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The use of a wind-driven power unit for supplying the heating cable assembly of an oil well, complicated by the formation of asphalt-resin-paraffin deposits

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Abstract. In this article authors propose application of the technology for preventing formation of asphalt-resin-paraffin deposits in the oil well of the Fainsk oil field by the thermal treatment with the use of a wind-driven power unit as an autonomous power source. The calculations confirm the efficiency of the electrothermal complex application at the Fainsk oil field.

1. Introduction

Extraction of paraffinic oils is accompanied by the formation of asphalt-resin-paraffin deposits (ARPD), which cause complications in the work of wellbore, oilfield equipment and pipelines, at the same time decreasing efficiency of production system and pumping plants [9, 10].

The choice of the optimal ARPD counter-measures and their efficiency depends on many factors, in particular, type of oil extraction system, thermobaric regime of fluid flow, composition and properties of the extracted products. Despite the wide variety of methods used to control ARPD, the problem is still far from being resolved and remains one of the most important in the oil industry [7, 9, 12, 8, 9].

The field practice of oil extraction shows that the main elements of ARPD accumulation are borehole pumps, lifting columns in the wells, flow lines of the wellhead, reservoirs of field collecting points. Most intensive ARPD deposition occurs on the inner surface of the lifting pipes in the wellbore. In the flow lines their formation increases in winter, when the ambient air temperature becomes significantly lower than the fluid flow temperature [6].

Most efficient ways to counter paraffin deposits are thermal methods applied in the wellbore shaft, based on the ability of the paraffins to melt at levels above the crystallization temperature of 35–50°C [5, 7, 10, 12, 13].

Heating prevents formation of ARPD deposits on the walls of pipes. As a result, the pipe cross-section remains constant and the oil production from the well is not reduced. Also, maintenance costs of downhole equipment decrease, due to which the economic efficiency of well operation is increased.

The aim of this paper is to study the issues related to defining the required installed capacity of a wind-driven power unit (WDPU) used as an autonomous power source for an electrothermal complex with a heating cable for removing and preventing the formation of ARPD in the shaft of the wellbore.
2. Methodology

Most of the modern oil fields are located in remote regions, which are not connected to the centralized power grid. As an alternative to the construction of new electrical networks, autonomous energy complexes based on wind power plants can be used [3].

The electric heating is done by means of a heating cable placed directly in the inner space of tubing in the wellbore, which allows the heating of any well types at fountain, gas-lift methods of oil production, along with application of submersible pumps. Such scheme for electric heating does not require underground operations, and in some cases, shutdown of the well. The process of lowering the load bearing heating cable is similar to the standard operations with geophysical instruments, and are carried out in the same way. The load-bearing heating cable directly contacts the fluid, so the heat transfer occurs almost with no losses.

2.1. Scheme of the electrothermal complex

The structure of the well electrothermal complex includes (Figure 1): 1 — transformer substation (if necessary); 2 — installation power supplying cable; 3 — control station for the oil heating unit; 4 — power cable; 5 — cable of temperature sensors; 6 — converter terminal box; 7 — safe lock; 8 — heating cable; 9 — cable of the temperature sensor in the thermosocket; 10 — lubricator; 11 — main lock; 12 — wellhead equipment; 13 — tubing; 14 — casing string; 15 — electric submersible pump; 16 — thermosocket with a temperature sensor; 17 — receiving pipeline.

![Figure 1. The structure of the well electrothermal complex.](image)

2.2. Calculation of heating cable setting depth

As the baseline data for the calculation of the heating cable setting depth, the well of the Fainskoye field (Khanty-Mansiysk autonomous district, Tyumen region) was chosen. The parameters of the selected well are presented in Table 1.

The composition of the ARPD, taken from the well 402 pad 29: asphaltenes — 2.39%, resins — 11.20%, paraffins — 3.54%.

The melting point of the paraffin extracted from the degassed oil in laboratory conditions is 62–70°C.
Table 1. Parameters of the wellbore.

| Parameter                                              | Value (Unit) |
|--------------------------------------------------------|--------------|
| Flow rate of the wellbore fluid at standard conditions | 40 (m³/day)  |
| Depth of the wellbore (m)                              | 3100         |
| Gas-oil ratio (m³/m³)                                  | 32.2         |
| Average value of wellbore inclination (deg)            | 8            |
| Formation pressure (MPa)                               | 25           |
| Inner diameter of production casing (m)                | 0.15         |
| Density of formation oil (kg/m³)                       | 746.4        |
| Oil specific heat (J/(kg·K))                           | 880          |
| Water cut                                              | 0.7          |
| Density of formation water (kg/m³)                     | 1050         |
| Formation water specific heat (J/(kg·K))               | 4100         |
| Formation temperature (K)                              | 363          |
| Casing inner diameter (m)                              | 0.0503       |

