Energy efficiency of well electric submersible pumps for oil production

F A Gizatullin¹, M I Khakimyanov² and I N Shafikov²

¹ Ufa State Aviation Technical University, 12, K. Marx ave., Ufa, 450008, Russia
² Ufa State Petroleum Technological University, 1, Kosmonavtov ave., Ufa, 450062, Russia

E-mail: hakimyanovmi@gmail.com

Abstract. Downhole artificial lift is the most energy-intensive process at the oil companies. In the current economic conditions, the oil companies are forced to optimize the power consumption for production processes. To do this, you must have a methodology for calculating the energy consumption of all oil-producing equipment. Energy losses occur in all parts of the electrical submersible pump units: submersible motors, electrical cables, transformers and control station. There are analytical expressions that allow finding the power consumption in all elements of the pumping unit. However, the energy consumption depends on many process and operating parameters, such as density, viscosity, water content wellbore fluid, gas content, temperature in the borehole. The authors conducted a study on the impact on the power consumption of various technological and operational parameters. When adjusting the pump performance varies depression and reservoir, respectively, and the oil recovery wells. Therefore, to determine the optimal performance of the pump for the payment by a particular well is problematic. The relationship between the formation and the depression change inflow well fluid can be determined according to well testing. The results of this research can be useful to specialists in the development of the oil-producing enterprises of measures to optimize energy consumption.

1. Introduction

Currently, oil companies are reducing their costs and planning energy consumption due to difficult economic conditions, unstable oil prices and continuous growth of electricity tariffs. We know that the most energy-intensive technological process at the oil companies is a well oil production [1, 2].

The main way of oil production in Russian Federation is the use of electric submersible pumps (ESP). The ESP units provide over 75% of all produced oil. The simplified scheme of ESP unit is shown in figure 1.
Figure 1. The simplified scheme of the ESP unit: 1 – centrifugal pump; 2 – protector; 3 – submersible motor; 4 – cable line; 5 – check valve; 6 – drain valve; 7 – transformer; 8 - control station.

The complex of equipment consists of a surface and submersible subsystems. Surface subsystem includes control station 8 and transformer 7. Submersible subsystem consists of centrifugal pump 1, protector 2, submersible motor 3, cable line 4, check valve 5 and drain valve 6.

When the ESP units is running, energy is expended to the well fluid lifting and to the loss of all ESP elements: the pump, the protector, the submersible motor, the cable line, the transformer, the control station, the filters and others [3].

2. The cable power loss

Power consumption of any ESP element we can calculate from the known analytical formulas. However, the problem of determining the specific energy consumption for each particular well is a difficult. This is because the many technological and operational parameters affect the power consumption (such as density, viscosity, water and gas content of the well fluid, temperature gradient in the well, and others) [4, 5].

For example, the wellbore temperature affects the resistance of the cable cores. In addition, the resistance changes the power loss in the cable:

$$\Delta P_{\text{LINE}} = \frac{1.732 \cdot \rho \cdot L_{\text{LINE}} \cdot [1 + \alpha \cdot (T_{\text{LINE}} - 20)] \cdot I^2}{F},$$

where $\rho$ – resistivity of the cable material, Ohm∙m (for copper $\rho=0.0195\cdot10^{-6}$ Ohm∙m); $\alpha$ – coefficient of copper thermal expansion ($\alpha=0.0041$), $L_{\text{LINE}}$ – the cable line length, m; $T_{\text{LINE}}$ – average cable line temperature, °C; $I$ – operating current, A; $F$ – cable section, m².
However, the average cable temperature calculating is a difficult task. We need to consider the geothermal gradient of well, self-heating of the cable by current, heat transfer through the shell from well fluid, well fluid heating from operating ESP unit.

