

Operation effectiveness of wells by enhancing the electric-centrifugal pump

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Abstract. We present the method to improve the operation effectiveness of wells by enhancing the electric-centrifugal pump. Some of the best ways to extend the electric-centrifugal pumps operating lifetime is using today's techniques as well as additional protective equipment as a part of the electric-centrifugal pump. In paper it is shown that high corrosiveness of formation fluid (a multi-component medium composed of oil, produced water, free and dissolved gases) is a major cause of failures of downhole equipment. Coil tubing is the most efficient technology to deal with this problem. The experience of coil tubing operations has proved that high-quality bottom hole cleaning saving the cost of operation due to a decreased failure rate of pumps associated with ejection of mechanical impurity.

1. Introduction

Nowadays, the use of electric-centrifugal pumps (ECPs) is the most advanced and efficient method of artificial oil lifts. High corrosiveness of formation fluid (a multi-component medium composed of oil, produced water, free and dissolved gases) is a major cause of the failures of downhole equipment operated using this method [1]. Lifetime of the electric-centrifugal pumps can be increased by using additional protective equipment as a part of the ECP. Many devices and techniques to develop the oilfield including artificial lift do not always satisfy requirements of the oil companies. Thus, it is important to propose a new technique and approach to improve the production efficiency, optimise plant and equipment uptime, and reduce product costs. The ECP can be used in producing well stock where oil, liquids and gases are present. To lower energy costs per ton of oil produced more profitable to use the ECP rather than the sucker rod pump. Therefore, the relevance of the theme is not in doubt.

2. The basic principle of the calculation of the ECP parameters

To select a borehole pump it is convenient to use the method of artificial lift. The basic principle of this method is based on the following information: the well productivity index (based on the hydrodynamic research findings), the inclinometer survey, the gas/oil ratio, the formation pressure, the saturation pressure, the well water cut, and the concentrations of entrained solids [2]. JSC «Tomskneft» uses the programm «WellFlo» to select ECP in one producing well. Calculation algorithm for ECP include: receiving information about productive formation and well geometry, choosing the ECP setting depth and required lift, calculating the gas separation at the pump output, adjustment of the pump service properties, and selecting the electric motor, cable, transformer, and control station.



The ECP setting depth is determined in accordance with requirements for the minimum bottom-hole pressure. The gas/oil ratio recommended value into a highly dispersed phase at the pump inlet is 35%. The optimum value of the gas/oil ratio at the ECP inlet is 30–40%. Taking into account this fact, it is necessary to find the range of the borehole having this value in the pressure line and further to find the pump-setting depth with allowance for bend angle of the borehole.

However, as EPC service treatment shows, with so much free gas onsite the pump, the time interval between overhauls increases by 10–15% [3].

The checking calculation of the pump-setting depth is done separately for 2–3 choices for equipment design as well as for another calculation.

It should be noted that checking calculation of pressure change along borehole in the depth higher than pump output and pressure change along oil-well tubing (OWT), one must have regard to gas separation at the ECP inlet. The separation index for the boreholes with pump, is found from [4,5]

$$\delta = \frac{1}{(1 + 0.6 \cdot (Q_{f.st} / W_0 \cdot F_h))}, \quad (1)$$

where W_0 is the relative velocity bubble gas floating-up, m/s; F_h is the cross-section area of the annular space between the casing pipe and electrical submersible motor (ESP), m².

To coordinate the pump characteristic with wells characteristic and thus, to determine the specific energy, transferring to gas-liquid mixture and fluid withdrawal rate maintenance in order to choose pump-setting depth, one could plot a head-flow characteristic graph for the well $Q=f(H_{well})$

$$H_{well} = H_{well.dn.} + P_{whp} / (p \cdot g) + h_{fr} - H_g, \quad (2)$$

where $H_{well.dn.}$ is the depth of the well dynamic level in which the fluid withdrawal holds, m; $P_{whp}/(p \cdot g)$ is the well-head pressure under average density of the gas-liquid mixture at the range «pump-well-head» into borehole, meter of liquid column; h_{fr} is the friction head loss, m H₂O.

If we don't have the data about the dynamic level, we could estimate it approximately:

$$H_{dnp} = L_1 - \frac{P_{ar} - Q_f / K}{\rho_{vo} \cdot g}, \quad (3)$$

where ρ_{vo} is the density of the oil-water mixture at the pump output.

