Study on Evaluation Method of System Efficiency of Pumping Wells

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Abstract. For a long time, there is no unified method and standard for efficiency analysis and evaluation index of pumping well system. Therefore, this paper studies the theoretical extreme value of pumping well system efficiency. Based on the model of system efficiency evaluation method, the single factor analysis and comprehensive impact analysis are carried out, and a set of simple and convenient evaluation method of pumping well system efficiency is found out by using examples. It provides strong technical support for relevant technical departments and different oil production units to reasonably formulate measures and plans.

Keywords: Pumping well; System efficiency; Extreme value; Evaluation.

1. Introduction

Rod pumping is one of the traditional mechanical oil production methods in the domestic and foreign petroleum industry, and it is also the artificial lifting method which has been absolutely dominant in the mechanical oil production. Many years of research work has accumulated rich experience in lifting design, working condition diagnosis, system efficiency analysis and other aspects of pumping wells, and formed a preliminary method of design, diagnosis test, and sensitivity analysis of system efficiency parameters. However, due to the different well conditions of each well, how to use a simple and convenient evaluation method to accurately reflect the working conditions of pumping wells, the level of system efficiency, and the amount of potential improvement needs to study the evaluation technology that can accurately reflect the system efficiency of pumping wells.

The main purpose of this work is to further study the technology of improving the efficiency of pumping well system, and through the analysis of the potential efficiency of the system, to realize the scientific evaluation of the efficiency of single well and block pumping well system. To provide scientific and accurate evaluation indexes that are in line with the actual situation and good technical and economic performance. So as to guide the design and implementation of field plan and measures, improve the understanding level of technical management and operation departments at all levels on the efficiency status and potential of pumping well system, and finally achieve the purpose of high-level management and application of oil production technology of pumping well in the whole oilfield.
2. System Efficiency Evaluation Model

2.1. Applicable Scope of the Model
This model assumes that:

a) Homogeneous reservoir with constant water saturation;

b) It is not ultra-low permeability reservoir or super heavy oil;

c) Neglecting the compressibility of rock and water;

d) The pressure of oil and gas is the same;

e) Quasi steady state flow;

f) Ordinary beam pumping unit;

g) The downhole friction is normal;

h) The pump works normally;

The model is suitable for vertical well, directional well, not heavy oil thermal recovery well (viscosity of degassed crude oil at 50 °C is less than 500mPa.s), daily liquid production is less than 200m3/d, and production GOR is less than 640m3/t.

2.2. Single Factor Analysis Results
The main factors that affect the efficiency of pumping well system obtained from single factor analysis include stroke, flushing times, well depth, pump diameter, viscosity, water cut, gas oil ratio, production and effective lifting height. In order to refine the classification, the influencing factors are divided into three categories: first, the natural factors of oil well, including well depth, viscosity, water cut, gas oil ratio, well bore structure; second, the human adjustable factors, including stroke, impulse, pump diameter, pump depth, rod string combination, motor power; third, the natural factors of oil well and the factors considered adjustable are related, including production and effective lifting height.

2.3. Comprehensive Relationship between System Efficiency and Influencing Factors
According to single factor analysis, the comprehensive relationship between system efficiency and influencing factors is analyzed.

a) Using the formula \( Q = 10t / d \), when \( f_w = 0 \), the corresponding relationship between efficiency, viscosity, gas oil ratio is established, and a new dimensionless physical quantity (oil gas comprehensive quantity) is constructed \( Z_{ru} \) (1). A new dimensionless physical quantity oil gas comprehensive quantity is constructed by using graph normalization, regression is made by using the least square principle, the relationship between system efficiency and oil gas comprehensive quantity is constructed (2). And finally the relationship between efficiency and viscosity, production gas oil ratio is obtained (3) (4).

\[
Z_{ru} = \frac{R}{R_{max}}
\]

\[
\eta = 0.384e^{-1.2997Z_{ru}}
\]

\[
Z_{ru} = \frac{R}{R_{max}}
\]

\[
R_{max} = -1 \times 10^{-5} u_o^2 - 0.0219u_o + 364.4
\]

b) When \( Q = 10t / d \), compare the relationship between oil and gas comprehensive quantity and system efficiency with \( f_w = 20\% \), \( f_w = 40\% \), \( f_w = 60\% \), \( f_w = 80\% \) in the same coordinate, and get the relationship between oil and gas comprehensive quantity and system efficiency with...
different water cut as shown in Figure 1

![Figure 1](image1.png)

**Figure 1.** Relationship between comprehensive oil and gas quantity $Z_{ru}$ and system efficiency.

c) Based on the principle of normalization and least square method, the relation curve between the system efficiency and the comprehensive quantity of oil, gas and water is obtained as shown in Figure 2.

