Decision-Making for Well Liquid Control Based on A New Oil Production Index

Depei Shi 1, Songjiang Dou 2, Lianmin Li 2, Tao Li 2, Min Jing 3,*

1CNPC oil-gas Exploration & development corporation, Beijing, China
2PetroChina Dagang Oilfield Company, Tianjin, China
3College of Energy, Chengdu University of Technology, Chengdu, China

*Corresponding author e-mail: Jing50162@stu.cdut.edu.cn

Abstract. In view of the problems of water cut rising too fast and liquid level keeping unreasonable in many oil wells in oilfield production, a comprehensive evaluation study on the reasonable liquid production capacity of oil wells is carried out. Based on the productivity formula, a dimensionless production capacity evaluation model is established by comparing the potential production capacity with the actual production rate. The reasonable liquid production potential is related to the meter oil production index liquid production potential related to water cut, the effective thickness liquid production potential related to sedimentary facies, and the production differential pressure liquid production potential related to liquid level. The comprehensive evaluation system of reasonable liquid volume is formed, and the main factors influencing the liquid production capacity are proposed through orthogonal test analysis, and the reasonable fluid adjustment scheme is determined through comprehensive evaluation. The reasonable liquid production capacity of oil wells in s Oilfield at present is put forward. Good development effect has been achieved after field implementation, which ensures high and stable production of s Oilfield for 5 years. This method has practical guiding significance for evaluating fluid production potential and maintaining high efficiency production.

1. Introduction

In the early stage of oilfield development, the production system of single well is generally formulated according to the understanding of geological data in the early stage, and the data of early oil test and production test. Due to the relatively small amount of preliminary data and limited reservoir knowledge, with the development of the oilfield, there are some problems such as the water cut of some wells rising too fast, or the liquid supply is insufficient or the liquid level is too high. In order to ensure the efficient production of the oilfield, it is necessary to adjust the liquid amount of the oil well.

At present, the adjustment of oil well fluid volume is mainly accomplished by fluid extraction. Usually, the dimensionless oil production and liquid production index are used to determine the reasonable fluid extraction time[1-3]. Or the extraction can be determined mainly according to the production performance of the oil well[4-6]. Some people also give extraction parameters and determined the weight coefficient to evaluate the extraction potential[7-9]. Or, through means of complex numerical modeling methods, multiple schemes can be used to compare and study reasonable
extraction timing, extraction amplitude and oil-increasing regularity of the reservoir[10-12]. Some oil fields in China have obtained certain oil increase effect with this method.

In a word, in areas lacking basic data such as phase permeability, numerical simulation and other methods lack credibility, and only considering dynamic characteristics of oil well production or artificially designated parameters for evaluation leads to incomplete considerations and unsatisfactory extraction effect [13]. Therefore, a new scale evaluation model of oil well liquid production capacity is established, which can pay equal attention to liquid extraction and water control, and achieve long-term stable production of oil field.

2. New dimensionless liquid production potential index was proposed

2.1. Dimensionless liquid production potential index

In the early stage of oilfield production, the production capacity formula is generally used to calculate the reasonable production of oil wells[14]. According to the production capacity formula, the actual production of oil well can be calculated by the formula:

$$Q_{oa} = J_{oa}(f_{wa}) \cdot H_{ea} \cdot \Delta P_a$$  (1)

In the formula, $Q_{oa}$ is the actual production, m$^3$/d; $J_{oa}(f_{wa})$ is practical rice productivity index under different water cut, m$^3$/d/MPa; $H_{ea}$ is the actual utilized effective thickness, m; $\Delta P_a$ is actual production pressure difference, MPa.

With the development going on, we have a further understanding of the reservoir based on the dynamic data, and some development indicators of the oil well are changing. At this time, the potential production of the oil well can be calculated by the following formula:

$$Q_{op} = J_{op}(f_{w}) \cdot H_{ep} \cdot \Delta P$$  (2)

Where, $Q_{op}$ is the potential yield, m$^3$/d; $J_{op}(f_{w})$ is potential under different water cut meter productivity index, m$^3$/d/MPa; $H_{ep}$ is the potential effective thickness, m; $\Delta P$ is reasonable production pressure difference, MPa.

In order to quantify the potential of reservoir fluid flow adjustment, the potential production of a well can be compared with the current actual production, which can facilitate the adjustment of fluid production, and the dimensionless extraction potential of a well can be defined:

$$IL_{p} = \frac{Q_{op}}{Q_{oa}} = \frac{J_{op}(f_{w})}{J_{oa}(f_{wa})} \cdot \frac{H_{ep}}{H_{ea}} \cdot \frac{\Delta P}{\Delta P_a}$$  (3)

Where, PIL is the extraction potential without dimension.

