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Research Article

Research on the Calculation Method of System Efficiency Considering Influence of Free-Gas

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Abstract: At present only the influence of free-gas to the pump efficiency was considered in the simulation of system efficiency of rod-pumped well, the energy of it released was overlooked, resulting in the simulation precision of system efficiency in high-GOR wells was low. Aiming at this phenomenon, a new theory was raised that the gas of the layer released energy in the lifting process including two parts: dissolved-gas expansion energy and free-gas expansion energy. The motor's input power of rod pumping system was divided into hydraulic horse power, gas expansion power, surface mechanical loss power, down-hole viscous friction loss power and down-hole sliding friction loss power. Using the theory of energy-conserving, the simulation model of free-gas expansion power was established, the simulating models of the motor's input power which were based on the energy method were improved and the simulation precision of system efficiency was enhanced. The simulation examples indicated that the free-gas expansion power can't be overlooked when calculating the input power and the new simulation models of system efficiency had higher simulation precision.

Keywords: Energy method, free-gas expansion energy, gas expansion power, input power, rod pumping system, system efficiency

INTRODUCTION

From the recently research we can see that optimization of suction parameters is the effective way to enhance the system efficiency of rod pumping wells and the system efficiency is one of most important indexes to evaluate energy-saving of rod pumping wells (Cui *et al*., 1994; Yao, 2005). Aiming to improve the accuracy degree of system efficiency, a lot of research work has been done by scholars of the world and many calculation methods have been summarized (Zheng and Deng, 2007; Dong *et al*., 1993a; Zhang, 2000; Gibbs, 1977). Zheng and Deng (2007) introduced one method of energy consumption; Gibbs (1991) and Dong (1993b) introduced one method of resolving wave equation; Zhang (2000) introduced one method of API. These previous models all considered that the free-gas had been blown out from the casing or the free-gas only influences the pump efficiency and ignored the energy of free-gas releasing itself. Zheng and Deng (2007) calculated dissolved-gas expansion power, but still ignored the free-gas expansion power.

Aiming at the situation that the gas oil ratio is high in some oilfields, an improved calculation method of system efficiency of rod pumping wells considering influence of free-gas was set up basing on the energy consumption.

SYSTEM EFFECTIVE POWER SIMULATION MODEL

Effective power, also known as hydraulic power is the needed power to enhance a certain amount of liquid to a certain distance within a certain time.

Effective power model: At present the effective power of rod pumping wells is calculated by the simplified formula recommended by oil industry standards (Petroleum and Natural Gas of PRC Trade Standard, 1994):

$$N_e = \frac{Q\rho_l Hg}{86400} \times 10^{-3} \tag{1}$$

where,

N_e = The effective power, kW
Q = The actual fluid production of oil well, m^3/d
ρ_l = The liquid density kg/m^3
H = The effective high, m
g = The acceleration of gravity, m/s^2

In which:

$$H = H_d + \frac{p_o - p_c}{\rho_l g} \tag{2}$$

$$\rho_l = f_w\rho_w + (1-f_w)\rho_o \tag{3}$$

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where,

H_d = The working fluid level, m
p_o = The oil pressure, Pa
p_c = The casing pressure, Pa
f_w = The water-cut, %
ρ_w = The water viscosity, kg/m^3
ρ_o = The crude oil viscosity, kg/m^3

Actual fluid production model: The actual fluid production can be obtained by the following equation (Dong, 2003b):

$$Q = 1440 \times \frac{\pi}{4} D^2 S n \eta \tag{4}$$

where,

D = The diameter of pump plunger, m
S = The polished rod stroke length, m
n = The stroke number, min
η = The pump efficiency

The pump discharge coefficient simulation model as follows:

$$\eta = \eta_S \eta_F \eta_L \eta_V \tag{5}$$

where,

η_S = The effective stroke coefficient of pump plunger
η_F = The coefficient of fullness
η_L = The pump coefficient of leaking
η_V = The volume ratio of gas dissolution crude oil under bottom pressure

The coefficients can be got as the following (Yao, 2005):

$$\begin{cases} \eta_S = S_P / S \\ \eta_F = \dfrac{1 - KR}{1 + R} \\ \eta_L = \dfrac{F_P S \eta_S \eta_F \eta_V - \Delta Q}{F_P S \eta_S \eta_F \eta_V} \\ \eta_V = \dfrac{1}{(1 - f_w) B_{ops} + f_w B_{wps}} \end{cases} \tag{6}$$

where,

S_p = The pump plunger stroke length, m
R = The pump intake gas fluid ratio, m^3/m^3
K = The clearance coefficient, $K = S_0/S$
S_0 = The clearance length, m
p_s = The pump intake bottom pressure(absolute), MPa
p_d = The pump discharge port pressure, MPa
F_p = The cross section area of pump plunger, m^2
B_{ops} = The crude oil volume ratio in the pump intake
B_{wps} = The water volume ratio in the pump intake
ΔQ = The fluid leakage between pump plunger and pump barrel in one stroke

The gas fluid ratio in borehole can be calculated by the following equation:

$$R = (1 - f_w)(R_p - \alpha p_s) \frac{p_{st}}{T_{st}} \frac{T_s Z_s}{p_s} \tag{7}$$

where,

R_p = The gas oil ratio in the oil well, m^3/m^3
α = The dissolving coefficient, m^3/ (m^3/MPa)
p_{st} = The standard pressure, MPa
T_{st} = The standard temperature, K
T_s = The pump intake temperature, K
Z_s = The gas deviation factor in the pump intake

INPUT POWER MODEL OF PUMPING SYSTEM

Zheng and Deng (2007) established a theoretical model for calculating the input power of suck-rod pumping system. In the model, the input power was divided into effective power, surface mechanical loss power, down-hole viscous friction loss power, down-hole sliding friction loss power and dissolved-gas expansion power. But the free-gas expansion power was ignored. So the input power is divided into effective power, surface mechanical loss power, down-hole viscous friction loss power, down-hole sliding friction loss power and gas expansion power basing on the original model.

