The Efficiency of Use of Heating Cables in Wells of Complicated Stock

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Depending on geological, physical and technological conditions and the composition of extracted fluids, the process of exploitation of producing wells can be complicated by asphalt-paraffin-resin deposition (APRD) on the surface of downhole equipment. Scientists and industrial workers have studied factors like pressure, temperature, the nature of wettability of the wetted surface, oil flow rate, resin, asphaltene and paraffin wax percentage in reservoir oil composition. That gives an opportunity to resolve problems of APRD prevention and removal purposefully. Methods of APRD prevention in oil producing wells were analysed, data of measuring of the thickness of APRD, formed on downhole equipment in the process of producing well exploitation, were obtained and treated during this research work. In addition, the depth where intensified paraffin formation starts was determined. It was recommended what devices and technologies for APRD prevention and removal to use to decrease the number of workovers and flushing of producing wells. The technology of APRD prevention by maintaining oil flow temperature with heating cable employment is proposed. During operation, the cable heats the internal or external surface of tubing string which, in turn, heat the fluid that moves through the string to the temperature equal or exceeding the temperature of deposition formation.

***Keywords:** asphalt-paraffin-resin deposition, sucker-rod pumping units, heating lines, well, paraffin deposition, equipment failures, solid particles.*

Introduction

During exploitation of wells by sucker-rod pumping units different complications occur: high viscosity of reservoir fluid, high curvature of wellbore, presence of sand formation of APRD and inorganic salts, gas influence, which lead to considerable decrease of well flow rate, and sometimes cause full termination of well operation (Ivanova et al., 2016, Ivanova et al., 2016, Baranov et al., 2017).

During oil production, the pressure and the temperature in producing wells decrease, gas evolves, the flow of fluids is cooled. This results in a decrease of oil solubility and APRD precipitation in sucker-rod pump and tubing string. (Fig. 1) (Baranov et al., 2017, Drachuk et al., 2017, Galikeev et al., 2015, Persiyancev, 2000).

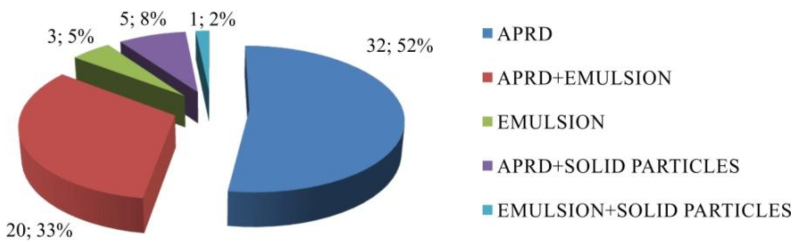

Fig. 1. Typical causes of complications in operation of sucker-rod pumping units.

Formation of APRD is influenced by (Baranov et al., 2017):

- downhole pressure drop below bubble point pressure, it results in hydrodynamic equilibrium imbalance,
- intensive gas evolution from oil,
- temperature decrease in the reservoir and wellbore,
- change of liquid-gas mixture motion speed,

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- the surface condition of the tubing string and sucker-rods,
- oil water ratio,
- hydrocarbon composition of every mixture phase.

Formation of paraffin deposition in wells occurs when pressure and temperature decrease and oil degasification begins. If downhole pressure exceeds bubble point pressure in the wellbore, the system remains in an equilibrium state, and only liquids move before reaching the area, where the pressure is equal to bubble point pressure (Ibragimov et al., 2000, Nasyrov et al., 2011). Then, the equilibrium state is disturbed, the volume of gas phase increases, the liquid phase becomes imbalanced and causes precipitation of paraffin. That is why the point of wax precipitation can be located at any depth and depends on well operation conditions. If the downhole pressure is lower than bubble point pressure, equilibrium state of the reservoir is disturbed, wax precipitates in the bed as well as in wellbore, starting from the bottom of the well. Paraffin deposition intensifies when downhole pressure and pre-critical temperature are reducing (Babalyan, 1965, Bogomol'nyj, 2003).

