PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

DESENVOLVIMENTO DE UM INIBIDOR DE DEPÓSITO DE ASFALTO-RESINA-PARAFINA E SUBSCANTIAÇÃO DOS PARÂMETROS TECNOLÓGICOS DE SUA INJEÇÃO NA ZONA DE FORMAÇÃO DE FURO INFERIOR

DEVELOPMENT OF AN ASPHALT-RESIN-PARAFFIN DEPOSITS INHIBITOR AND SUBSTANTIATION OF THE TECHNOLOGICAL PARAMETERS OF ITS INJECTION INTO THE BOTTOM-HOLE FORMATION ZONE

РАЗРАБОТКА ИНГИБИТОРА АСФАЛЬТОСМОЛОПАРАФИНОВЫХ ОТЛОЖЕНИЙ И ОБОСНОВАНИЕ ТЕХНОЛОГИЧЕСКИХ ПАРАМЕТРОВ ЕГО ЗАКАЧКИ В ПРИЗАБОЙНУЮ ЗОНУ ПЛАСТА

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RESUMO

O problema da formação de depósitos de asfalto-resina-parafina (ARPD) em campos de petróleo dentro do sistema “poço - zona de formação de fundo de poço” ainda é relevante. Para impedir a formação de ARPD no sistema "zona de formação de fundo de poço - poço", os inibidores de ARPD devem ter propriedades de alta adsorção e baixa dessorção em relação à rocha. A composição de inibidores geralmente inclui surfactantes. Os surfactantes não iônicos, ou seja, os poliésteres são amplamente utilizados para evitar a formação de ARPD. No entanto, atualmente, pouco se sabe sobre inibidores com um efeito combinado, por exemplo, possuindo propriedades dispersoras de depressores em relação à ARPD. O trabalho objetivou desenvolver um inibidor combinado possuindo não apenas propriedades dispersoras de depressores, mas também boas propriedades de adsorção e dessorção em relação à rocha para impedir a formação de ARPD. O artigo apresenta os resultados da pesquisa sobre o desenvolvimento de um inibidor da ARPD, bem como da determinação de suas propriedades dispersoras, inibidoras e corrosivas do depressor; a temperatura da saturação de óleo com parafina também foi determinada. Os estudos da adsorção do inibidor da ARPD foram realizados pelos métodos estático e dinâmico. Já o processo de dessorção do inibidor foi estudado por filtragem de óleo através de uma amostra saturada da rocha usando um modelo a granel e um material do núcleo. O impacto da taxa de fluxo de fluido na taxa de dessorção do inibidor foi estudado. Foram calculados os parâmetros tecnológicos da injeção da solução inibidora da ARPD na zona de formação do fundo dos poços de produção. A composição desenvolvida possui altas propriedades inibidoras em relação à ARPD, propriedades dispersoras de depressores, baixa atividade corrosiva em relação a uma superfície metálica e é capaz de reduzir a temperatura de saturação de óleo com parafina.

Palavras-chave: *depósitos de asfalto-resina-parafina, inibidor, zona de formação de fundo de poço, temperatura de saturação de óleo com parafina, adsorção, dessorção.*

ABSTRACT

The problem of the formation of asphalt-resin-paraffin deposits (ARPD) in oil fields within the “well – bottom-hole formation zone” system is still relevant. To prevent the formation of ARPD in the “bottom-hole formation zone – well” system, the ARPD inhibitors must have high adsorption and low desorption properties concerning the rock. The composition of inhibitors often includes surfactants. Nonionic surfactants, namely, polyesters, are widely used to prevent the formation of ARPD. However, currently, little is known about inhibitors with a combined effect, for example, possessing depressor-dispersing properties for ARPD. This work aimed to develop a combined inhibitor possessing not only depressor-dispersing properties but also having good adsorption and desorption properties to the rock to prevent the formation of ARPD. The paper presents the research results on the development of an ARPD inhibitor, as well as the effects of determination of its depressor-

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dispersing, inhibiting, and corrosive properties; the temperature of oil saturation with paraffin is determined as well. The studies of the ARPD inhibitor adsorption were carried out by the static and dynamic methods. In contrast, the process of the inhibitor desorption was studied by oil filtering through a saturated sample of the rock using a bulk model and core material. The impact of the fluid flow rate on the inhibitor desorption rate was studied. The technological parameters of the ARPD inhibitor solution injection into the bottom-hole formation zone of production wells were calculated. The developed composition has high inhibiting properties concerning the ARPD, depressor-dispersing properties, low corrosive activity for a metal surface, and is capable of lowering the temperature of oil saturation with paraffin.

Keywords: *asphalt-resin-paraffin deposits, inhibitor, bottom-hole formation zone, temperature of oil saturation with paraffin, adsorption, desorption.*