Gas expansion power simulation model: The energy is released in the process of lifting by the gas in the layer including: dissolved-gas expansion energy and free-gas expansion energy.

Dissolved-gas expansion power: The power used to lifting system when the dissolved-gas turns to volume expansion energy is called dissolved-gas expansion power:

$$P_e = \begin{cases} \dfrac{10^3 \alpha Q_o p_b p_w}{86400} \ln \dfrac{p_b}{p_w} & (p_s \ge p_b, p_w < p_b) \\ 0 & (p_s \ge p_b, p_w \ge p_b) \\ \dfrac{10^3 \alpha Q_o p_s p_w}{86400} \ln \dfrac{p_s}{p_w} & (p_s < p_b, p_s > p_w) \\ 0 & (p_w > p_s, p_s < p_b) \end{cases} \tag{8}$$

where,

p_e = The dissolved-gas expansion power, kW
Q_o = The oil production, m^3/d
p_b = The bubble point pressure, MPa
p_w = The tubing head pressure(absolute), MPa

Free-Gas expansion power: The power used to lifting system when the free-gas turns to volume expansion energy is called free-gas expansion power:

$$P_z = \frac{10^5 (R_p - \alpha p_s) Q_o p_w}{86400} \left[\ln \frac{10 p_s + 1}{10 p_w + 1} + \frac{p_w}{p_s} - 1 \right] \quad (9)$$

where,
P_z = The free-gas expansion power, kW

Gas expansion power: Gas expansion power is the sum of dissolved-gas expansion power and free-gas expansion power:

$$P_g = P_e + P_z \quad (10)$$

where,
P_g = The gas expansion power, kW

Other power simulation models: Zheng and Deng (2007) gave the other power simulation models.

Surface mechanical loss power:

$$P_u = P_d + (F_u - F_d) Snk_1 + (F_u + F_d) Snk_2 \quad (11)$$

where,
P_u = The surface mechanical loss power, kW
F_u, F_d = The average polish rod load in upstroke and down stroke, kN
k_1, k_2 = The transmissibility coefficient of transmission power and polished rod power

Viscous loss power:

$$P_r = 1.5 \pi^3 S^2 n^2 \sum_{i=1}^{N} \mu_i l_i \frac{m_2 - 1}{(m_2 + 1) \ln m - (m_2 - 1)} \quad (12)$$

where
P_r = The viscous loss power, kW
N = The sucker rod number
μ_i = The fluid viscosity in section zone i, mPa/s
l_i = The tubing length in section zone i, m
m = The ratio of pipe diameter and rod diameter

Sliding friction loss power:

$$P_k = 2 f_k q_r g L S n \quad (13)$$

where,
P_k = The sliding friction loss power, kW
f_k = The friction coefficient between rod and pipe
L = The horizon course length of borehole deviation, m
q_r = The rod gravity, N/m

Input power simulation model: Input power is the sum of all other powers:

$$P_i = P_u + P_r + P_k + N_e - P_g \quad (14)$$

where,
P_i = The input power, kW

System efficiency simulation model: System efficiency can be written as follows:

$$\eta_i = \frac{N_e}{P_i} \times 100\% \quad (15)$$

where,
η_i = The system efficiency

APPLICATION

Taking the five oil wells of one oilfield as example, the formulation calculation is taken and compare with the testing results. The base data of the well are shown in Table 1. The results are shown in Fig. 1.

As shown in Fig. 1, the calculation error is smaller using this model in higher gas oil ratio wells and the simulation result is more close to the measured value. It shows that free-gas expansion power is the energy that cannot be overlooked. The energy plays an important role in the process of lifting, reduces the input power and enhances the system efficiency.

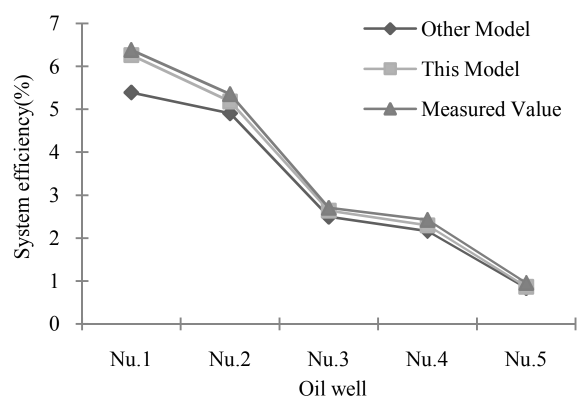

Fig. 1: System efficiency contrast

Table 1: Base data of the five well

Wells	Stroke/m	Stoke number/min	Pump diameter/mm	Depth of plunger/m	PFL/m	Water cut/%	GOR/(m^3/m^3)	Output/(t/d)
1	5	3	44	1800	1500	30	50	4.04
2	5	4	44	1820	1662	25	100	4.01
3	4	3	57	1900	1750	25	150	1.39
4	4.5	3	38	1950	1762	20	200	1.14
5	4.5	2.5	70	2000	1840	22	250	0.60

CONCLUSION

- The free-gas does not only reduce the pump efficiency, but also releases energy in the expansion. So the free-gas expansion power calculated model is built.
- Gas expansion power is composed of dissolved-gas expansion power and free-gas expansion power. The model takes the gas energy use into account fully, improves the input power simulation model and enhances the system efficiency simulation accuracy.
- From the example, we can see that the simulation result is more close to the measured value. The free-gas expansion energy could not be ignored. And the study the free-gas plays to the lifting system must be thought over when calculating the input power.

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