In the pumping method of exploitation, intake pressure p_{pr} is lower than bubble point pressure p_s. It results in wax precipitation in pump suction and on production casing walls. The tubing string is divided into two zones. The first one includes the outlet side of the pump with sudden pressure increase, exceeding bubble point pressure. Liquid moves in this interval. In the second zone, the pressure decreases to bubble point pressure and below with intensive paraffin precipitation. As for natural flow wells, if downhole pressure is kept equal to bubble point pressure, wax precipitation should be expected in tubing string (Gavrilyuk et al., 2014, Guskova et al., 1999).

If the downhole pressure is reduced to values equal to p_s or lower than p_s in order to stimulate inflow, the probability of gas evolution and wax precipitation increases in every interval including wellbore and tubing string (Getman et al., 2014).

The following processes contribute to deposition and formation of plugs of precipitated paraffin:

- adsorptive processes which occur on boundary metal - paraffin - tarry substances;
- products of reservoir damage, solid particles;
- surface roughness;
- moving speed and structure of liquid-gas mixture flow
- electrokinetic effects, causing electrification of both pipe wall surface and paraffin crystals surface, which intensify adhesion of paraffin to metal (Guskova et al., 2010).

Paraffin deposition on the internal surface of the tubing string starts on the depth, where the temperature of the well corresponds to paraffin crystallisation point. APRD accumulation in the flow channel of tubing string leads to pumping units output decrease, reducing of time between overhauls (Guskova et al., 2010, Egorov, 2013). Thickness of APRD gradually increases from the place 500 - 900 m deep, where they start accumulating and reaches its peak on depth of 50-200 m from the top of the well, then it slowly decreases to 1-2 mm near the well-head (Ivanova et al., 2011, Abramov et al., 2014, Božek, 2013). Deposition diagram is drawn according to the results of the study of the thickness of APRD formation on tubing string walls during pipe removal from the well (Fig. 2). It is observed that both the intensity of paraffin deposition and amount of hot oiling operations decrease under peak fluid viscosity (water cut is less than 75%) (Ivanova et al., 2017, Baranov et al., 2017).

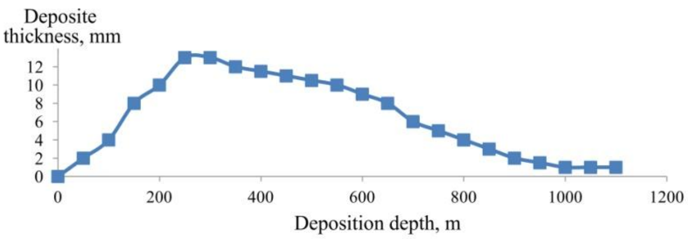

Fig. 2. Measurements of deposite thickness during well servicing.

The paraffin falling out of oil and its covering of the walls of pipes are contributed by the decline of temperature and pressure of the moving flow of fluid in the well by tubing to their defined critical values. Thus, one of the important factors, influencing on the formation of ARPD, is a decline of the temperature of the liquid below than the temperature of saturation (to the temperature of the beginning of paraffin crystallisation). This condition is the necessary condition for the formation of paraffin deposits. The producing fluid (emulsion) cools down because of the heat exchange with surrounding rocks during the lifting and soil during the collection and transportation, and also as a result of phase transitions. The decline of reservoir pressure below the pressure of saturation also brings to cooling down of the flow and change of oil composition. Here at rare gases and lightest hydrocarbons transit to the gas area. Degassing for different oils variously influences on the paraffin saturation point. This fact is explained not only by the change of dissolving ability in relation to it but also flocculating action on micelles of asphaltenes. From many literature sources, it follows that ARPD in the hole walls can be found beginning from the depth approximately 1000 m to the depth 200...50 m (achieving a maximum here). Higher the layer of ARPD diminishes due to washing off deposits by the flow of the well fluid.

The factor, strongly influencing on the ability of ARPD formation on the surface of pipes with the change of temperature is also the liquid flow velocity. It determines the hydrodynamic regime. It is known that at the debits of oil more than 70 ton/day paraffin deposits are not observed. The characteristics of the surface substantially influence the formation of deposits. The considerable roughness of the surface (height of combs of 7–9 km and more) helps in the formation of paraffin deposits, and high polarity of pipes' surface, vice versa, hinders the formation of deposits (Seredyuk et al., 2009).