2.3. Determination of the oil saturation temperature with paraffin

To determine the saturation temperature of oil with paraffin, the following formula is used [9]:

\[
\begin{align*}
t &= t_0 + 0.2 \cdot P - 0.1 \cdot G = 30.11 + 0.2 \cdot 25 - 0.1 \cdot 32.2 = 31.9^\circ C = 304.9^\circ K, \\
t_0 &= 11.398 + 34.084 \cdot \lg C_p = 11.398 + 34.084 \cdot \lg 3.54 = 30.11^\circ C,
\end{align*}
\]

where \( t \) — saturation temperature of oil with paraffin in the reservoir conditions (K); \( t_0 \) — saturation temperature of oil with paraffin in surface conditions (°C); \( P \) — formation pressure (MPa); \( G \) — gas factor (m³/m³); \( C_p \) — concentration of paraffin in oil (%).

Paraffin precipitation in the well starts at a depth corresponding to the Initial point of paraffin crystallization. Then, mass formation of paraffin begins in the subsequent interval, and deposition of resins occurs closer to the wellhead and in on-land pipelines [2, 11].

2.4. Determination of the oil saturation temperature with paraffin

The temperature distribution along the depth of the well can be described by the formula:

\[
\begin{align*}
T(H) &= T_1 - (L - H) \cdot \frac{0.0034 + 0.79 \cdot \omega \cdot \cos \alpha}{10^{0.98\sqrt{[86400 \cdot 20^2 \cdot 3100]}}} ,
\end{align*}
\]

where \( T_1 \) — formation temperature (K); \( L \) — depth of the wellbore (m); \( H \) — current depth, measured from the wellhead (m); \( \alpha \) — angle of wellbore deviation from vertical (degrees); \( Q_V \) — flow rate of the well in standard conditions (m³/day); \( d \) — inner diameter of tubing (m); \( \omega \) — geothermal gradient (degrees/m), calculated by the formula:

\[
\omega = \frac{T_1 - T_n}{(L - H_n) \cdot \cos \alpha} = \frac{363 - 278}{(3100 - 30) \cdot \cos 8^\circ} = 0.02796,
\]

where \( T_n \) is the temperature of the neutral layer (K); \( H_n \) is the depth of the neutral layer (m).

The temperature of the neutral layer for the oil region of Western Siberia is assumed to be \( T_n = 278^\circ K \). The depth of the neutral layer from the Earth's surface varies from 20 m to 40 m, in this work value \( H_n = 20 \) m is taken.
An example of temperature calculation in the well at a depth of 100 m:

$$ T(H) = 363 - (3100 - 100) \cdot \frac{0.0034 + 0.79 \cdot 0.02796 \cdot \cos 8^\circ}{10^{4/[6600 - 20 \cdot 0.0502^{24}]} } = 298.1 \text{ K}. $$

| Current depth, H (m) | Temperature, T (K) |
|-----------------------|--------------------|
| 0                     | 296.0              |
| 100                   | 298.1              |
| 200                   | 300.3              |
| 300                   | 302.5              |
| 400                   | 304.6              |
| 500                   | 306.8              |
| 600                   | 309.0              |
| 700                   | 311.1              |
| 800                   | 313.3              |
| 900                   | 315.4              |
| 1000                  | 317.6              |

| Current depth, H (m) | Temperature, T (K) |
|-----------------------|--------------------|
| 1100                  | 319.8              |
| 1200                  | 321.9              |
| 1300                  | 324.1              |
| 1400                  | 326.2              |
| 1500                  | 328.4              |
| 1600                  | 330.6              |
| 1700                  | 332.7              |
| 1800                  | 334.9              |
| 1900                  | 337.1              |
| 2000                  | 339.2              |
| 2100                  | 341.4              |

Table 2. Calculation results of the temperature distribution along the depth of the wellbore.

Results of the calculations are presented in the table 2. It can be concluded that the heating cable must be lowered to a depth of 500 m.

2.5. Calculation of required heat energy

The amount of heat energy required to heat the water-oil mixture in the well can be determined by the formula:

$$ Q = c \cdot m \cdot \Delta T, \quad (4) $$

where $Q$ — the amount of heat received by the substance upon heating (J); $c$ — the specific heat of the heated substance (J/(kg·K)); $m$ — the mass of the heated substance (kg); $\Delta T$ — the difference between the final and initial temperatures of the substance (K).