АННОТАЦИЯ

На сегодняшний день проблема образования асфальтосмолопарафиновых отложений (АСПО) на нефтяных месторождениях в системе «скважина-призабойная зона пласта» является актуальной. Чтобы предотвратить образование АСПО в системе «призабойная зона - скважина», ингибиторы АСПО должны обладать высокими адсорбционными и низкими десорбционными свойствами по отношению к породе. В состав ингибиторов часто входят поверхностно-активные вещества. Неионогенные поверхностно-активные вещества, а именно полимеры сложных эфиров, широко используются для предотвращения образования АСПО. Однако, в настоящее время мало известно об ингибиторах с комбинированным эффектом, например, обладающих депрессорно-диспергирующими свойствами по отношению к АСПО. Работа направлена на разработку ингибитора комбинированного действия, обладающего не только депрессорно-диспергирующими свойствами, но также обладающего хорошими адсорбционными и десорбционными свойствами по отношению к породе для того, что предотвратить образование АСПО. В статье представлены результаты исследований по разработке ингибитора АСПО, а также определены его депрессорно-диспергирующие, ингибирующие и коррозионные свойства; температура насыщения нефти парафином. Исследования адсорбции ингибитора АСПО проводились статическим и динамическим методами. Процесс десорбции ингибитора был изучен путем фильтрации нефти через насыщенный образец породы с использованием насыпной модели и кернового материала. Было изучено влияние скорости течения жидкости на скорость десорбции ингибитора. Рассчитаны технологические параметры закачки раствора ингибитора АСПО в призабойную зону пласта добывающих скважин. Разработанный состав обладает высокими ингибирующими свойствами по отношении к АСПО, депрессорно-диспергирующими свойствами, низкой коррозионной активностью по отношению к металлической поверхности и способен снизить температуру насыщения нефти парафином.

Ключевые слова: *асфальтосмолопарафиновые отложения, ингибитор, призабойная зона пласта, температура насыщения нефти парафином, адсорбция, десорбция.*

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1. INTRODUCTION:

Oil production at the fields of the Russian Federation is often associated with unwanted formation of asphalt-resin-paraffin deposits in the bottom-hole formation zone, on the walls of underground well equipment, and in the above-ground lines of the oil and gas gathering and processing system (Yemelyanov *et al.,* 2018, 2019; 2020; Plaskova *et al.,* 2019;).

Currently, chemical methods are the most widely used to prevent the formation of ARPD. Their principle of operation is based on adsorption processes, occurring at a boundary of a liquid and solid surface. Thus, chemical methods are divided by this feature into methods based on the use of wetting agents, modifiers, depressors, and dispersants.

The principle of operation of wetting agents is based on the formation of a hydrophilic film on the solid surface of well equipment, which in turn prevents the adhesion of paraffin crystals to the pipes and creates conditions sufficient for their removal by fluid flow. Modifiers, when interacting with paraffin crystals, changing their wettability, keep them in a suspended, dispersed state, make them rounder, compared to their initial needle-like or diamond shape. The principle of operation of depressors resides in the adsorption of their molecules on paraffin crystals, thereby complicating the process of combining thereof into a single system. Dispersants reduce oil-freezing point. Dispersants increase the thermal conductivity of oil and slow down the process of paraffin crystallization. Due to the increase in duration for paraffin crystals being in a dispersed suspended state, the possibility of removal thereof from the well equipment at the wellhead increases (Windyandari *et al*., 2018;).

To date, the use of ARPD inhibitors to protect well equipment and the BHFZ is a matter of urgency. However, it is often the case that their cost is high, most of the components, included in their composition, are toxic, and an individual selection of reagents for oils with different properties is required. According to field experience, when dosing the ARPD inhibitor for the well bottom-hole, it often enters the reservoir fluid after the formation of paraffin solid phases has begun. This is because the creation of ARPD can occur earlier than the reservoir fluid enters the well, namely in the BHFZ and in the pore space of the oil reservoir.

Despite the diversity of scientific papers devoted to the study of methods for removing organic deposits in oilfield equipment, as of today, the technique for preventing the formation of ARPD by dosing inhibitors in the BHFZ remains poorly studied and unsubstantiated. To solve this problem, it is expedient to use the known technique for preventing scaling, wherein the inhibitor is dosed in the BHFZ (Antipin et al., 1987; Kashchavtsev et al., 2004; Mishchenko 2007; Faskhutdinov et al., 1996).

According to the technique for preventing the formation of ARPD by the injection of reagents into the BHFZ, the duration of the inhibitor removal is determined by the processes of its adsorption and subsequent desorption. In this case, the inhibitor removal by the reservoir fluid up to a minimum effective concentration determines the period of protection of the oilfield equipment from ARPD and the time between injections, when injecting it into the BHFZ. The efficiency of the inhibitor use and the frequency of its injection are determined by the duration of its adsorption-desorption processes occurring in the BHFZ; therefore, to select and substantiate the technique, these processes need to be studied (Solazzi and Zrnić, 2017; Kopish and Marques, 2020).

The study aimed at determining the efficiency of the use of the ARPD inhibitor, as well as its adsorption and dispersing properties with respect to the rock, have been conducted.

2. MATERIALS AND METHODS:

A chemical composition, with a reference designation of IN-1, was developed by us as an ARPD inhibitor, wherein the IN-1 is a composition based on a mixture of olefins and the product of the interaction between unsaturated fatty acids and complex ethylene amines, amino alcohols and mixtures thereof. The ARPD inhibitor (IN-1) acts as a blocking agent to prevent the formation of heavy paraffins, which have a tendency towards sedimentation in fluids under the action of a gravitational field or centrifugal forces and does not require harsh conditions. For better dissolving in oil, it is sufficient to heat the IN-1 reagent to a temperature of 30-40ºC.

Besides, an indirect method for determining the temperature of oil saturation with paraffin, via rheogoniometry, was used to determine the kinematic viscosity of oil with and without adding the IN-1 at a gradual decrease in temperature. To determine the adsorption properties of the IN-1 reagent, a bulk formation model, which is quartz sand, was chosen as the adsorbent. Its grain-size composition with a particle diameter of 0.25-0.1 mm – 85 wt.%; 0.1-0.05 mm – 15 wt.%. The IN-1 reagent was preliminary dissolved in a paraffin oil model, at different concentrations (0.05–2%). Since the ARPD formation begins with the separation of the solid phase of paraffin, only the paraffin oil model was used during the studies. Using the EASYDROP system for measuring the contact angle of wetting and interfacial (surface) tension, the surface tension was measured at the boundary with distilled water, followed by the construction of a calibration curve, that allows one to determine the studied reagent concentration in the fluid by the changes in the surface tension (Neizvestnaya *et al.,* 2018; Szafarczyk, 2019; Prodanova *et al.,* 2019;).