Results and discussion

The analysis of deposits in tubing strings has demonstrated that:

- paraffin content in deposits increases from bottom to the top of the well reaching peak value near the well-head;
- paraffin melting temperature decreases from the bottom to the top of the well;
- in a period of full paraffin blockage of pipes paraffin deposits reach 10 – 15 % (by weight) of paraffin accumulated in oil;
- hydrophilic nature of the surface leads to a decrease in the intensity of paraffin sticking;
- the more infusible paraffin is, the greater adhesion and sticking abilities of crystals are observed.

In the presence of one or several factors complicating the oil production process, wells are converted to complicated stock which consists of more than 50% of the whole amount of wells equipped by sucker-rod pumping units. This stock is exposed to significant risk of premature failures of equipment which cause downtime of well. Table 1 demonstrates the distribution of premature failures of sucker-rod pumping units. It was identified that sucker-rod breakage occurs due to oscillatory loads caused by APRD formation, corrosion impact of environment on the column and metal fatigue.

Tab. 1. Causes of failures of sucker-rod pumping units of the well stock.

Causes of failures of sucker-rod pumping units	**2015**		**2016**	
	Amount of failures	**%**	**Amount of failures**	**%**
Sucker-rod breakage	41	36	43	39
Sucker-rod twist-off	12	11	14	12
Failure of sucker-rod pump	39	35	34	31
Leakage of submersible equipment	6	5	9	8
Other	15	13	11	10

The main part of wells shut down for well servicing due to sucker-rod breakage, or twist-off is complicated by APRD (table 2). Three types of complications occur the most often during well exploitation in Udmurtia: APRD formation, highly viscous water-oil emulsion formation and solid particles in well production.

Tab. 2. Causes of failures of candidate wells.

well	**Actual cause of failure**	**Complication in submersible equipment operation**
1	Sucker-rod breakage	APRD, solid particles
2	Sucker-rod breakage	APRD, solid particles
3	Sucker-rod twist-off	APRD, emulsion
4	Sucker-rod breakage	APRD, emulsion, solid particles
5	Sucker-rod breakage	APRD
6	Valve choking	APRD
7	Sucker-rod breakage	APRD, emulsion
8	Sucker-rod breakage	APRD
9	Valve choking	APRD
10	Sucker-rod breakage	APRD

APRD formation on the external surface of sucker-rod string and the internal surface of the tubing string is entailed by the growth of peak loads and decrease in minimal loads applied to horse-head of beam unit (Fig. 3). It leads to normal well operation failure and the growth of force of hydrodynamic friction in the tubing string, that can cause accidents resulting in well killing and well servicing. APRD formation increases the load applied to horse-head, reducing the operational life of the downhole equipment. As a result, the amount of premature failures increases and wells are brought in well stock subject to frequent workover. These all cause a decrease in time between overhauls.

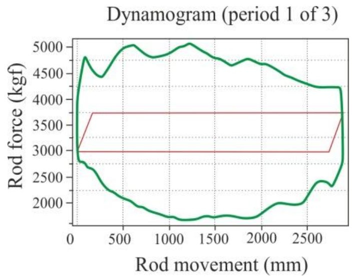

Fig. 3. Dynamogram of well № 1.

The time between overhauls (TBO) is one of the indicators characterising well operation in time. The time between overhauls - is mean time of continuous well operation in days between two overhauls. TBO is determined for active wells stock, all well stocks and every recovery method.

Calculation of TBO of well operation is made for the rolling year, i.e. for 12 months from the beginning of the analysed period. It is also calculated for the current month (for 30 or 31 days from the beginning of the analysed period).

The number of workovers includes all workovers, carried due to failures of downhole equipment of well stock happened during the calculation period. In addition, it includes conducting well interventions for bottom-hole treatment to increase well productivity.

Workovers connected with the following factors are not taken into account during TBO calculation:

- wellhead accessories replacement;
- change of the length of pipe suspension within the limit of 100 metres;
- polished rod replacement.

Workovers, connected with well flushing, well shifting, replacement of one operation mode with another, change of equipment type, removal of sand plugs, scaling and APRD, are taken into account during calculation of TBO of well operation.

The main directions of well interventions for increasing of TBO of wells equipped with sucker-rod pumping units include the following:

1. downhole equipment condition monitoring,
2. the control of bringing the well on to stable production,
3. carrying out mitigation response in well operation.

