mu_d}\beta - 2 + \dfrac{\sin\theta}{1-\mu_d}\beta} \tag{2}$$

where C is formation cohesion, the unit is MPa. σ_{ZO} is overburden strata pressure, the unit is MPa. μ_d is dynamic Poisson's ratio, the value is generally less than 0.25. β is Biot Constant of Porous Elastic Media. P_e is pressure at the outer boundary of the reservoir, the unit is MPa. θ is internal friction angle of formation.

The critical production pressure difference ΔP_{cr1} for sand production in reservoirs is:

$$\Delta P_{cr} = P_e - P_{wcr} \tag{3}$$

In addition, Li (2005) obtained from the experimental study that the bottom hole flow pressure was often lower than the saturation pressure during the production of oil wells. Local degassing occurs to the wellbore. With the release of dissolved gas, the volume of crude oil was compressed, and the degree of crude oil saturation decreases. With the increase in crude oil viscosity and oil-water viscosity ratio, water channeling will occur. With the increase in degassing range, production was not proportional to pressure difference. With the increase of pressure difference, production will decrease and degassing amount will reach a certain extent. With the increase in pressure difference, the increase in production will gradually reach zero, so the pressure difference of oil wells should not exceed the critical production pressure difference. The output formula for degassed crude oil is as follows:

$$Q_O = \frac{0.543K_h h}{\ln\left(\dfrac{a+\sqrt{a^2-\left(\dfrac{l}{2}\right)^2}}{\dfrac{l}{2}}\right)+\left(\dfrac{\beta h}{l}\right)\ln\left(\dfrac{\beta h}{2r_w}\right)}\int_{P_{wf}}^{P_r}\frac{K_{ro}}{\mu_o B_o}\mathrm{d}p \tag{4}$$

By solving the above formula (Formula (4)), the critical production pressure difference ΔP_{cr2} of different reservoirs is obtained.

The production pressure difference must satisfy the requirement of sand-free formation and be less than the critical production pressure difference. Finally, the low values of ΔP_{cr1} and ΔP_{cr2} are chosen as the critical pressure difference ΔP_{cr}.

By solving the critical pressure difference ΔP_{cr} of a single well, the maximum liquid production $Q_{\max 1}$ of a single well can be obtained.

2.2. The Study of Rational Production Allocation

In addition to geological reservoir factors, the fluid production of a single well was also affected by pumps and surface equipment. The fluid production of a single well was proportional to the rotational speed and frequency, Li (2002).

Given the current liquid production rate and frequency, the maximum liquid production rate of a single well $Q_{\max 2}$ can be calculated when the rated maximum frequency of the pump was known.

2.3. Maximum Fluid Production Capacity

The maximum liquid production of a single well should not exceed $Q_{\max 1}$ at critical pressure difference and $Q_{\max 2}$ at maximum pump frequency. The lowest value should be taken as the maximum liquid production $Q_{\max}$ of a single well.

3. Analysis of Shut-In Coning

In order to adjust the fluid production structure, Secondly, it is necessary to analyze the effect and time of the cone pressing.

The reason for bottom water coning was the pressure drop around the wellbore during the production of oil wells, and the oil-water interface will increase from the production of oil wells.

After shut-in, the gravity difference between formation water and oil gradually falls back to point A through the water at point B, thus forming the coning effect, Xiao, Li, & Xiao (2009). **Figure 1** was a sketch of shut-in coning. The time

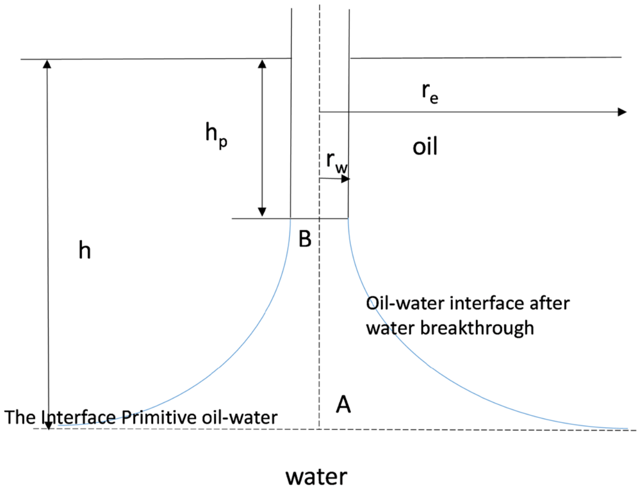


Figure 1. Sketch of shut-in coning. Where h is reservoir thickness, the unit is m. h_p is perforation thickness, the unit is m. The unit is m. r_e is reservoir boundary distance, the unit is m. r_e is well radius, the unit is m.

