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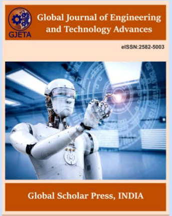

(Review Article)

Contemporary issues of well operation using centrifugal pumps

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Abstract

This paper opens a new page in the theory of electric-centrifugal pump control and oil production. Emerging ideas give us the opportunity to predict the state of a centrifugal pump during operation, facilitate a new approach to the centrifugal-pump selection procedure, provide a scientific explanation of the separation process, explore scaling processes in centrifugal pumps, develop salt-deposition prediction methods and bring us closer to a scientific basis for automation of the entire pump-operation process.

Implementation in oil-recovery practice of the findings developed in this collection of articles will surely enhance the economic efficiency of the method under consideration and allow for the creation of an environmentally-friendly method of oil production. Obtained results are fundamental and form the basis of the centrifugal-pump control theory.

Keywords: Oil Field; Electric Centrifugal Pumps; Production Problems; Pump Control Automation

1. Introduction

Over 90% of global oil production is performed using electric-centrifugal pumps. The study of submersible (downhole) motors with temperature sensors strongly indicates (despite the established viewpoint of oilmen) that motor temperature is not always related to a pump's thermal behavior. On the contrary, with minimum heat release, i.e. when the motor is running in an operating cycle close to an idle run, the pump generates maximum heat, which may lead to a break-down of the unit in general. Experimental and theoretical studies found that the current problems of centrifugal-pump operation are directly linked with the pump's thermal behavior. Thermal behavior of a centrifugal pump has not been studied so far.

The control stations currently in use are only concerned with the state of downhole motors and barely deal with centrifugal pumps at all. Therefore, all attempts at automating the centrifugal pumps startup and ramp-up and tracking its operation have thus far been unsuccessful.

This paper deals with the solution of contemporary issues of centrifugal-pump operation linked with salt deposition and break-downs due to a reduction in the electric resistance of the "cable-motor" system, as well as with planning operating modes - from periodic to the permanent mode of operating parameters.

For the first time ever, the problem of thermal behavior of a centrifugal pump during pumping of gas-liquid mixtures has been raised [1, 2]. The obtained solution points at the complex dependence of the pump's temperature on the operating parameters of the conveyed liquid (yield, water cut, and pump suction pressure), the centrifugal pump's state (pump efficiency, free-gas content in the produced mixture) and rheological parameters of reservoir oil, such as suction pressure and gas factor (1):

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$$\Delta T_w = T_w - T_f = \frac{\varphi}{1-\varphi}\frac{q_0 P_н P_{вх} R_2}{2(1-B)h\Gamma P_a}\left\{\frac{1}{\alpha}+\frac{\delta_{из}}{\lambda_{из}}\right\} \text{ ....(1)}$$

where T_w – temperature inside the pump housing,

T_f – liquid-gas-mixture temperature at pump intake,

R_2 – radius of the cylindrical pump housing (0.05 m),

$P_{нас}$ - saturation pressure (atm),

Γ - reservoir gas-oil ratio (m^3/m^3),

h – pump stage head (m) with free-gas content

φ in the mixture,

$\delta_{из}$ – thickness of the gas bubbles on the pump surface (about 0.002 m),

B – producing watercut as a decimal fraction (less than 0.98),

$\lambda_{из}$ – heat-conductivity of the gas blanket on the pump housing's surface (W/(m*K),

α – coefficient of convection heat-transfer (W/(m^2*K)) n the labyrinths of the pump's working elements to the liquid-gas mixture,

q_0 – power density of the heat source per pump stage (W/m^3),

$P_{ат}$ – atmospheric pressure, atm.

The calculations show that depending on the operating parameters, the pump's temperature may reach 300 °C and even exceed this value.

Coordinating the work of the formation and the oil-lifting unit (ESP unit) is one of the main tasks over which both consumers (oil-producing enterprises) and equipment manufacturers rack their brains. That said, the ESP unit's suction pressure is one of the major parameters of its operation. An ESP unit's condition and service life depend on water cut, gas factor and suction pressure.