Struggle against APRD is conducted by two directions: prevention from APRD formation and removal of APRD.

In order to prevent from APRD formation, it is recommended to carry out the following operations:

- injection of inhibitors (RTF-1 (РТФ-1 Russian State Standard), RT-1M (РТ-1М), SNPH-7941 (СНПХ-7941), dissolvan 4316 (диссолван 4316), etc.) in the tubular annulus by dosage pumps. Depending on oil properties and its water cut, the dose ranges from 50 to 200 g per tonne of the produced fluid. The dosage is carried out through wellhead dosage units UDE (УДЭ), UDS(УДС) in the amount of 50-100 g per cubic meter of the produced fluid.
- applying lined pipes;
- exclusion of flushing of the bottom-hole zone with fresh water;
- applying special well-killing fluids (oil based hydrophobic emulsion solutions, etc.).
- To remove APRD, it is recommended to carry out the following operations:
- hot oiling of the tubing string and steaming by mobile dewaxing unit 2ADP-12/150 (2АДП-12/150), modernised mobile dewaxing unit ADPM-16/150 (АДПМ-16/150 Russian State Standard) and mobile steam heaters;
- flushing of tubing string by solvents RT-1U (РТ-1У), SNPH-7870A (СНПХ-7870А), hexane fraction, solutions of surfactants ML-72 (МЛ-72), ML-80 (МЛ-80), hydrophobic-emulsive solutions;
- hot water well flushing with inhibitors RTF-1 (РТФ-1), RT-1M (РТ-1М);

- in the case of small wellbore deviation (zenith angle of the wellbore is 5 - 10º), lamellar scraper on sucker-rods with rod rotator may be used.

Thermal methods of APRD removal have found the widest use. These methods are based on the combined effect on APRD to melt it and reduce the power of adhesion to the surface. Hot oiling and hot water well flushing are the most widely used on oilfields of Udmurtia.

Despite considerable efficiency, dewaxing of wells by means of hot oiling has several drawbacks. The high flow rate of stock-tank oil (up to 30 cubic meters per well) is required for well treatment. Under small reservoir pressure the main part of mud migrates to producing reservoir, that results in sudden well killing and reduces its productivity. In some wells, the share of non-return of oil is up to 50%.

Deposits flushed out to the top of the well after well cleanout go through valve units, clogging them and causing premature failures of oilfield equipment. The major drawback of oil dewaxing by hot water is the absence of heat source on the well. The use of special heating cable lines in order to prevent from APRD formation will allow increasing of purge period, decreasing amount of failures of downhole equipment, caused by APRD formation.

Paraffin-based oil has a considerable share of all oil produced on oilfields of Udmurtia. Production of paraffin-base oil is entailed by the occurrence of new phases in oil flow - gas bubbles and paraffin crystals. Complications caused by paraffin crystals deposition in the bottom-hole zone as well as in tubing string, ground-based communication lines and tanks lead to a decrease in oil recovery. To reduce the number of failures caused by APRD formation, it is necessary to break schedules of well flushing by chemicals as well as schedules of dewaxing by means of hot oiling.

As for wells equipped by the sucker-rod pump, well fluid can be heated by heating cable only in the case if it runs outside the tubing string (Fig. 4) because there are sucker rods inside.

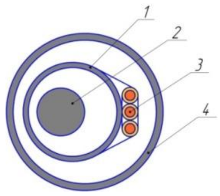

Fig. 4. The location of the heating cable in the well for warming the fluid in the well: 1 - tubing string, 2 - sucker-rods, 3 - heating cable, 4 – casing.

Heating cable lines are widely used in oil production to remove APRD formations on downhole equipment. This technology is an alternative to thermal treatment of wells by hot oiling.

Selection of candidate wells for installation of cable lines is carried out in accordance with specific requirements:

- the presence of free power on package transformer substation (PTS);
- increased necessity in use of heating cable lines. It is related to the wells with the ineffectiveness of hot oiling as well as wells with complicated access for special machinery;
- small purge period (less than 60 days) and high frequency of repairs caused by APRD (more than two times a year).

Having analysed well stock subject to frequent workover, it is proposed to equip 10 wells with heating cable lines to reduce the number of well workovers. Candidate wells are demonstrated in table 3.