The friction head loss caused by the hydraulic friction into the OWT can be found as for Newtonian fluid:

$$h_{fr} = \lambda \cdot \frac{H_{well} \cdot \omega^2}{2 \cdot g \cdot D}, \quad (4)$$

where λ is the hydraulic resistance coefficient; ω is the linear flow rate, m/s.

$$\omega = \frac{Q_n \cdot v_h + Q_b \cdot v_v}{86400 \cdot F_{pct}}, \quad (5)$$

We can approximately calculate the pressure relevant to the gas lift effect into buried pipes:

$$H_g = 4 \cdot D \cdot G_{o.act} \cdot (1 - (P_w / P_{pump})^{1/3}) \cdot [1 - B(\bar{P})], \quad (6)$$

where D is the outer diameter of the OWT in inches; P_{pump} is the saturation pressure after the gas separation; $B(\bar{P})$ is the average well water cut in the eductor under average pressure condition $P = 0.5 \cdot (P_{in} / P_w)$.

In order to plot a graph of the head-flow characteristic, the several values of the production rate (as a rule 5 – 6 points, starting from 0) are taken. And then one can plot point by point $Q = f(H)$ the formation heat line H_{well} of the well.

Further, the graph of the head-flow characteristics should be superimposed on the graph of the pump characteristics to find the point of intersection. This point indicates the well production rate that is equal to pump capacity. Selection of the OWT diameter should be determined as a function of production rate:

Table 1. Selection of the OWT diameter (for ECP)

Production rate, m ³ per day	less than 150	150–300	more than 300
The inside diameter of the oil-well tubing, mm	50.3	62	76

Taking into account the typical head-flow characteristics of the ECP, production rate, and required lift, we can choose several pumps, which meet drainage requirements for operation under conditions:

$$0.6 \leq Q_f / Q_{w.b} \leq 1.2,$$

where $Q_{w.b}$ is the pump capacity measured for water flow in optimum performance.

The point of intersection of these graphs indicates the pump capacity measured for water flow.

In practice, the discharge liquid characteristics differ from the water characteristics caused by occurrence of the oil-water mixing. Therefore, if the pressure at the pump output is smaller than the saturation pressure, the free gas occurs in pump. Due to this fact, we need to adjust the pump characteristics to the discharge liquid and free gas to improve accuracy.

The dependence of the pump head, the pump capacity and coefficient of efficiency on the viscosity of the discharge liquid are considered by using the specific coefficients. When the viscosity of the pumping step is raised, the following indexes are also increasing: the flow resistance, the energy loss in liquid in which wheel disk rotates, as well as the friction of the wheel rotor pin. It leads to reduction of the pump head, pump capacity, and efficiency coefficient by while the power consumption.

When the gas/oil ratio at the ECP inlet is 5–7 % and less, the impact of the gas can be negligible. Further re-calculation of the pump characteristic measured by water to the pump characteristic measured by viscous liquid is made by the P.D. Lyapkov-Maksimov graphical diagram. It can be used for viscous liquid with viscosity less than 0.03–0.05 cm²/s under formation conditions. If the viscosity of the liquid exceeds this value, it is essential to make adjustments of the pump operating characteristics [6].

Additionally, the kinematic apparent viscosity (m²/s) is using as a viscosity rating of the well production. It is calculated by the formula

$$\nu_{ap} = \mu_{ap} / \rho_{in}, \quad (7)$$

where μ_{ap} is the apparent viscosity under the appropriate temperature and the fluid shear rate, ρ_{in} is the average density of the production fluid in device channel, kg/m³.

$$\rho_{in} = \rho_o \cdot \beta + \rho_w \cdot \beta_w, \quad (8)$$

where β and β_w are the volume ratio of the oil and volume ratio of the water correspondingly.

It could be mentioned, that the dependence of the pump head, the pump capacity and coefficient of efficiency on the viscosity of the discharge liquid could be estimated by using the coefficients

$$K_{w,Q} = H / H_w = Q / Q_w, \quad (9)$$

$$K_\eta = \eta / \eta_e, \quad (10)$$

where H_w , Q_w and η_e are the pump head, the pump capacity and coefficient of efficiency measured by water under standard conditions; H , Q , η are the same parameters measured by viscous liquid.

The coefficients K_η , Q and K_η depend on the Reynolds Number in ECP channels

$$Re_w = \frac{4.3 + 0.816 \cdot n_s^{0.274}}{n_s^{0.575}} \cdot \frac{Q}{\gamma_{ex}} \cdot \sqrt[3]{\frac{n_l}{Q_{w,opt}}}, \quad (11)$$

where n_s is the pumping step power-speed coefficient, n_l is the pump speed, 1/s.

$$n_s = 193 \cdot n_l \cdot Q_{w,opt}^{0.5} \cdot \frac{(g \cdot H_{w,opt})^{-0.75}}{z_n}, \quad (12)$$

where $Q_{w,opt}$ and $H_{w,opt}$ are the pump capacity and pump head measured by water that will give optimal performance, z_n is the number of the pumping step.