The studies of the ARPD inhibitor (IN-1 reagent) adsorption were carried out by two methods: static – using a bulk model and dynamic – using core material, which renders possible to specify the amount of the inhibitor adsorption on pore walls, referred to the pore surface area. A well-known technique for determining the reagent adsorption under static conditions was used during the studies (Babalyan *et al*., 1983). The inhibitor equilibrium concentration in the solution after adsorption is determined by the change in the surface tension of the fluid with increasing concentration of this substance in the solution using the calibration curve (Figure 3). The study of the ARPD inhibitor adsorption on the core pore walls under dynamic conditions was conducted as follows. An oil-saturated core was placed in the core holder, through which oil, with the ARPD inhibitor (5 wt.%) dissolved therein, was subsequently pumped until the inhibitor concentration at the core holder inlet and outlet became equivalent. Samples were periodically taken to determine the surface tension at the boundary with distilled water, and the values obtained were used to determine the ARPD inhibitor concentration in oil.

The process of the IN-1 inhibitor desorption was studied by oil filtering through a saturated sample of the rock via two methods: using a bulk model and core material. To determine the desorption process, samples of the bulk model (50 g) were placed in separation test flasks, with subsequent injection of the inhibiting solution – oil with the IN-1 inhibitor dissolved therein (20 wt.%). The concentration of the inhibitor was selected empirically. When its concentration in oil exceeds 20%, the reagent is quickly removed at the initial stages of filtration, which is economically unprofiTable. When the inhibitor concentration in oil is less than 20%, the amount of pore volumes of oil, needed for the reagent removal, is halved. Therefore the time of the reagent presence in the rock as well as the reagent efficiency is reduced.

To achieve adsorption equilibrium, the inhibited bulk model was left for a day. The inhibiting solution desorption was implemented by passing through the inhibited bulk model of oil without reagent. The volumetric flow rate of the fluid through the rock was 3 ml/min. At the outlet of the separation test flask, 3 ml of working solution was taken to be analyzed for the ARPD inhibitor content. Oil was injected until its percentage content in the bulk model pores became constant. The impact of the fluid flow rate on the inhibitor desorption rate was studied. The studies were carried out at various volumetric flow rates of the fluid (from 0.5 to 3 ml/min). The research results are presented in Figure 5.

Proceeding from the obtained results of laboratory studies of the ARPD inhibitor adsorption-desorption processes, it is possible to calculate the technological parameters of squeezing the solution, inhibiting the ARPD, into the BHFZ of production wells.

To calculate the amount of the ARPD inhibitor for injection into the BHFZ, the formula, proposed in scientific papers by Antipin Yu.V., Ibragimov G.Z., and Khisamutdinov N.I., was accepted for determining the amount of the scaling inhibitor with injection into the BHFZ (Antipin *et al.*, 1987; Ibragimov and Khisamutdinov, 1983; Rahim, 2018; Jasińska, 2019).

$$m_{инг} = Q_{скв} \cdot (1-\beta) \cdot C_{эф} \cdot t \cdot \rho_{ж} \cdot A \quad (1)$$

where: $m_{инг}$ is the calculated amount of the ARPD inhibitor for injection into the BHFZ, kg; $Q_{скв}$ is a well productivity by the fluid, m^3/day; $C_{эф}$ is the ARPD inhibitor concentration in the produced fluid, ensuring the required protective effect in the system, kg/m^3; t is the planned time for the inhibitor removal from the formation (120-180 days); $\rho_{ж}$ is the produced fluid density, kg/m^3; β is a volumetric fraction of water in the produced well products.

Formula 1 contains a coefficient A, considering the unevenness of the scaling inhibitor removal from the BHFZ. According to the scientific papers by Antipin Yu.V., Ibragimov G.Z., and Khisamutdinov N.I., it is recommended to take it from 1.5 to 2 (Kashchavtsev and Mishchenko, 2004; Lateef *et al.,* 2019; Zakki *et al.,* 2019;), without the choice of a specific value being substantiated.

Proposed is a graphical method for determining the coefficient A depending on the fluid volumetric flow rate (well production rate), according to experimental diagrams for the dependence of the ARPD inhibitor concentration in oil at the core holder outlet on the number of pore volumes of pumped oil. The coefficient A is determined as the ratio of the volume of the ARPD inhibitor removed from the formation during its uneven removal to the hypothetical volume of the ARPD inhibitor during uniform removal.

In the diagram, this will be determined as the area ratio of the Figures, bounded by the functions $f_1(n)$ and $f_2(n)$:

$f_1(n)$ is the curve of the ARPD inhibitor desorption at uneven removal;

$f_2(n)$ is the hypothetical curve of the ARPD inhibitor desorption at uniform removal.

3. RESULTS AND DISCUSSION:

It was revealed that the developed chemical composition IN-1 has high inhibiting properties with respect to the ARPD, possesses depressor-dispersing properties, has low corrosive activity with respect to a metal surface, and reduces the temperature of oil saturation with paraffin.

To determine the temperature of oil saturation with paraffin via rheogoniometry, a paraffin oil model was used (5 wt.% of paraffin). The reagent concentration in oil made 0.2 wt.%. The diagram for the dependence of oil viscosity on temperature, according to which, by the subsequent use of the indirect method, the temperature of oil saturation with paraffin was determined, was built.