Tab. 3. Candidate wells for installation of heating cable lines.

well №	The number of workovers, operations per year	TBO, days	Purge period, days
1	4	72	30
2	5	48	29
3	4	73	32
4	3	106	35
5	2	172	32
6	5	48	30
7	2	175	31
8	5	46	30
9	3	107	30
10	2	178	30

Automated self-regulating line heater (АСЛН-1) for well fluid heating consists (structurally) from heating and electronic parts. The scheme of the unit is demonstrated in Fig. 5.

Heating part is presented as heating cable with termination device. Cable type, cross-section diameter and material of electric conductors are determined after heat calculation and depend on well operation conditions, the viscosity of fluid produced, interval and intensity of APRD formation. The electronic part of the unit is presented as a field control station. Field control station consists of electronic power elements and the heating control unit.

Field control station has the following degrees of protection:

- from current overload;
- of resistance of insulation of heater (threshold value 300 kOhm);
- from overheat of heating cable accordingly to the mean temperature of the electric conductor.

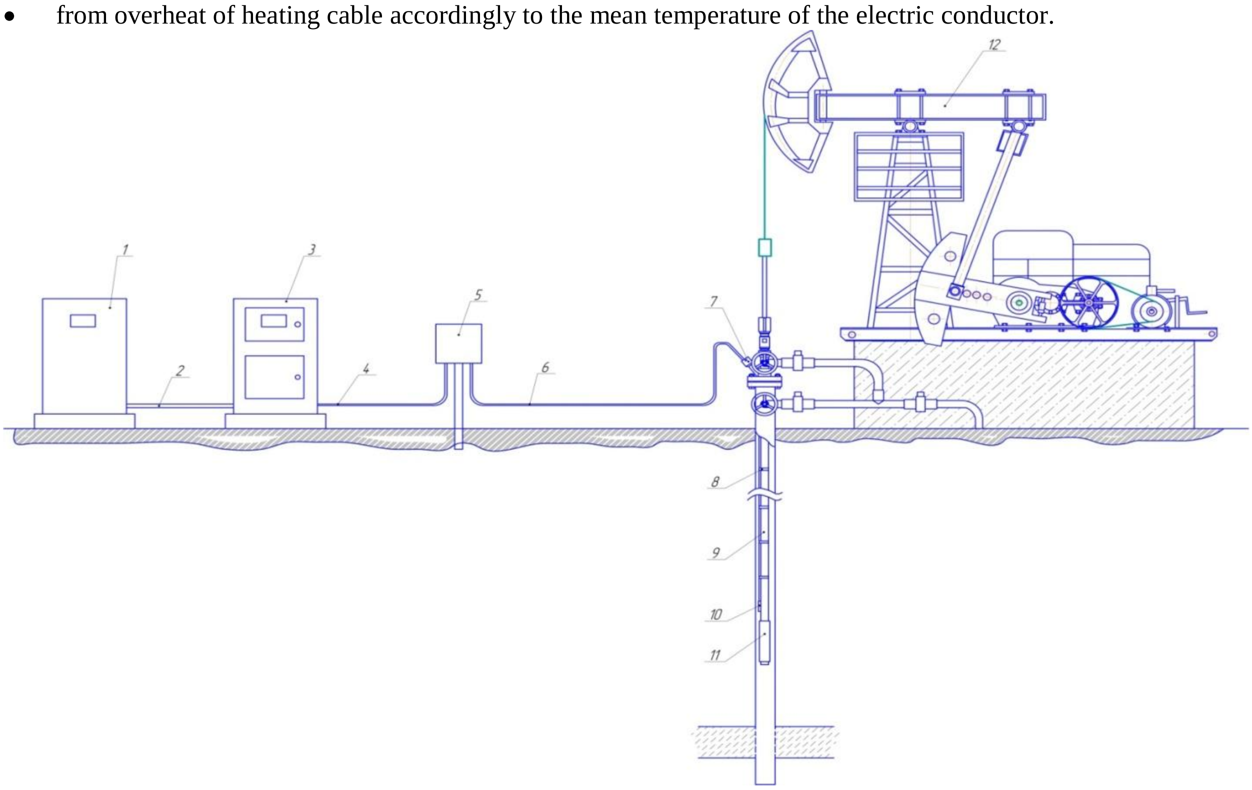

Fig. 5. Schematic location of heating cable unit on the well: 1 - transformer substation, 2 - feed cable of the unit, 3 - heating cable control station, 4 - power line, 5 - terminal box, 6 - heating cable, 7 - cable inlet device with sealing gland, 8 - metal belts for cable fixing, 9 - tubing string, 10 - termination device of heating cable, 11 - sucker-rod pump, 12 - beam-pumping unit.