Specific heat of water-oil mixture is determined by:

$$ c_{\text{mix}} = c_{\text{oil}} \cdot (1 - b) + c_{w} \cdot b = 880 \cdot (1 - 0.7) + 4100 \cdot 0.7 = 3134 \text{ J/(kg · K)}, \quad (5) $$

where $c_{\text{mix}}$ — the specific heat of the water-oil mixture (J/(kg·K)); $c_{\text{oil}}$ — the specific heat of oil (J/(kg·K)); $c_{w}$ — the specific heat of the formation water (J/(kg·K)); $b$ — coefficient of water cut.

The mass of the water-oil mixture column in the tubing is determined by:

$$ m = V \cdot \rho_{\text{mix}}, \quad (6) $$

where $m$ — mass of the water-oil mixture column in the tubing (kg); $V$ — volume occupied by the water-oil mixture (m³); $\rho_{\text{mix}}$ — density of the water-oil mixture (kg/m³).

The density of the water-oil mixture in the tubing is determined by:

$$ \rho_{\text{mix}} = \rho_{\text{oil}} \cdot (1 - b) + \rho_{w} \cdot b = 746.4 \cdot (1 - 0.7) + 1050 \cdot 0.7 = 958.92 \text{ kg/m}^3, \quad (7) $$

where $\rho_{\text{oil}}$ — density of formation oil (kg/m³); $\rho_{w}$ — density of formation water (kg/m³).

The volume occupied by the water-oil mixture in the tubing is determined by the formula:

$$ V = 0.25\pi \cdot d^2 \cdot h, \quad (8) $$

where $d$ — inner diameter of the tubing (m); $h$ — height of the heated water-oil mixture column (m).
In order to prevent the formation of paraffin plugs throughout the wellbore it is necessary to heat the entire column of the water-oil mixture in the tubing from the point of paraffin initial crystallization to the wellhead. As a result of mentioned above calculations, it was found that the initial temperature of paraffin crystallization is 304.9 K, at a depth between 400 and 500 m. According to the calculated data, the temperature in the wellbore changes on average by approximately 2.16 K for every 100 m of the well (see Table 2). Thus, it is necessary to calculate the amount of heat required to heat the water-oil mixture by 2.16 K in the interval 0–500 m from the wellhead using a heating cable.

The heated volume occupied by the water-oil mixture in the tubing is:

\[ V = 0.25\pi \cdot d^2 \cdot h = 0.25 \cdot 3.14 \cdot 0.0503^2 \cdot 500 = 0.9936 m^3. \]

The heated mass of the water-oil mixture column in the tubing is:

\[ m = V \cdot \rho_{mix} = 0.9936 \cdot 958.92 = 952.75 kg. \]

The amount of heat required to heat the water-oil mixture in the tubing is:

\[ Q' = c_{mix} \cdot m \cdot \Delta T = 3134 \cdot 952.75 \cdot 2.16 = 6455320.2 \cdot 1.793 \text{ kW} \cdot \text{h}. \]

The inner diameter of the production string is 0.15 m, and the outer diameter of the tubing string is 0.0603 m. Thus, the annulus of the well is represented by a ring of water-oil mixture, 0.0449 m thick.

The ratio of the outer diameter of the tubing string to the inner diameter of the casing is 2/5. Noting this, the energy losses when the column of liquid is heated are equal to 40% of the previously calculated amount of heat, and in the considered case are equal to \( Q'' = 0.332 \text{ kW} \cdot \text{h}. \) In addition, it is necessary to take into account that the efficiency of warming is influenced by the rate of fluid outflow from the well. This type of heat losses (additional losses), can be calculated by the formula and are equal to:

\[ Q'' = \left( \frac{Q_v}{24} - V \right) \cdot Q = \left( \frac{40}{24} - 0.9936 \right) \cdot 1.793 = 0.558 \text{ kW} \cdot \text{h}. \] (9)

Thus, to prevent deposition of ARPD in the shaft of an oil well, the water-oil mixture in the interval 0–500 m from the wellhead must be heated by the means of a heating cable. For this purpose, it is necessary to spend 3.72 kW·h of thermal energy (Q), of which 19.3% will be spent on compensation of heat losses in the annulus of the well (Q''), and 32.5% to compensate losses from heat removal due to the flow of liquid with a given production rate (Q///).