required for bottom water to fall back to the oil-water interface from the bottom of the well:

$$t_{BA} = \frac{\mu_W \varnothing \left(h - h_P\right)}{K \Delta \rho_{wo} g} \tag{5}$$

where t_{BA} is the time when bottom water falls back from bottom hole to crude oil-water interface, the unit is d. $\Delta\rho_{wo}$ is the formation water oil density difference, the unit is kg/m^3. g is gravity acceleration, the unit is m/s^2. μ_W is viscosity of water, the unit is mPa·s. $\varnothing$ is formation rock porosity, the unit is %. K is reservoir permeability, the unit is mD.

4. The Analysis of Rational Production Allocation

In order to develop oilfields at a high speed, oil production was the most important index. According to the specific conditions of oilfields, liquid production was limited, and can only be developed at a high speed by adjusting the structure of liquid production. Combined the lifting capacity and cone pressing effect of the 2, 3 part analysised, and considered the conditions of field implementation at the same time, Kang, Feng, & Li (2011). The development strategy was given as follows:

1) Increase fluid production of low water cut wells. Considering the influence of sand production and degassing on production, and combining with the limitations of pumps and field equipment, the maximum liquid production is given.

2) High water cut wells are shut down to allow fluid and cone pressing at the same time. By calculating the time required for bottom water to fall back to the oil-water interface from the bottom of the well, the opening time can be determined. After well opening, reopening will take part in a new round of fluid production structure adjustment, Wang, Cheng, & Cheng (2011).

3) By calculating the maximum fluid volume of each well, the oil wells with

lower water cut are selected as far as possible for fluid extraction, and the hydraulic cone is shut down with high water cut. It is necessary to calculate the time required for each well bottom water to fall back to the oil-water interface, so as to determine the opening and shutting time of each well. The combination of the two forms a strong bottom water offshore reservoir, and the adjustment strategy of fluid production structure of the high water cut stage is limited by fluid volume, Clark & Pilehvari (1993).

5. The Analysis of the Field Test Result

Take A oilfield as an example, A oilfield is an offshore strong bottom water reservoir with a structural range of only 35 m and an effective thickness of only 20 m. Under the condition of high-speed development, water cut rises very fast. The average time for water cut to reach 90% in a single well is only three months. The oilfield has been exploited for 15 years, and the water cut is as high as 96%, and the daily liquid production is as high as 40,000/day. Due to limited offshore facilities, the liquid treatment of the oilfield has been completed. Saturated, unable to increase oil through liquid extraction.

5.1. Selection of the Wells with Liquid Extraction Production

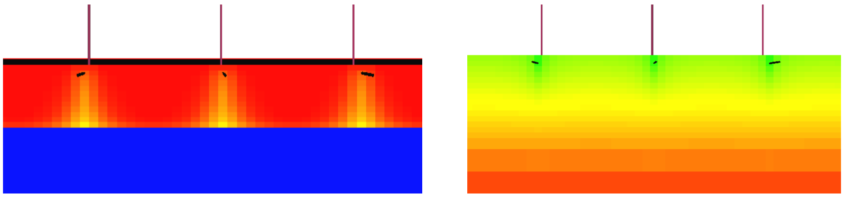
According to the previous analysis of the maximum liquid production capacity, the critical pressure of sand production and degassing for all single wells in A oilfield are calculated Clark & Pilehvari (1993). The maximum liquid production under the maximum bottom hole flow pressure is calculated by choosing the low value as the maximum bottom hole flow pressure. Combining with the maximum liquid production under the limit of single well pump and ground equipment, the low value is selected as the maximum liquid production of single well, and finally the space for liquid extraction and water cut are selected. Relatively low (water cut less than 96%) wells carry out fluid extraction (**Table 1**).