Multiple and time-consuming investigations of an ESP unit's operation allow us to identify three zones of ESP operation that are clearly distinct in terms of quality. In the first zone, distinguished by a low content of free gas in the pumped fluid, the actual pump parameters do not differ from the test values for clean fluid (with no gas); in this case, the pump's efficiency is at its peak. Let's call the suction pressure, corresponding to the low gas content in the pumped fluid, the "optimum suction pressure P_{opt} "(the pump is running in the first zone). The second zone of ESP operation is characterized by increased gas content in the pumped fluid, due to which the actual parameters of the pump differ from the test values, where there is no free gas; however, the pump keeps running steadily (with no shutdowns) with acceptable efficiency. Let's call the suction pressure in this operating mode the "permissible pressure P_{perm}". Let's call the third zone of ESP operation below permissible pressure the "limit suction pressure P_{lim}". In this case, the pump runs unsteadily, with occasional trip-outs due to pump starvation and frequent stops, which finally ends up with the unit's failure for various reasons. In such an operating mode, an ESP unit with a capacity below 50 m^3/d fails due to a reduction in the electric resistance of the whole system – typically, with salt deposition in the labyrinths of the pump stages. Speaking in a more formal mathematical language, the centrifugal pump's operating domain falls into three ranges of suction-pressure values:

$$P_{пр} \rightarrow \begin{cases} P_{пр} \geq P_{опт} \\ P_{пред} \prec P_{пр} \prec P_{опт} \\ P_{пр} \leq P_{пред} \end{cases} \text{ .... (2)}$$

The optimum suction pressure is the one, under which there is no free gas in the mixture; in this case the pressure is equal to the saturation pressure.

$$P_{опт} = P_{нас.} \quad \text{…………………………} \quad (3)$$

The following temperature values correspond to the suction pressure values:

$$P_{опт} \Rightarrow T_{опт}$$

$$P_{доп} \Rightarrow T_{доп} \quad \text{………………} (4)$$

$$P_{пред} > T_{доп}$$

The permissible temperature of the ESP unit's cable line can be assumed as $T_{доп}$. The aim of a centrifugal pump's operation in various modes is to prevent the pump's temperature from rising over the permissible limit. If a pump is running at a high temperature, the R=0 of the cable line may occur, and the formation-fluid boiling will start accompanied by salt deposition [13].

The periodic operation of centrifugal pumps is a forced measure during oil well operation and, from the standpoint of thermodynamics, is represented by a series of transient processes involving heat transfer from a source inside the pump's body.

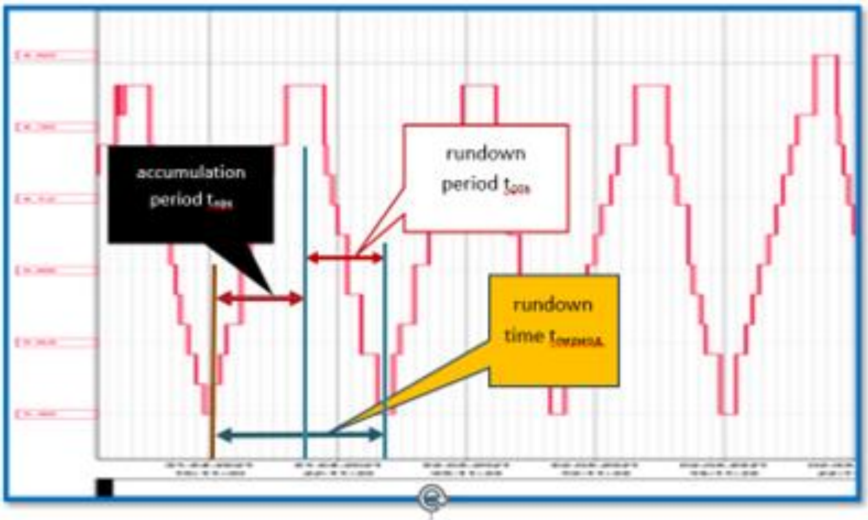

Figure 1 Time-based historical graphs of the centrifugal pump's suction pressure variation. Let's denote the fluid accumulation time at the centrifugal pump inlet as $t_{нак}$ and the rundown time as $t_{отк}$.

The record of suction pressure variations of the centrifugal pump is shown in Figure 1. The pump's suction pressure changes (rudely) from 3.4 MPa to 4.5 MPa. Let's denote the rundown time as $t_{отк}$, and the accumulation time as $t_{нак}$.