3. Selection of WDPU

According to the work [4], the coefficient of installed capacity usage (CICU) of the wind turbine in the electrothermal complex depends on the average annual wind speed; variations in the distribution of wind speeds by gradation, heating cable resistance and control method. The minimum values of the CICU of the WDPU in structure of the complex, depending on the average annual wind speeds, are presented in Table 3 [1].

| Annual wind speed (m/s) | Minimal CICU (%) |
|------------------------|-------------------|
| 4                      | 10                |
| 5                      | 16.3              |
| 6                      | 22.8              |
| 7                      | 27.1              |
Minimum average power of the WDPU as a part of the electrothermal complex with a heating cable for removing and preventing the formation of ARPD in the shaft of an oil well, based on the minimum CICU (see Table 3) and the time of reaching target temperature \(T = 306.8 \text{ K}\) per hour can be determined by the formula:

\[
P_{WG(\text{min})} = \frac{Q}{k} = \frac{Q' + Q'' + Q'''}{k},
\]

where \(P_{WG(\text{min})}\) — minimum average power of the WDPU at the time of reaching the target temperature of 1 hour (kW); \(Q'\) — the amount of heat required to heat the water-oil mixture in the tubing (kW·h); \(Q''\) — the amount of heat required to compensate for heat losses in the annulus (kW·h); \(Q'''\) — the amount of heat required to compensate for heat losses due to the flow of liquid with a given production rate (kW·h); \(k\) — minimum projected CICU of the WDPU (\%).

The temperature in the wellbore in the interval 0–500 m from the wellhead, taking into account the variation in the power of the WDPU in the structure of the electrothermal complex at different average annual wind speeds can be determined according to the formula:

\[
T(0–500) = \frac{P_{WG} - P_{WG(\text{min})}}{Q(1^\circ\text{C}) \cdot t} + T(500),
\]

where \(P_{WG}\) — the average power of the WDPU at the time of reaching the target temperature of 1 hour (kW); \(Q(1^\circ\text{C})\) — the amount of heat required for heating the water-oil mixture in the range of 0–500 m from the wellhead by means of a heating cable to \(1^\circ\text{C}\) or \(1 \text{ K}\) (kW·h / K); \(T(500)\) — projected temperature in the wellbore at a depth of 500 m from the wellhead (K).

Calculation results of the average steady-state temperature in the wellbore at the interval 0-500 m are shown in Figure 2.

![Figure 2](image-url)

**Figure 2.** Dependence of the average steady-state temperature in the wellbore at the interval 0–500 m from the installed capacity of the WDPU, taking into account the average annual wind speed.
4. Conclusions
As the result, the use of WDPU with an installed capacity of more than 40 kW as an autonomous power source in the electrothermal complex with a heating cable ensures the maintenance of an average steady-state temperature in the wellbore above the initial ARPD crystallization point.

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References
[1] Abramovich B N and Sychev Yu A 2017 Problems of ensuring energy security for enterprises from mineral resources sector J. of Mining Inst. 217 132-9
[2] Aleksandrov A N and Rogachev M K 2017 Determination of temperature of model oil solutions saturation with paraffin Int. Res. J. 6 101–8
[3] Belsky A A and Dobush V S 2016 Oil well electrical heating facility utilizing heating cable powered by autonomous wind-driven power unit Proc. Int. Conf. Dynamics of Systems, Mechanisms and Machines, Dynamics (IEEE) pp 1–4
[4] Belsky A A and Dobush V S 2017 Autonomous electrical heating facility supplied by wind turbine for elimination of oil wellbore paraffin deposits Proc. Int. Conf. on Industrial Engineering, Applications and Manufacturing (IEEE) pp 1–4
[5] Glushchenko V N, Silin M A and Gerin Iu G 2009 Prevention and removal of asphaltene, resin and paraffin deposits (Moscow: Interkontakt. Nauka) p 475
[6] Ibragimov N G, Tronov V P and Guskova I A 2010 Theory and practice of methods for controlling organic deposits at a late stage of the development of oil deposits (Moscow: Neftyanoe khozyaystvo) p 240
[7] Ivanova L V, Burov E A and Koshelev V N 2011 Asphalten, resin and paraffin deposits in the processes of extraction, transport and storage Oil and gas business 1 268-84
[8] Korobov G Y and Mordvinov V A 2012 Study of adsorption and desorption of asphaltene sediments inhibitor in the bottomhole formation zone Int. J. of Appl. Eng. Res. 12 267-72
[9] Korobov G Y and Mordvinov V A 2013 Temperature distribution along well bore Neftyanoe khozyaystvo 4 57–9
[10] Morenov V and Leusheva E 2016 Energy Delivery at Oil and Gas Wells Construction in Regions with Harsh Climate Int. J. of Eng. Trans. B 29 274–9
[11] Struchkov I A and Rogachev M K 2017 Risk of Wax Precipitation in Oil Well Natural Resources 26 67–73
[12] Struchkov I A and Rogachev M K 2017 Wax precipitation in multicomponent hydrocarbon system J. of Petroleum Exploration and Production Technology 7 543-53
[13] Struchkov I A and Roschin P V 2016 Effect of light hydrocarbons on wax precipitation Int. J. of Appl. Eng. Res. 11 9058–62