5.2. The Increment of Oil Production under the Condition of Increase Liquid Production

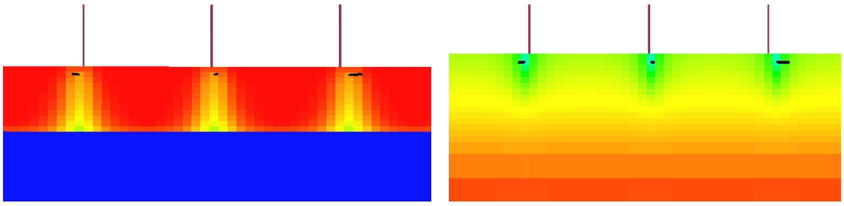
Through field experiments, the production of B well has been greatly increased from 1700 cubic metres per day to 2761 cubic metres per day, the daily oil production has increased by 73 cubic metres meters, and the water cut has decreased by 1.4%. And through Petrel-RE-2017 mechanism model, the influence can be extended by extracting liquid to increase oil production (**Figure 2**).

Statistical analysis shows that in the history of A oilfield, the average change rate of water cut is 0.08% (**Figure 3**), which has little effect. Therefore, the influence of liquid extraction on water content change is neglected.

By calculating the fluid increment of a single well after lifting, assuming that the water cut is constant, the oil increment of a single well is proportional to the fluid increment. Thus, the oil increment after single well lifting is calculated to



Differential pressure 0.6 MPa



Differential pressure 0.9 MPa

Figure 2. Scope of sweep under different pressure difference.

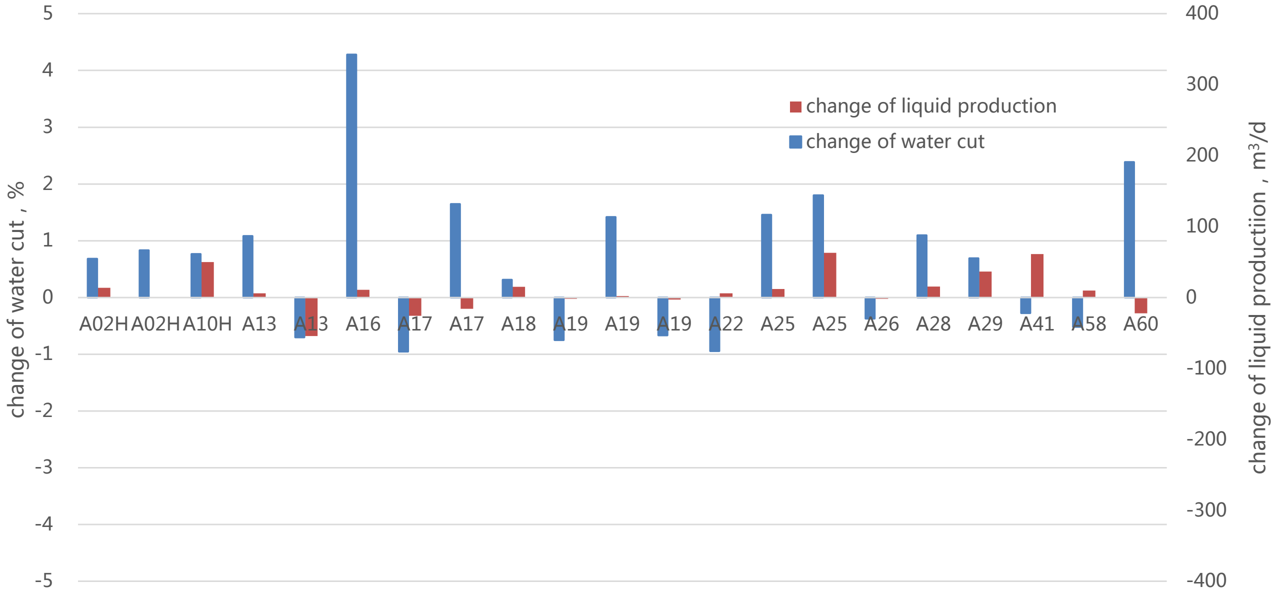


Figure 3. Chart of influence of liquid yield change on water content change caused by frequency increase/frequency decrease.