The research results are presented in Table 1 and Figures 1 and 2. The temperature of oil saturation with paraffin for paraffin oil (5 wt.% of paraffin) was determined via rheogoniometry and the method of visual observation. The temperature of oil saturation with paraffin for the IN-1 reagent-free oil made 35°C. The optimal concentration of the inhibitor (0.2%), wherein the temperature of oil saturation with paraffin virtually remains unchanged, was determined. Upon adding the IN-1, the temperature of oil saturation with paraffin decreased by 8°C. With the increase in paraffin content in oil up to 7 wt.%, the temperature of oil saturation with paraffin increased by 4°C (from 35 to 39°C), i.e., proportionally increasing with the increase in paraffin content. Micrographs of paraffin oil (7 wt.%) with the IN-1, added in the amount of 0.2 wt.%, and without the IN-1, were made. The micrographs were taken at a temperature of 37°C (average formation temperature of Tatarstan fields). As is seen from the micrographs in Figure 1, upon injection of the developed ARPD inhibitor (0.2 wt.%) into paraffin oil, the process of paraffin crystals formation slows down.

As is seen from Figure 2, the temperature of oil saturation with paraffin without adding the IN-1 is 35°C; with a further decrease in temperature, a sharp increase in the kinematic viscosity of oil is observed. Upon adding the ARPD inhibitor in oil, the temperature of oil saturation with paraffin decreases from 35 to 26°C. Thus, it can be concluded that the developed IN-1 reagent can act as the ARPD inhibitor to prevent the formation of deposits in well equipment and the BHFZ.

As is seen from Figure 3, the highest rate of increase in the IN-1 inhibitor adsorption is observed in the range of low values of its initial concentration in oil. This is since the IN-1 inhibitor has a high surface tension to the bulk model. When adding the inhibitor in the amount from 0.5 to 1%, the adsorption isotherm approaches the “plateau” region, i.e., the adsorption equilibrium. The adsorption equilibrium occurs at the reagent concentration of more than 0.5%. It means that when IN-1 is added in the amount of more than 0.5%, the inhibitor rate of advance will be equal to the rate of injection. The value of the limiting adsorption, wherein the entire surface of the adsorbent is filled with adsorbate, made 0.0147 ml/g (0.219 ml/m^2).

Figure 4 presents the dynamics of changes in the ARPD inhibitor concentration in oil at the core holder outlet. The value of the limiting adsorption on core material under dynamic conditions made 0.520 ml/m^2. The results of the study of the ARPD inhibitor adsorption on a core sample used under a dynamic mode, as well as under a static one, prove that the developed reagent has adsorption properties with respect to the rock.

The results of studying the impact of the fluid flow rate on the inhibitor desorption rate confirm that with an increase in the fluid volumetric flow rate, the rate of the inhibitor desorption from the formation increases as well. For example, when the fluid flow rate increases from 0.5 ml/min to 3 ml/min, the reagent removal time reduces by 19 times. When calculating the technological parameters of the inhibiting solution injection into the BHFZ, it is necessary to take into account the fluid filtration rate (volumetric flow rate) in the BHFZ.

Studies of the inhibitor desorption from the pore walls, depending on the different length of the bulk model, were carried out. Two samples of the bulk model, with a length of 3.5 and 7 cm, were studied. The fluid volumetric flow rate made 0.5 ml/min. The research results are presented in Figure 6.

As is seen from Figure 6, at the bulk model length of 3.5 cm, the time of the ARPD inhibitor removal until the minimum effective concentration is achieved makes approximately 600 minutes, and at the bulk model length of 7 cm – 1300 minutes. Thus, it can be concluded that an increase in the volume of the formation, being treated with the solution, inhibiting the ARPD, results to a proportional increase in the time of the inhibitor removal.

The ARPD inhibitor (20%) was injected into a core with a different volume of pumped oil after the inhibitor was squeezed. The oil filtration rate made 0.5 ml/min. The impact of the volume of pumped oil on the subsequent inhibitor desorption from the core pore walls was studied. The dependence of the ARPD inhibitor relative concentration in oil at the core holder outlet on the volume of pumped oil is presented in Figure 7.

The results obtained make it possible to conclude that when injecting the inhibitor into the BHFZ, it is necessary to squeeze it into the formation using at least 5 ... 10 times the volume of displacement fluid, to reduce the loss of the inhibitor at the initial stage of well operation after treatment. It is recommended to use oil as a displacement fluid.

Furthermore, the ARPD inhibitor was

injected into the core, with its subsequent squeezing with oil in the amount of 10 pore volumes at different volumetric flow rates. The research results are presented in Table 2.

Table 2. *Impact of the fluid volumetric flow rate on the duration of the ARPD inhibitor protective effect*

Qкерн, ml/min	0.5	1	2	3
n, units	200	127	61	35

where *Qкерн* is the fluid volumetric flow rate by the core; *n* is the number of pore volumes of the pumped oil until a minimum effective concentration of the ARPD inhibitor is achieved.

The determination of the coefficient A at oil volumetric flow rate of 0.5 ml/min (0.00072 m^3/day) is graphically presented in Figure 8, and analytically shown in formula (2).

$$A = \frac{S_1}{S_2} = \frac{\int_{n_{i-1}}^{n_i} f_1(n)dn}{\int_{n_{i-1}}^{n_i} f_2(n)dn} = \frac{\sum C_i \cdot (n_i - n_{i-1})}{C_{\min эф} \cdot (n_i - n_{i-1})} \qquad (1)$$

where S_1 is the area of the Figure, bounded by the function $f_1(n)$; S_2 is the area of the Figure, bounded by the function f_2 (n); n_i is the number of pore volumes of oil pumped through the core, fr.unit; C_i is the inhibitor concentration at the time of selection from the core holder, %; $C_{\min эф}$ is the minimum effective concentration of the ARPD inhibitor, %.