![Figure 2](image2.png)

**Figure 2.** Relationship between system efficiency and comprehensive oil, gas and water quantity.

The corresponding formula is:

$$ \eta = 0.36 e^{-1.2783Z_{ru}} $$

(6)

The comprehensive quantity $Z_{ru}$ of oil, gas and water is:

$$ Z_{ru} = Z_{ru}/Z_{ru\ max} $$

(7)

The corresponding relationship between the maximum comprehensive oil and gas quantity and water cut is as follows:

$$ Z_{ru\ max} = 0.1301 f_w^2 - 0.0942 f_w + 1.0342 $$

(8)

The comprehensive oil and gas quantity $Z_{ru}$ is:

$$ Z_{ru} = \frac{R}{R_{max}} $$

(9)

Corresponding to different water content, $R_{max}$ formula is different:

$$ f_w=0, \quad R_{max} = -1 \times 10^{-2} u_o^2 - 0.0219 u_o + 364.4 $$

(10)

$$ f_w=0.2, \quad R_{max} = -2 \times 10^{-2} u_o^2 + 0.0148 u_o + 446.67 $$

(11)

$$ f_w=0.4, \quad R_{max} = -1 \times 10^{-4} u_o^2 + 0.1228 u_o + 576.53 $$

(12)
\[ \text{fw}=0.6, \quad R_{\text{max}} = -1 \times 10^{-3} u_o^2 + 0.1793 u_o + 762.01 \quad (13) \]

\[ \text{fw}=0.8, \quad R_{\text{max}} = -4 \times 10^{-3} u_o^2 + 0.5591 u_o + 1160.6 \quad (14) \]

d) Under different production conditions, change the production to obtain the corresponding relationship between the efficiency under different production and the comprehensive oil, gas and water quantity, as shown in Figure 3.

![Figure 3](image-url)  
**Figure 3.** Relationship between system efficiency and oil, gas and water comprehensive quantity.

### 3. Application Example of System Efficiency Comprehensive Evaluation

By using this model, the oil well system efficiency control chart drawing and single well system efficiency evaluation are carried out in a certain block of Huabei Oilfield.

#### 3.1. Basic Data

See Table 1 for basic data and production data of a block.

**Table 1.** Example well basic data and production data.

| No. | Well   | Daily liquid production (m³/d) | GOR | Water content (%) | Tubing pressure (MPa) | Casing pressure (MPa) | Dynamic liquid level (m) | Pump diameter (mm) | Stroke (m) | Impulse times (min⁻¹) |
|-----|--------|--------------------------------|-----|-------------------|-----------------------|-----------------------|------------------------|-------------------|------------|----------------------|
| 1   | C102-10| 8                              | 3   | 1                 | 0.5                   | 0                     | 1400                   | 38                | 4          | 4                    |
| 2   | C102-18| 18                             | 1   | 1                 | 0.8                   | 0                     | 1721                   | 38                | 4          | 4.8                  |
| 3   | C102-19| 18                             | 1   | 0.12              | 0.5                   | 0                     | 1505                   | 38                | 4          | 4.8                  |
| 4   | C102-22| 17                             | 1   | 0.1               | 0.5                   | 0                     | 1913                   | 38                | 4          | 4.8                  |
| 5   | C102-23| 14                             | 1   | 9.4               | 0.5                   | 0                     | 1995                   | 38                | 4          | 4.8                  |
| 6   | C102-25| 4                              | 1   | 0.4               | 0.5                   | 0                     | 1837                   | 38                | 4          | 4.8                  |

#### 3.2. Upper Limit of System Efficiency Theory

The theoretical upper limit of single well system efficiency and current system efficiency are obtained by using the research method, and the comparison with the system efficiency provided on site is shown in Table 2. Thus, the efficiency potential value and efficiency realization rate of each well are shown in Table 3. Based on the analysis of the system efficiency realization rate, we can evaluate the system efficiency of each single well or different production blocks, and take corresponding measures to improve the system efficiency and system efficiency realization rate of pumping wells.
Table 2. Theoretical upper limit of single well efficiency, current efficiency and field provided efficiency comparison.

| No. | Well  | Upper limit of system efficiency theory | Current system efficiency | Provide system efficiency on site |
|-----|-------|----------------------------------------|---------------------------|----------------------------------|
| 1   | C102-10 | 35.41                                   | 14.84                     | 13.79                            |
| 2   | C102-18 | 34.03                                   | 27.77                     | 26.91                            |
| 3   | C102-19 | 29.82                                   | 26.89                     | 27.92                            |
| 4   | C102-22 | 31.1                                    | 21.51                     | 20.78                            |
| 5   | C102-23 | 36.37                                   | 35.8                      | 35.14                            |
| 6   | C102-25 | 36.31                                   | 14.35                     | 14.49                            |

Table 3. Efficiency potential and efficiency realization rate of single well.

| No. | Well  | Efficiency potential | Efficiency realization rate (%) |
|-----|-------|-----------------------|---------------------------------|
| 1   | C102-10 | 21.62                              | 38.94                           |
| 2   | C102-18 | 7.12                                | 79.08                           |
| 3   | C102-19 | 1.9                                 | 93.63                           |
| 4   | C102-22 | 10.32                               | 66.82                           |
| 5   | C102-23 | 1.23                                | 96.62                           |
| 6   | C102-25 | 21.82                               | 39.91                           |

4. Conclusion

The concept of dimensionless physical quantity $Z_{ru}$ is proposed in this model. Through the analysis of single factor and comprehensive influence, the theoretical upper limit value of single well system efficiency is obtained, the highest system efficiency realization rate is calculated according to the measured system efficiency, and the potential of pumping wells is evaluated and analyzed according to the realization rate of system efficiency, so as to realize the scientific evaluation of single well and block pumping well system efficiency, and to provide information for the field implementation of improving the system efficiency of pumping wells scientific and accurate theoretical basis. The evaluation and application of this method can better tap the potential and increase efficiency of pumping wells, effectively reduce the production cost of oil field enterprises, and realize the sustainable development of oil field under the current international environment of low oil price, which is of great significance for improving the quality and reducing consumption of oil field and increasing production of crude oil.

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