There are three possible variants of control station work: "Manual", "0", "Automate". In mode "Manual" protection accordingly, insulation resistance and temperature of electric conductors of the cable are switched off. This mode is used for power circuit checking.

Programming of control station is carried out in mode "0". Mode "Automate" is used as major and allows manageable and controlled exploitation of the unit. The pressurisation of the inlet of cable in the well is fulfilled by special cable inlet device with sealing gland, also being an auxiliary element.

On the surface, electric conductors are inserted in terminal box. Terminal box is connected to control station by power conducting cable. To provide automatic regulation of heating over the temperature, a resistance thermometer (temperature sensor) is connected to the heating cable control station, connected via a cable to the control station.

The main technical characteristics of АСЛН-1 (Russian State Standard) heater are demonstrated in table 4 (Vdovin E.A., 2005).

The heating cable is installed on the external wall of the tubing string by means of steel belts for cable fixing and protector-centralisers.

The growth of heated reservoir fluid ΔT on the top of the well is determined by the formula:

$$\Delta T = \frac{7.5 \times P}{Q},\ ^{\circ}C \tag{1}$$

where P – the power of heating cable line, kW; Q – well flow rate, tonnes per day.

Tab. 4. The main technical characteristics of the АСЛН-1 heater.

Name	АСЛН-1 heater *Russian State Standard*
Heating cable length, m	1300
Cable type	КНМПпБП-120 3x10 Russian State Standard
Cross-section of electric conductors, mm^2	10
Electric resistance of conductors to direct current, Ohm	
for cable	3.77
for control station	0.4
Electric resistance of insulation, MOhm	
for cable	10000
for control station	10000
Peak temperature of insulation of electric conductors, °C	+120
Well fluid	Oil, gas, gas condensate, reservoir water with the content of H_2S, CO_2 being up to 0.003%

In this unit cable of type, КНМПпБП-120 is used. It is a flat cable with conductors made of steel and copper wires isolated from each other by polypropylene insulation, the cable is armoured by the steel galvanised band, with a continuously allowable temperature of heating of conductors being equal to 1200 °C.

Setting depth of heating cable depends on the depth of intensive paraffin precipitation. For oils of vereiskian - bashkirian horizon the depth of paraffin deposits reaches the value from 200 to 1300 m. Peak thickness of deposits changes in the interval from 200 to 300 m (Fig. 5).

Paraffin melting temperature on vereiskian - bashkirian object is 51.40 °C. Reservoir temperature is 24 °C. To compensate heat losses during lifting of reservoir fluid and provide the temperature of APRD melting 270 °C are necessary.

Then power needed to keep the temperature higher than the point of paraffin crystallisation for well №1 will be:

$$P = \frac{Q \times \Delta T}{7.5} = \frac{13.5 \times 15}{7.5} = 27 \text{ , } kW/h \qquad (2)$$

Calculations for wells № 2 – 10 are carried similarly. The results of the calculations for these wells are demonstrated in table 5.

Tab. 5. The power of heating cable line for wells.

Well №	***Qж, cmpd***	***ΔT, °C***	***P, kW/h***
1	13.5	15	27
2	12.5	16.2	27
3	7.8	26	27
4	16.7	12	27
5	12	17	27
6	9	23	27
7	14.1	14.4	27
8	15.2	13.5	27
9	19	10.8	27
10	19.2	10.5	27

Interval of APRD formation varies from the depth of 1000 m to the top of the well. Fluid flow rate before installation of heating cable was 25 cmpd. After installation of heating cable amount of hot oiling decreased by more than 3 times (Fig. 6). By means of that, we managed to bring out the wells from well stock subject to frequent workover with a drop in failures caused by APRD and reduce the number of workovers by 3 times. In addition, the time between failures (TBF) was increased. The time between overhauls increased from 36 to 873 days. Before implementation of the heating cable, it was necessary to carry out dewaxing of downhole treatment using hot oiling every 30 days. After the implementation of this equipment, the well dewaxing treatment was not necessary. The results of pilot testing are demonstrated in Fig. 7.