To:

$$J_{p} = \frac{J_{op}(f_{w})}{J_{oa}(f_{wa})}, \quad H_{p} = \frac{H_{ep}}{H_{ea}}, \quad \Delta P_{p} = \frac{\Delta P}{\Delta P_a}$$  (4)

In the formula, $J_{op}$ is the exponential extraction potential of oil production in meters, dimensionless. The dimensionless liquid production potential can be simplified as:

$$IL_{p} = J_{p} \cdot H_{p} \cdot \Delta P_{p}$$  (5)

Where, $H_{p}$ is the extraction potential of effective thickness, dimensionless; $\Delta P_{p}$ is producing pressure differential fluid potential, dimensionless.

For this reason, the dimensionless fluid production potential index of oil Wells mainly includes three factors: rice production potential, effective thickness potential and production pressure differential potential.
2.2. Physical significance of dimensionless extraction capacity value

2.2.1. Oil production index liquid production potential. If the change of reservoir permeability is not taken into account in the development process, the dimensionless oil production index and fluid production index are calculated by the following formulas:

\[ J_0(f_w) = \frac{K_{ro}(S_w)}{K_{rmax}}, \quad J_L(f_w) = \frac{J_0(f_w)}{1-f_w} \]  

Where, \( J_0(f_w) \) is dimensionless oil production under different water cut, the dimensionless; \( K_{ro}(S_w) \) is different water saturation of oil phase relative permeability and dimensionless; \( K_{rmax} \) is the maximum relative permeability of oil phase, dimensionless; \( f_w \) is theoretical water content, dimensionless; \( J_L(f_w) \) is fluid productivity index under different water cut, dimensionless.

In this way, the dimensionless rice production index liquid production potential ratio can be calculated by the formula:

\[ J_p = \frac{J_{lp}(f_{wa})(1-f_w)}{J_{la}(f_{wa})(1-f_{wa})} \] 

\[ f_{wa} = \frac{1}{1+(\mu_w/\mu_o)(K_{ro}(S_w)/K_{rw}(S_w))} \]

In the formula, \( f_{wa} \) is the actual water content, dimensionless; \( \mu_w \) is water viscosity, mPa·s; \( \mu_o \) is oil viscosity, mPa·s; \( K_{rw}(S_w) \) is different water saturation of water phase relative permeability and dimensionless.

Based on the phase permeability data of similar oilfields in this area and adjacent areas, the dimensionless production fluid and oil production capacity curves are calculated and solved. Reservoirs with different permeability have different variation characteristics (Fig. 1). Based on different dimensionless production fluid, oil production curves and water cut, the evaluation and analysis of oil production potential with rice production index can be carried out.

![Figure 1. Dimensionless fluid production and oil production capacity](image)

2.2.2. Liquid production potential of effective thickness. During the development process, the effective thickness fluid production potential is mainly reflected in the continuous production capacity of the reservoir, which is determined by the permeability capacity of the reservoir. The permeability of reservoir is usually related to reservoir physical properties, microscopic pore structure characteristics, capillary pressure, reservoir heterogeneity, etc., which is mainly represented by reservoir flow unit (FZI) and reservoir coefficient. Flow zone index (FZI) is an important method for the division of flow units (Equation 9). The reservoir coefficient is mainly reflected by the oil status of the reservoir (Equation 10).

\[ FZI = \frac{1-q_e}{q_e} \sqrt{\frac{K}{q_e}} \]  

\[ R_c = q_e \cdot h \cdot S_o \]
∅ is effective porosity type, %; h is the effective thickness, m; S₀ is oil saturation, dimensionless decimal; K is permeability, 10⁻³μm²;

The study of the project shows that the distribution of flow units and reservoir coefficient have a good correlation with the distribution of different sedimentary microfacies[17]. Researchers will Niger S oilfield reservoir flow unit is divided into five types, its sedimentary types of delta front deposition (Table 1), including I class and II class reservoir flow units better properties, mainly distributed in underwater distributary channel and debouch bar microfacies; III class and IV class medium, reservoir physical property is mainly distributed in interchannel and sand sheet; V class worst reservoir property, mainly for the underwater distributary channel between sedimentary type. In other words, the permeability of reservoir is mainly controlled by the sedimentary environment [15]. The liquid production potential of effective thickness is actually a function related to sedimentary microfacies.