The range of the fluid volumetric flow rates by the core was taken, corresponding to the average range of well production rates. The calculation results are presented in Table 3.

In Table 3, the coefficient A correlates with the fluid volumetric flow rate by the core. It is necessary to recalculate the fluid volumetric flow rate by the core during plane-parallel filtration flow to the well production rate during plane-radial filtration. The complexity resides in the fact that the fluid filtration rate in the BHFZ differs at different distances from the well. Therefore, it is proposed to compare the fluid filtration rate in the core with the average logarithmic rate of the fluid filtration in the BHFZ.

The average logarithmic rate of the fluid filtration ($V_{cp.log}$) is derived from formula (3):

$$\upsilon_{cp.\log} = \frac{\upsilon_1 - \upsilon_2}{\ln \frac{\upsilon_2}{\upsilon_1}} = \frac{\frac{Q}{F_1} - \frac{Q}{F_2}}{\ln \frac{R}{r}} = \frac{Q \cdot (R - r)}{2 \cdot \pi \cdot h \cdot R \cdot r \cdot \ln \frac{R}{r}} = \frac{Q_{скв}}{2 \cdot \pi \cdot h \cdot r \cdot \ln \frac{R}{r}} \qquad (2)$$

where u_1 is the fluid filtration rate near the well wall with a radius r, m/s; υ_2 is the fluid filtration rate in the BHFZ at a distance *R* from the well, m/s; *R* is the radius of squeezing (based on the experience of preventing scaling via the technique of injecting the inhibitor in the BHFZ, to achieve good results, it is sufficient to squeeze the inhibitor solution 1-2 m deep into the formation) (Antipin *et al.*, 1987; Lyushin *et al.*, 1983; Radoičić and Jovanović, 2018); *h* is an opened effective formation thickness, m; since *R*>>*r*, then $R - r \approx R$.

The fluid filtration rate by the core is derived from formula (4):

$$\upsilon_{керн} = \frac{4 \cdot Q_{керн}}{\pi \cdot d_{керн}^2} \qquad (3)$$

The core with a diameter of *dкерн = 0.03 m* was used.

By equating formulae (3) and (4), we get the equation, relating the fluid flow rate in the core to the well production rate (formula 5):

$$Q_{скв} = \frac{8 \cdot Q_{керн} \cdot h \cdot r \cdot \ln \frac{R}{r}}{d_{керн}^2} = 8888{,}88 \cdot Q_{керн} \cdot h \cdot r \cdot \ln \frac{R}{r} \qquad (4)$$

Proceeding from the obtained results of laboratory studies, it is recommended to use in calculations Qкерн=0.5 ml/min, since, under these conditions, the ARPD inhibitor gradual desorption from the rock pores takes place, the inhibitor is released and enters the well with the formation fluid, providing the requirements for the prevention of the ARPD formation in the BHFZ and, accordingly, in the well.

Therefore, considering the results and recommendations of laboratory studies, taking into account the values of the fluid volumetric flow rate by the core, the well production rate will be calculated according to the following formula:

$$Q_{скв} = 6{,}4 \cdot h \cdot r \cdot \ln\frac{R}{r} \qquad (5)$$

Thus, the results of experimental studies of adsorption-desorption processes make it possible to determine the amount of the developed ARPD inhibitor (IN-1), required for injection into the BHFZ, taking into account the well productivity, unevenness of the inhibitor removal from the BHFZ, and the volume of displacement fluid.

4. CONCLUSIONS:

1. The developed chemical composition IN-1 has high inhibiting properties with respect to the ARPD, possesses depressor-dispersing properties, and has low corrosive activity with respect to a metal surface.
2. The temperature of oil saturation with paraffin for paraffin oil was determined via rheogoniometry and the method of visual observation. Upon adding the ARPD inhibitor in oil, the temperature of oil saturation with paraffin decreases from 35 to 26°C. The developed IN-1 reagent can act as the ARPD inhibitor to prevent the formation of deposits in well equipment and in the BHFZ.
3. During the study of the ARPD inhibitor adsorption properties with respect to the rock, under static conditions, the value of the limiting adsorption, when the entire surface of the adsorbent is filled with adsorbate, made 0.0147 ml/g (0.219 ml/m2). The value of the limiting adsorption on core material under dynamic conditions made 0.520 ml/m2. The results of the study of the ARPD inhibitor adsorption, on a core sample, under a dynamic mode, as well as under a static one, prove that the developed reagent has adsorption properties with respect to the rock.
4. The results of studying the impact of the fluid flow rate on the inhibitor desorption rate prove that with an increase in the fluid volumetric flow rate, the rate of the inhibitor desorption from the formation increases as well. An increase in the volume of the formation, being treated with the solution, inhibiting the ARPD, results to a proportional increase in the time of the inhibitor removal. When injecting the inhibitor into the BHFZ, it is necessary to squeeze it into the formation using at least 5 ... 10 times the volume of displacement fluid, to reduce the loss of the inhibitor at the initial stage of well operation after treatment. It is recommended to use oil as a displacement fluid.
5. Based on the obtained results of laboratory studies of the ARPD inhibitor adsorption-desorption processes, the paper presents calculations for the technological parameters of squeezing the solution, inhibiting the ARPD, into the BHFZ, and substantiates the choice of coefficient A, which accounts the inhibitor uneven removal from the BHFZ, depending on the fluid volumetric flow rate (well production rate). Coefficient A is determined graphically, according to diagrams for the dependence of the ARPD inhibitor concentration in oil at the core holder outlet on the number of pore volumes of pumped oil.