- As the ESP unit starts up, the pump's temperature is Тпр; prior to the ESP's stop – Тотк. From the standpoint of thermodynamics [11 - 14], during the rundown time the centrifugal pump's temperature rises from Тпр to the boiling point Ткип [7, 8]. If we assume that Тпр nearly matches the gas-fluid mixture temperature at the centrifugal pumps suction, it can be calculated on the basis of a known geothermic gradient in the wellbore, which is equal to▯=0.03 oC/m. The unknown temperature Ткип can be determined on the basis of some technical considerations: say, the pump's temperature shall not exceed the working temperature limit of the cable extension attached to this pump$T_{пр.каб}$. It is necessary to identify such a temperature that does not cause boiling [11, 13] of associated water (hence salt deposition) in the centrifugal pump chamber, i.e.:

$$T_{р} < T_{кип} < T_{пр,уд.} \quad \text{…………………………..} (5)$$

Where: Tк – associated water boiling point at the pressure of $P_{пр}$, permissible operation temperature of the cable extension $T_{пр.уд.}$ is determined by experiment by means of identification of the permissible leakage current value depending on the cable extension temperature; $T_р$ – pump's working temperature at $P_{пр}$.

Thus, in planning periodic operation mode, it is essential to learn how to operate a centrifugal pump in such a way so as to eliminate salt deposition and protect the flat section of the cable line against overheating.

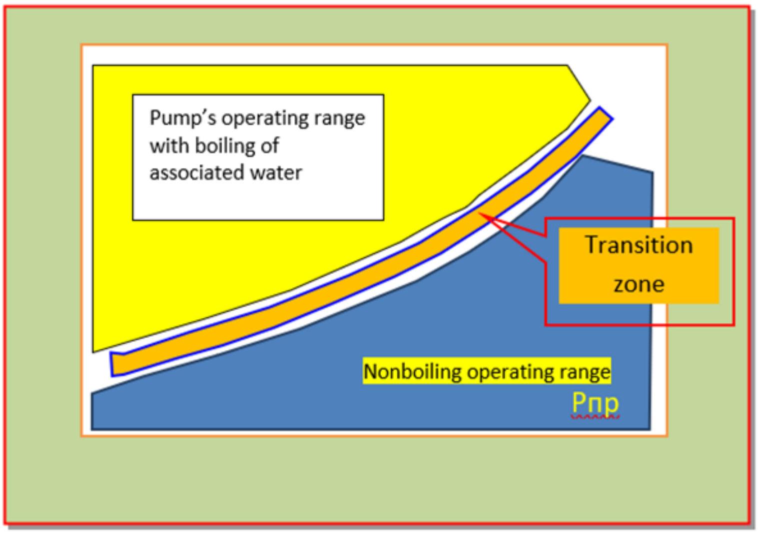

Figure 2 Oilfield water boiling point vs. pressure Рпр – centrifugal pump's suction pressure, Тн – temperature inside the pump (associated water temperature)

Figure 2 shows the dependency graph of the formation-water boiling point vs the pressure inside the centrifugal pump [12]. As the pressure continues to grow, the boiling point increases and only slightly depends on the concentration of dissolved salts. Transition of the pump temperature from the oilfield water "nonboiling region" to the boiling range is characterized by the presence of a transition zone. The width of the transition zone shown in Fig. 3 is conditioned by the minor dependency of the water boiling point at the given pressure on the concentration of dissolved salts (not exceeding 2°C) [13].

- The problem of periodic operation without salt deposition in the pump is solved in a similar way. For this purpose, let's calculate the suction pressure, under which the centrifugal pump stops due to "hydraulic blocking of the liquid" - shutdown due to electric current decrease:

$$P_{пр} = \rho_{см} * g * (H_{д.в.} - H_{э.в.}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where $H_{д.в.}$ – vertical depth of the dynamic fluid level; $H_{э.в.}$ – vertical depth of the ESP location in the well; $\rho_{см}$ – density of the mixture; g – gravity acceleration.

- Let's calculate the pump's temperature at the pump starvation pressure [1-6] using the equation (1). Let's compare the pump's temperature with the boiling point under the given pressure Рпр. If the pump's temperature meets the requirement (5), no failures or salt deposition in the ESP unit take place. If the inequation (5) is disturbed, we are obliged to choose the way of putting the pump's temperature down. One of the ways is the periodic operation with stops for cooling.
- When planning periodic operation, it is important to determine the centrifugal pump's running time. Herewith, the main goal is to provide long-term operation of the ESP unit without salt deposition, produce the maximum possible volume of the mixture and reduce the specific energy consumption for this production.

For this purpose, let's develop an IPR curve for the well (crossplot of drawdown vs flow rate).