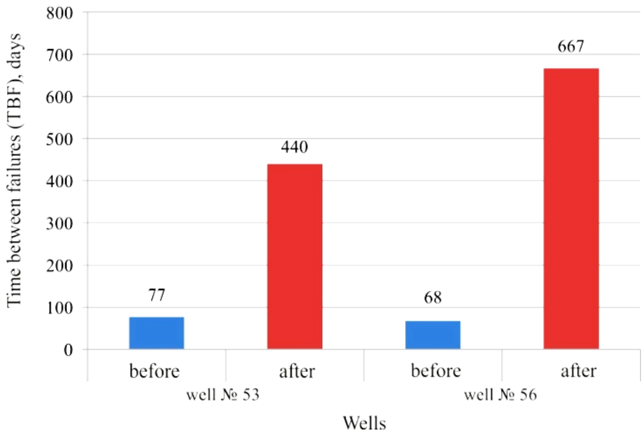

Fig. 6. Increase in TBF of wells.

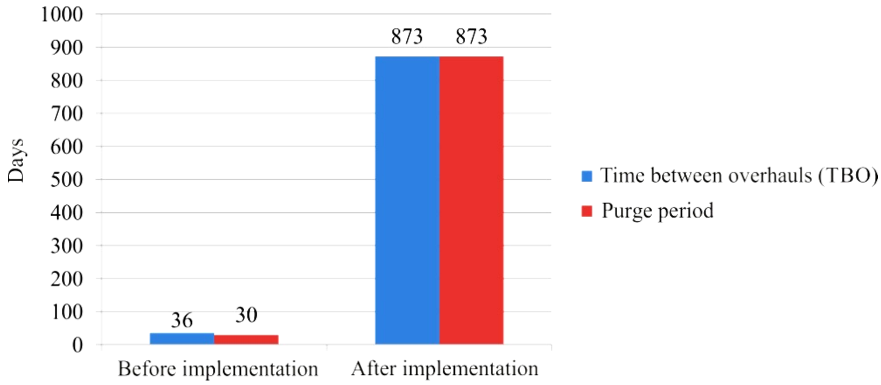

Fig. 7. The results of pilot testing of heating cable on wells of Udmurtia oilfields.

Despite existing power consumption, these units pay for themselves due to drop in expenses on prevention from APRD and its removal. The expenses decrease due to reducing of some workovers and income for incremental oil production resulting from TBO increase. Results of implementation of heating cable lines on oilfields are demonstrated in table 6. The number of workovers caused by APRD decreased by 35 - 40 times after installation of heating cable lines. The use of this technology allowed full rejection of dewaxing of downhole equipment by hot oiling treatment.

Tab. 6. Results of implementing heating cable lines.

Well №	Before implementation		After implementation	
	The number of workovers caused by APRD	The number of flushings for APRD removal	The number of workovers caused by APRD	The number of flushings for APRD removal
1	3	12	0	0
2	7	12	1	0
3	1	12	0	0
4	7	12	2	0
5	1	12	0	0

Summary

Thermal methods of prevention from APRD are based on maintenance of the temperature of oil flow with the use of heating cable. During operation, the cable heats the internal or external surface of tubing string which, in turn, heats the fluid that moves through the string to the temperature equal or exceeding the temperature of deposition formation. After the implementation of this equipment, dewaxing well treatment was not required. This technology is applicable in the removal of APRD formed, provided the calculation of the heating current and the operating time of the heating cable, especially for melting the deposits on the tubing walls.

The increasing exploitation of wells of complicated stock makes it important to understand the mechanism of wax deposition and the methods available to prevent and remediate wax deposits in different systems. This often involves the use of thermal treatment to deliver a fit for purpose wax control and management strategy suitable for a particular development. The thermal technology relates to oil and other industries associated with the production, transport and storage of oil (condensate), and can be used to remove and prevent asphalt, resin and paraffin deposits (ARPD) in wells, oilfield equipment and the bottom hole formation zone, the oil storage tanks.

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