5. REFERENCES:

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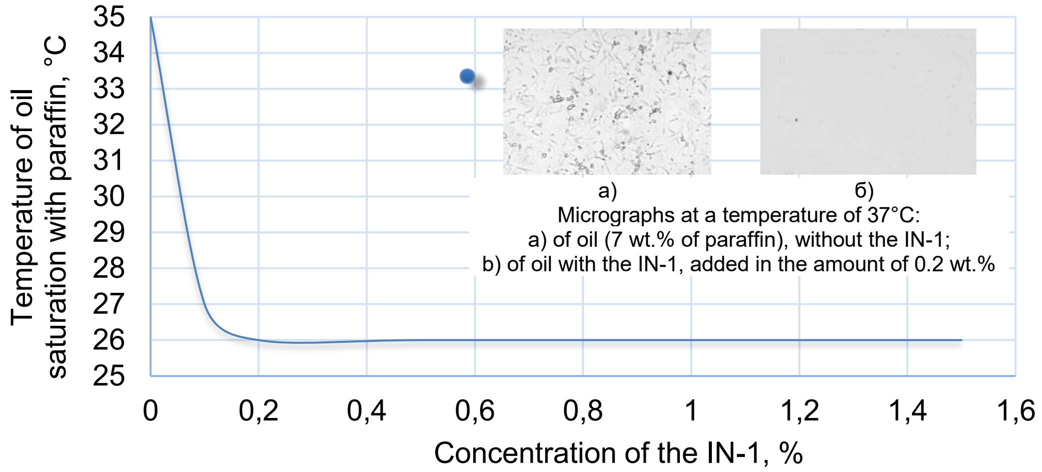
***Table 1**. The results of the determination of depressant-dispersing, inhibiting and corrosive properties of the ARPD inhibitor (the IN-1 reagent)*

No.	The inhibitor concentration in oil, %	Oil-freezing point, ºC	Depressor effect ∆T, ºC	Inhibiting property, %	The inhibitor corrosion rate (mm/year) at temperature:	
					20°C	37°C
1	0	-23	0	0	0.0756	0.1134
2	0.1	-28	5	8.3	0.0325	0.0362
3	0.5	-32	9	25	0.0342	0.0369
4	1	-39	16	37.5	0.0311	0.0336
5	1.5	-45	22	45.8	0.0318	0.0324

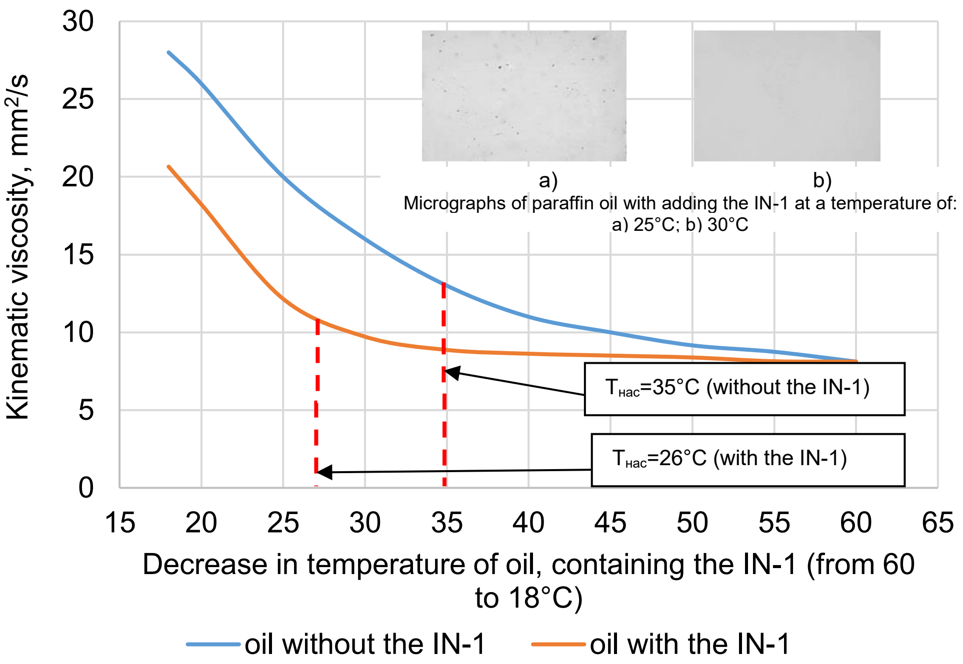
***Table 3.** The results of determining the coefficient A at different volumetric flow rates of the fluid*

The fluid volumetric flow rate ($Q_{керн}$), ml/min	The coefficient of the inhibitor removal unevenness (A), units
0.5	1.4
1	2.2
2	4.6
3	8



Micrographs at a temperature of 37°C:
a) of oil (7 wt.% of paraffin), without the IN-1;
b) of oil with the IN-1, added in the amount of 0.2 wt.%

Figure 1. *Dependence of the temperature of oil saturation with paraffin on the IN-1 concentration in oil*



Micrographs of paraffin oil with adding the IN-1 at a temperature of:
a) 25°C; b) 30°C

$T_{нас}$=35°C (without the IN-1)

$T_{нас}$=26°C (with the IN-1)

Figure 2*. Dependence of kinematic viscosity of oil, with and without adding the IN-1, on temperature*