3. The energy consumption dependence from density and viscosity of well fluid

The dependence between specific energy consumption and well fluid viscosity is very interesting. It is known that fluid viscosity changes pump characteristics such as head, flow and efficiency [6, 7]. These changes are defined by the appropriate coefficients:

\[
K_{Qv} = 1 - 4.95 \cdot \eta_v^{0.57} \cdot Q_{0W}^{0.85}, \tag{2}
\]

\[
K_{\eta v} = 1 - 1.95 \cdot \eta_v^{0.4} \cdot Q_{0W}^{0.23}, \tag{3}
\]

\[
K_{H v} = 1 - 1.07 \cdot \eta_v^{0.6} \cdot q_{IN} \cdot Q_{0W}^{0.57}, \tag{4}
\]

where \( K_{Qv} \) - factor of viscosity effects to flow; \( K_{\eta v} \) - factor of viscosity effects to efficiency; \( K_{H v} \) - factor of viscosity effects to head; \( \eta_v \) - effective viscosity of mixture, m\(^2\)/s; \( Q_{0W} \) - optimal pump flow on water, m\(^3\)/day; \( q_{IN} \) - relative flow at the pump inlet.

Figure 2 shows dependence between viscosity well fluid and specific energy consumption of ESP unit. It’s seen that the specific energy consumption will vary in the range from 3.76 to 3.96 kW∙h/m\(^3\) for viscosity range 0...1.4∙10\(^{-3}\) m\(^2\)/s.

![Figure 2. The dependence of the specific energy consumption by ESP unit from well fluid viscosity.](image)

Figure 3 shows the dependence curves between viscosity and specific energy consumption for different densities of well fluid. It has been seen that specific energy consumption increases if viscosity and density increase. The 3-D graph of specific energy consumption dependence from viscosity and density of well fluid is shown in figure 4.
4. The dependence of the energy consumption from the frequency of the supply voltage

It is known that the variable frequency drive use is one of the main ways to reduce the energy consumption of oil production [8, 9]. In most cases the optimum pump performance and the drive rotational speed are determined empirically – sequential change with a certain step.

Optimal performance calculation is difficult because fluid flow varies with pressure in the well. The formation depression changes as a result of well pump regulation.

The fluid flow changes too. We must do hydrodynamic researches of wells to get a necessary data. For example, we must measure the pressure build-up curve and the level build-up curve [10].

Figure 5 shows the dependence between the supply voltage frequency and specific energy consumption. The graphs show that the minimum specific energy consumption of this well can be achieved at frequency 28 Hz. At lower frequencies the specific energy consumption is increased due to reduce the amount of produced fluid. And at high frequencies specific energy consumption is increased due to higher motor consumption.
Figure 5. Dependence between the specific energy consumption of ESP unit with VFD and frequency.

It should be noted that the mode of the well operation with the lowest specific energy consumption is not always rational from an economical point of view [11]. When expensive oil and cheap electricity oil companies produce the maximum amount of oil with any power consumption. The benefit from additional oil compensates all electricity costs.

5. Conclusion
Thus, we can draw the following conclusions:

- For an exact determination of the specific energy consumption well pump units we must take into account a number of technological and operational parameters: density, viscosity and water content of the well fluid, the average temperature of the cable, the gas content and others.
- The losses in the cable have a significant influence on energy consumption of the pump unit. The cable line losses dependent from the temperature. Determination of the average temperature of the cable is difficult problem. The temperature of the cable depends the geothermal gradient of well, self-heating of the cable by current, heat transfer through the shell from well fluid, well fluid heating from operating ESP unit.
- The specific energy consumption is very dependent from density and viscosity of the well fluid. The viscosity affects pump characteristics such as head, flow and efficiency.
- The pump unit regulation changes formation depression and fluid flow. Therefore, we cannot determine the optimum pump performance for a particular well by calculation. In practice, the pump capacity is determined empirically by adjusting it incrementally.
- We can determine the relationship between depression and changes in reservoir inflows wellbore fluid according to well test, in particular by measuring of the pressure build-up curve and level build-up curve.
- The best way to improve the efficiency of well pumping equipment is the use of variable frequency drive.

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