We can find the coefficient K_w , Q , K_η using the special graphs from Lyapkov [6] and the value Re_w whereat we can re-calculate the characteristic of the ECP measured by water to characteristic of the ECP measured by viscous liquid. Moreover, we can use the approximating formulas to find these coefficients apart from the graphical method.

For laminar flow:

$$K_{w,Q} = Re_w / (Re_w - 50 + 200 \cdot (Q_w / Q_{w,opt}));$$

$$K_\eta = 0.485 \cdot \lg Re_w - 0.63 - 0.26 \cdot (Q_w / Q_{w,opt}).$$

For turbulence flow:

$$K_{w,Q} = 1 - (3.585 - 0.821 \cdot \lg Re_w) \cdot (0.027 + 0.485 \cdot (Q_w / Q_{w,opt})),$$

$$K_\eta = 0.274 \cdot \lg Re_w - 0.06 - 0.14 \cdot (Q_w / Q_{w,opt}),$$

where Q_w is the pump capacity measured by water flow under required condition, m³/s.

The power consumption can be found from formula:

$$N = 10^{-3} \cdot g \cdot Q_w \cdot H_w \cdot \rho_{wo} \cdot K_{H,Q}^2 / (\eta_w \cdot K_\eta). \quad (13)$$

When the gas/oil ratio at the ECP inlet is under 7 % it could be negligible. When the gas/oil ratio increases, the head-flow characteristic shifts left while the ECP coefficient of efficiency falls. In practice, to avoid the deleterious effect of the gas it is helpful to install the equipment with special gas separator designed by P.D. Lyapkov [5].

3. Use of the coil tubing technology to stimulate wells after hydraulic fracturing.

Coil tubing is the most efficient technology for post-hydraulic fracturing proppant flowback. The experience of coil tubing operations has proved that high-quality bottom hole cleaning and well stimulation with nitrogen save the cost of ECP operation due to decreased failure rate of pumps

associated with ejection of mechanical impurities. Using coil tubing, firstly, one can lower a flexible pipe into a well very rapidly (up to 50 m/min). Secondly, nitrogen can be injected through it to form a very light fluid column. During the cleaning, the clean-up flow goes to the well and perfectly cleans a wellbore.

Moreover, the coil tubing provides the possibility to achieve an earlier payback and save on costs of further well operation. Quick payback is associated with a number of factors, such as a shorter period of well stimulation; reduction of oil losses due to saving time of well stimulation; longer service life of the well after commissioning; reduction of negative impact on a formation during treatment; and increase in revenue from oil sales [7].

4. The use of a flexible ball joint as a part of ECPs.

As known [8], when ECPs are operated in areas with a high bend angle induced by lateral forces, cases and shafts are often subjected to off-design stresses. This causes one-sided wear of parts and reduction time between overhauls. When running ECP of a certain lateral dimension, the maximum allowable bend angle is defined by allowable elastic strain of the materials of which ECP is made. According to regulations of Russian and foreign manufacturers, the maximum allowable bend angle of the well is equal to 2 per 10 meters. According to the same regulations, ECP should be installed in the well where it is not subjected to deflection or at least fits into a well segment.

The use of the flexible ball joint (FBJ) as a part of ECP makes it possible to achieve the well potential; to prevent torque retention loss because of asymmetrically tightened bolts of ESP intersectional flange connections by removing bending loads acting on ECP when it passes through intervals with a high bend angle [8].

When operating in area with a bend angle above the allowable level, i.e. in a stress-strain state, the ECP fitted with a FBJ is well fit in a deviated borehole and, therefore, can be operated with a higher stability. The maximum bend angle of FBJ is 5° or 10°, depending on a version [9].

5. Conclusion

The reasonable selection of pumping equipment and optimization of its operation allow to improve the operational efficiency of wells, to evaluate the equipment, and to calculate rational operating parameters.

The maximum effect of energy efficiency improvement can be achieved by enhancing the performance of electrical submersible pumps. For this purpose, it is necessary to use a balanced approach to select each element of ECP (cable, pump, submersible motor, etc.) and also to optimize the pump operation after its commissioning. In general, the introduction of the proposed methods into production will significantly increase time between overhauls of wells fitted with ECPs for artificial lift and, therefore, increase daily output of mineral resources.

6. References

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