On the IPR curve, we identify the optimal flow rate at a certain drawdown:

$$Q_{ж} = f(\Delta P) \text{……………. (8)}$$

Let's calculate the ESP unit's service life for pumpout at optimal flow rate:

$$t_{от} = \frac{Q_{ж.о.}}{Q_{о.п.ЭЦН}}, \text{ day ……………………….. (9)}$$

The ESP's operating mode can be determined from (11) using the rundown time $t_{от}$ and the accumulation time

$$T_{нак} = 24 - t_{от}. \text{ …………………(10)}$$

The other method of the pump's temperature decrease is the application of a frequency converter in order to bring down the pump shaft speed.

- The pump's temperature can be adjusted by changing the pump shaft speed, say, with the help of a control station with a frequency converter.

Example: in the well equipped with an ESP unit with the capacity of Q_{on1} the well production rate drops down to Q_{on2} . At the same time, the pump's suction pressure drops down from P_{on1} to P_{on2} . Let;s calculate the relative drop of the well production rate as follows:

$$\frac{Q_{on1}}{Q_{on2}} = n \text{ ………………… (11)}$$

Let's decrease the pump shaft speed by *n* times:

$$\omega_{on2} = \frac{\omega_{on1}}{n} \text{ ………………… (12)}$$

Then, as follows from (7), the free-gas content at the pump's suction will decrease [1 - 4], as will the free-gas content ratio in (7):

$$\varphi_{on2} < \varphi_{on1} \text{ ………………… (13)}$$

The power density of the motor in (7) will decrease as follows:

$$q_{o2} = \frac{q_{o1}}{n^3} \text{ ………………… (14)}$$

Concurrently, the decrease of the well production will lead to the rise of the pump's suction pressure:

$$P_{np2} = P_{np1} + \frac{Q_{on1} - Q_{on2}}{k} \text{ ………………… (15)}$$

Where *k* – well-productivity factor.

Substituting the data from (11 – 15) into (7), assuming that the pump's efficiency will change to a very slight degree, we'll get:

$$\Delta T_{on2} < \Delta T_{on1} \text{ ………………… (17)}$$

- Increase of the pump shaft speed for the sake of production enhancement is planned in the same way

2. Conclusion

By changing the operating mode of the centrifugal pump it is possible to eliminate its failures due to a reduction in the electric resistance of the "cable-motor" system and salt deposition - all without using any chemical reagents. The entire process of adjustment and calculation can be easily programmed and the obtained software can be installed on a control computer as an aide to process engineers.

References

[1] Gareyev A.A./ Regarding the significance of thermal condition in electric centrifugal pump units (ESP). “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector), No. 1, 2009, pp. 23-29

[2] Gareyev A.A./ Regarding maximum-permissible gas content at centrifugal pump intake. “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector), No. 2, 2009, pp. 21-25.

[3] Gareyev A.A./ Regarding the thermal behavior and thermal-shock phenomenon of electric centrifugal pumps, “Neftyanoye khozyaistvo” (Oil Facilities), No. 3, 2011, pp. 122-126.

[4] Gareyev A.A./ Regarding gas-separation coefficient at pump intake, “Neftyanoye khozyaistvo” (Oil Facilities), No. 6, 2009, pp. 90-93.

[5] Gareyev A.A./ Regarding the thermal behavior of electric submersible pumps. Moscow: VNIIOENG, “Neftepromyslovoye delo” (Oilfield Engineering), Series “Equipment and Technologies for Oil-and-Gas Facilities,” 2010, No. 6, pp. 35-41.

[6] Gareyev A.A./ Regarding the thermal behaviour of a centrifugal pump for oil recovery Engineering Science (ES): August 9, 2019, p. 28 - 33

[7] Gareyev A.A./ Current Issues of Oil Production at Offshore Fields, Ocean Journal of Chemical and Petroleum Engineering, OJPCE, 2021

[8] Gareyev A.A./ Environmental issues of transient behavior, Petroleum & Petrochemical Engineering Journal, October 2021, p. 23 – 32

[9] Gareyev A.A./ Salt deposition in electric submersible centrifugal pumps under intermittent operation

[10] Gareyev A.A./ Regarding the salt-deposition mechanism. “Neftepromyslovoye delo” (Oilfield Engineering). 2017, No .4, pp. 35-45;

[11] Gareyev A.A./ Regarding the prediction of salt-deposition in ESP units. “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector). Moscow 2018, No. 5, pp. 37-42;

[12] Gareyev A.A./ Salt deposition in centrifugal pumps as a result of boiling. “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector). Moscow 2018, No. 2, pp. 51-56;

[13] Gareyev A.A./ Techniques for electric centrifugal-pump operation without salt deposition (task description) “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector). Moscow 2018, No. 3, pp. 27- 31