Table 1. Percolation capacity of different microfacies in front delta sediments

| Type of flow unit | Types of sedimentary microfacies | Storage coefficient | FZI index |
|------------------|---------------------------------|---------------------|----------|
| I class          | Subaqueous distributary channel | 100                 | 1.2-2.53 |
| II class         | River mouth dam                 | 40                  | 0.75-1.2 |
| III class        | The river edge                  | 18-40               | 0.5-0.75 |
| IV class         | Sand sheet                      | 10-18               | 0.32-0.5 |
| V class          | Interchannel                    | <10                 | <0.5     |

2.2.3. Differential pressure extraction potential ratio in dimensionless production. During production, the potential for differential production pressure is directly reflected in the degree of submergence in the well. Too small submergence not only leads to a short pump inspection period, but also difficult to maintain long-term stable production of the oil well, resulting in a small potential pressure difference in fluid production; If the submerging is too large, it will not only increase the load of the pumping unit, but also waste the potential production of the oil well, and the differential pressure potential of the produced fluid production has a great potential. It is shown that the differential pressure regulation potential of a well can be defined by the ratio of the current submergence to the reasonable submergence. Equation 11 can be used to calculate:

\[ \Delta P = \frac{\Delta P}{\Delta P_a} = \frac{\rho_L \cdot g \cdot (h - DFL)}{\rho_L \cdot g \cdot (h - DFL_a)} = \frac{h - DFL}{h - DFL_a} \]

(11)

Where, DFL is the reasonable moving fluid level and DFL_a is the actual moving fluid level, m.

2.2.4. Dimensionless liquid production potential index. Therefore, the dimensionless extraction potential can be calculated by

\[ IL_p = \frac{J_{L_p}(f_{wa})(1-f_{wa})}{J_{L_a}(f_{wa})(1-f_{wa})} \cdot F_{(SM)} \cdot \frac{h - DFL}{h - DFL_a} \]

(12)

Where, \( F_{(SM)} \) is the extraction potential of dimensionless sedimentary microfacies;

3. Comprehensive evaluation system of reasonable liquid production capacity of oil well

3.1. Quantitative evaluation of extraction capacity factors

The main parameters that affect the liquid volume adjustment effect have the potentiality of production pressure difference, oil production index, effective thickness and so on, and these factors will affect the liquid extraction effect to different degrees. Considering the actual production, the water cut grade is
usually divided into 5 levels (Table 2). The microfacies in delta front can also be divided into five kinds: underwater distributary channel, mouth bar, channel margin, sheet sand and interchannel sediment. Based on reasonable submergence degree, the actual submergence degree and its ratio can be normalized and divided into five levels. Therefore, the influence of three factors and five levels on the extraction effect can be analyzed. Simple and operable orthogonal experimental design method was adopted to study the influence degree of each factor, and L15(56) orthogonal experiment was used for analysis.

### Table 2. Influencing factors and levels of fluid production potential in the front Delta

| Factors                  | Dimensionless submergence | Water/% | Types of sedimentary microfacies             |
|--------------------------|---------------------------|---------|----------------------------------------------|
| A kind of level          | >2                        | <2      | Subaqueous distributary channel              |
| Second Three kinds of level | 1-2                     | 2-20    | River mouth dam                              |
| Three kinds of level     | 1                         | 20-60   | The river edge                               |
| Four kinds of level      | 0.51                      | 60-90   | Sand sheet                                   |
| Five kinds of level      | <0.5                      | >90     | Interchannel                                 |

Through range analysis, it is found that the range of submergence reaches 2.96, which is the main factor affecting liquid production capacity. The order of factors affecting liquid production capacity is as follows: submergence > water-bearing BBB > sedimentary microfacies; submergence is the main factor deciding whether to adjust liquid volume; the influence of sedimentary microfacies and water content is relatively small. Therefore, the submergence parameters of the pump in the study area can be selected, and the reasonable liquid regulation scheme can be determined by comprehensive evaluation considering the sedimentary microfacies and water cut factors (see Figure 2).

3.2. Advantage of dimensionless extraction capacity value

Dimensionless fluid potential than associated with water can be decomposed into the rice productivity index of fluid potential, the effective thickness of the sedimentary facies related fluid potential, as well as the working fluid level related production pressure differential fluid potential, water cut, sedimentary facies, as well as the working fluid surface function, involving the development geology, reservoir performance, engineering process, relatively comprehensively considering the main influence factors in the development process.

The new evaluation method of single well fluid production capacity follows the reservoir productivity formula and makes the parameters dimensionless, which can not only quantitatively...
describe the various influencing parameters in the process of reservoir development, but also eliminate
the problem that the artificial control factors may lead to the distortion of the calculation results.

4. Study area application effect

4.1. Necessity analysis of liquid volume adjustment
Niger S oilfield for the shallow, middle and high permeability, conventional thin oil is given priority to
strip off base oil reservoir, the early use of natural energy development, reservoir after the production
of natural energy is stronger, have confirmed that side of the fault sealing ability is poorer, the well
working fluid level between 10-480 - m, the output elasticity is 49.2, each produced 1% geological
reserves of pressure drop of 0.065 MPa, belong to the category of natural energy is strong. In order to
maintain stable production and benefit development, it is necessary to evaluate the fluid production
potential of a single well and select a reasonable working system based on the premature water
breakthrough and large production decline of oil Wells in the reservoir edge.