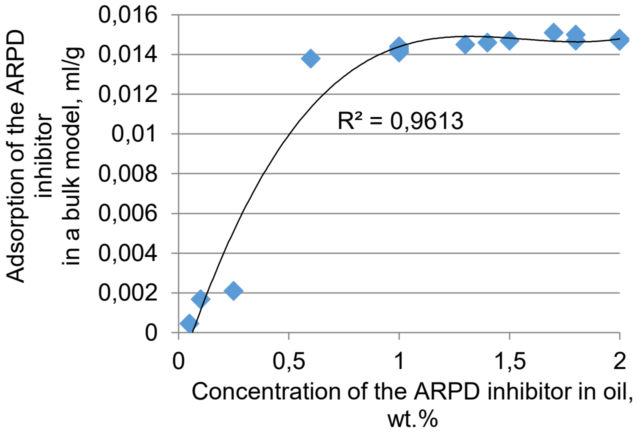


Figure 3. *Adsorption of the ARPD inhibitor (IN-1 reagent) on the surface of the bulk model depending on its concentration in oil*

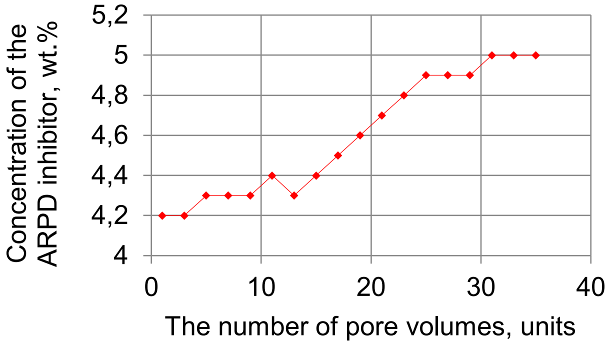


Figure 4. *Dynamics of changes in the ARPD inhibitor concentration in oil at the core holder outlet*

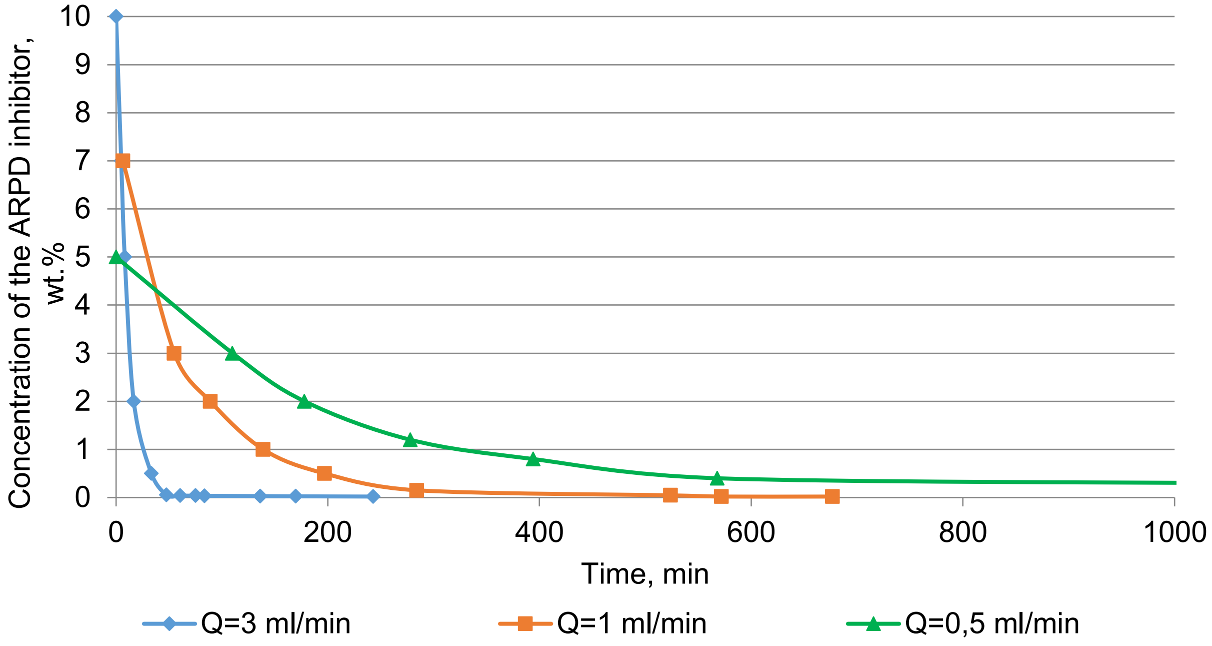


Figure 5. *Profile of the ARPD inhibitor removal when changing the fluid volumetric flow rate by the core*