Table 1. Single well maximum fluid production scale of an oil field.

Serial number	Well number	differential pressure MPa	Critical pressure of sand production MPa	Degassing critical pressure MPa	Maximum bottom hole flow pressure MPa	Fluid production under maximum bottom hole flowing pressure m³/d	Maximum liquid production at maximum frequency m³/d	Current liquid production m³/d	Maximum liquid production m³/d
1	C07	2.2	3.2	6.3	3.2	850	1230	519.5	850
2	C27	0.8	4.9	5.8	4.9	5000	1900	853.7	1900
3	C29	0.6	4.5	6.8	4.5	4800	1800	666.7	1800
4	C68	3.5	4.3	5.2	4.3	650	860	530.6	650
5	C59	3.5	4.2	5.5	4.2	1300	1832	1100.8	1300
6	C40	2	3.9	5.4	3.9	850	1423	428.6	850
Total								4099.9	7350

be 139.0 m^3/d (**Table 2**).

An oil field is now in a saturated state of liquid handling capacity. The total of 3250.1 m^3/d of fluid is extracted from 6 wells in **Table 2**. Some wells need to let off fluid. In order to achieve the goal of high-speed development of offshore oilfields, all wells in A Oil field were sorted according to water cut, and the highest water cut wells (**Table 3**) were selected to shut down and let off fluid. 6 wells will increase oil production by 139.0 m^3/d and shut down 3 wells, resulting in a loss of 38.3 m^3/d. Finally, reasonable allocation of liquid yield per well is adopted to increase oil production. After shutdown of high water wells, after a certain period of gravity coning, re-opening takes part in a new round of fluid production structure adjustment.

6. Conclusions

Based on reservoir engineering and seepage mechanics combined with field technology, the adjustment of production structure in A oilfield was studied, and the following conclusions and understandings were obtained:

1) By analyzing the influence of sand production and degassing on single well production, the maximum reasonable pressure difference of single well was obtained.

Table 2. Oil increment after single well lifting in an oil field.

Serial number	Well number	Production status				Oil increment based on the pump		
		Water cut %	Oil production m^3/d	Liquid production m^3/d	Frequency Hz	Maximum liquid prodution of current pump m^3/d	Fluid increment based on current pump capacity m^3/d	Oil increment based on current pump capacity m^3/d
1	C07	95.9	21.3	519.5	54.9	850	330.5	13.6
2	C27	95.9	35	853.7	45	1900	1046.3	42.9
3	C29	95.8	28	666.7	52	1800	1133.3	47.6
4	C68	96	21.4	530.6	51.9	650	119.4	4.8
5	C59	95.2	53.3	1100.8	55	1300	199.2	9.6
6	C40	95.1	21	428.6	55.1	850	421.4	20.6
Total				4099.9		7350	3250.1	139.0

Table 3. A oil field shut-in coning.

Serial number	Well number	Oil production m^3/d	Liquid production m^3/d	Water cut %
1	C73	12.4	1000.0	98.8
2	C76	13.6	1134.0	98.8
3	C1	12.3	1150.0	98.9
Total		38.3	3284.0	

2) The maximum liquid yield of a single well was not only related to fluid and reservoir physical properties, but also limited by pumps and surface equipment. The maximum liquid yield of a single well was obtained by comprehensive analysis.

3) In high water-cut oilfields, single well frequency-raising or frequency-lowering would increase and decrease the fluid production proportionally, but it has little effect on water cut.

4) The cause of bottom water coning in high water wells was the pressure drop around the wellbore during production, which was helpful for coning by shutting down the wellbore.

5) A strategy of adjusting production structure is provided to increase and stabilize oil production in the case of limited fluid volume.

In this paper, through the study of fluid production structure adjustment, under the circumstance of limited fluid treatment in the oilfield, it provides a scheme for formulating and implementing fluid production structure adjustment in the oilfield, and realizes increasing and stabilizing oil production under the condition of constant fluid production in the oilfield, provides reference and guidance for oil field production when it encounters bottleneck of liquid handling capacity.

Conflicts of Interest

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

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