4.2. Evaluation of fluid production potential of single well
Based on the phase permeability data of similar oilfields in this area and adjacent areas, the
dimensionless fluid recovery and oil recovery capacity is evaluated. The evaluation results are shown in
Figure 1.For the medium and high permeability reservoir, when the water cut is less than 10%, the
extraction potential is larger, and the water cut is higher than 70%, followed by the extraction capacity.
When the water cut is 10-70%, the extraction capacity is relatively small.

Sedimentary reservoir evaluation shows that 6 Wells are located in distributary channel microfacies,
4 Wells are located in channel lateral microfacies, and 2 Wells are located in sheet sand microfacies.The
distributary channel microfacies oil reservoir is thick, homogeneous and has good reservoir physical
properties. The interchannel microfacies is the second. The thickness of sheet sand microfacies oil layer
is relatively thin and the reservoir physical property is poor.

First, the submergence degree of each well is calculated through the dynamic fluid level, and then
the reasonable submersible reservoir characteristics, oil well production, fluid physical properties and
electric pump parameters are calculated. By comparing the submergence degree of a single well with
the theoretical dynamic fluid level, the production differential pressure extraction potential was
optimized (Table 1). According to the comprehensive evaluation of fluid production potential, there were
4 Wells with low extraction potential, 4 Wells with medium extraction potential and 4 Wells with high
extraction potential.

| Well | Water potential (dimensionless) | Sedimentary factor potential (dimensionless) | Production differential pressure potential (dimensionless) | Comprehensive potential (dimensionless) | Potential evaluation |
|------|-------------------------------|------------------------------------------|--------------------------------------------------------|--------------------------------------|---------------------|
| S-1  | 0.30                          | 1.00                                     | 1.98                                                   | 0.60                                 | Low                 |
| S-2  | 0.75                          | 1.00                                     | 1.84                                                   | 1.38                                 | Middle              |
| S-4  | 0.40                          | 1.50                                     | 1.99                                                   | 1.20                                 | Middle              |
| S-6  | 1.00                          | 0.50                                     | 2.12                                                   | 1.06                                 | Middle              |
| S-8  | 0.20                          | 0.50                                     | 1.49                                                   | 0.15                                 | Low                 |
| S-9  | 1.50                          | 1.50                                     | 2.06                                                   | 4.64                                 | High                |
| S-10 | 1.00                          | 1.50                                     | 2.06                                                   | 3.09                                 | High                |
| S-11 | 0.40                          | 1.00                                     | 1.99                                                   | 0.79                                 | Low                 |
| S-12 | 0.40                          | 1.50                                     | 1.90                                                   | 1.14                                 | Middle              |
| S-13 | 1.50                          | 1.00                                     | 2.05                                                   | 3.07                                 | High                |
| S-14 | 1.50                          | 1.50                                     | 2.05                                                   | 4.60                                 | High                |
| S-15 | 0.40                          | 1.50                                     | 1.56                                                   | 0.94                                 | Low                 |
4.3. Implementation effectiveness

According to one well and one strategy, a reasonable lifting mode and production system should be optimized. High-potential oil Wells are recommended to switch to large pumping system for extraction production, medium-potential oil Wells are recommended to switch to large pumping system for extraction production, and Wells with relatively small potential are recommended to adopt no extraction or reduced fluid production. After the implementation of the adjustment of 12 Wells, the daily oil production of the oilfield increased by 319.27m³/d, and the water-cut rise rate was effectively controlled. Based on the decision method of extraction and well selection, the dynamic management measures have been continuously optimized in the process, and the high and stable production has been maintained for 5 years in this oilfield, which also proves that the method is economical and effective.

5. Conclusion

(1) The dimensionless fluid production capacity evaluation model was established, and it was proposed that the dimensionless fluid production potential ratio was a function of water cut, sedimentary facies, and dynamic fluid level, which reflected the multi-factor characteristics of development geology, reservoir performance, and technology, and could accurately quantify the fluid production capacity, eliminating the influence of human factors.

(2) The comprehensive evaluation system of reasonable liquid quantity was formed. Through orthogonal test analysis, it was proposed that the main factor affecting the liquid production capacity was the degree of submergence. At the same time, considering the factors of sedimentary reservoir and water cut, the reasonable liquid adjustment scheme was determined by comprehensive evaluation.

(3) This decision method was applied to Niger S oilfield, and the field practice shows that it has good adaptability, simple and reliable, which is helpful to the efficient development of oil field and provides a reference for large-scale promotion.

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