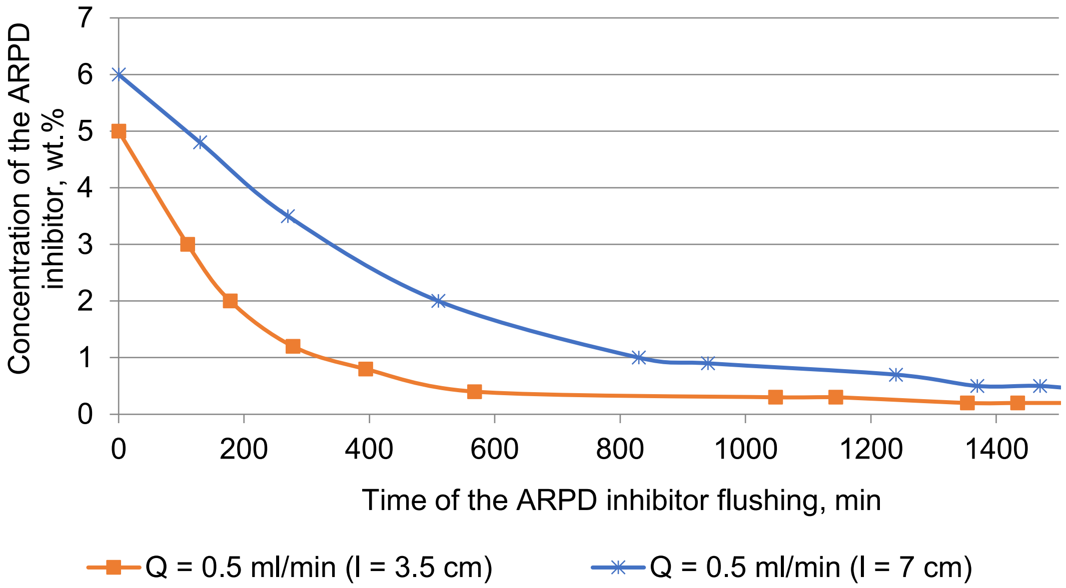


Figure 6. *Profile of the ARPD inhibitor removal at a change in the bulk model length depending on the time of the ARPD inhibitor flushing with oil*

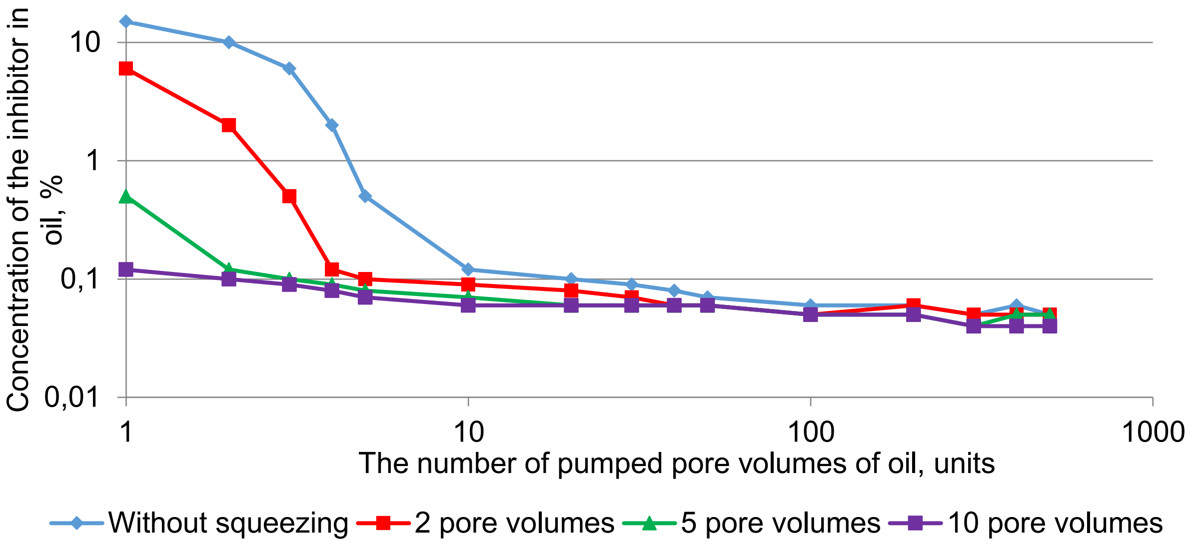


Figure 7. *Dependence of the ARPD inhibitor concentration in oil at the core holder outlet on the number of pumped pore volumes of oil*

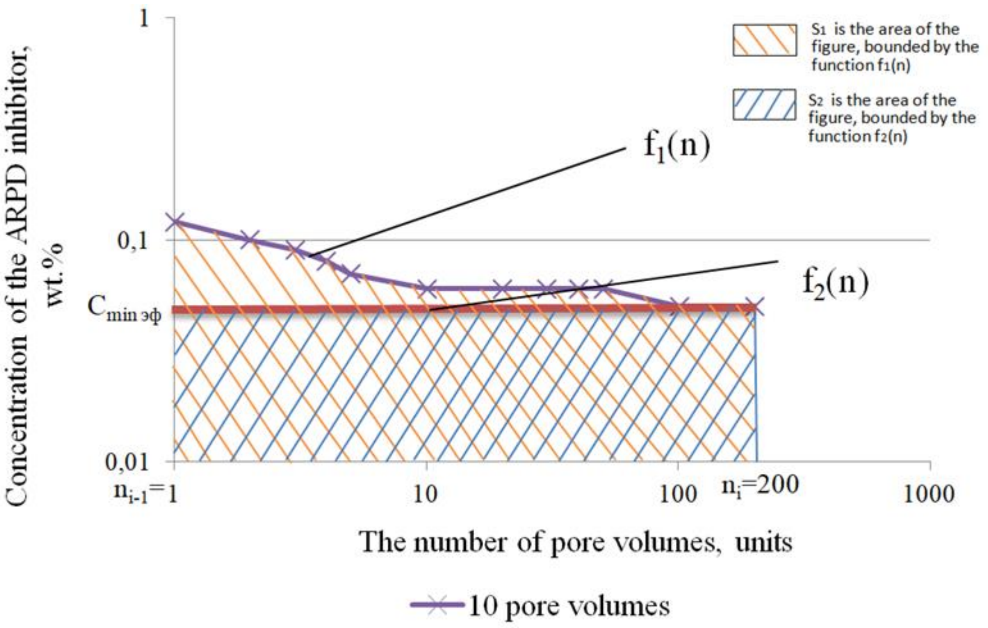


Figure 8. *Determination of the coefficient A in a graphical manner at the fluid volumetric flow rate by the core of 0.5 ml/min*