PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

SUBSTANCIAÇÃO E SELEÇÃO DE UM INIBIDOR PARA EVITAR A FORMAÇÃO DE DEPÓSITOS DE ASFALTO-RESINA-PARAFINA

SUBSTANTIATION AND SELECTION OF AN INHIBITOR FOR PREVENTING THE FORMATION OF ASPHALT-RESIN-PARAFFIN DEPOSITS

ОБОСНОВАНИЕ И ВЫБОР ИНГИБИТОРА ДЛЯ ПРЕДУПРЕЖДЕНИЯ ОБРАЗОВАНИЯ АСФАЛЬТОСМОЛОПАРАФИНОВЫХ ОТЛОЖЕНИЙ

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RESUMO

Atualmente, a maioria dos campos de petróleo está em estágio avançado de desenvolvimento, o que está associado a vários desafios durante a produção de produtos de reservatório, incluindo a formação de depósitos de asfalto-resina-parafina (ARPD) em sistema de “zona de formação de fundo de poço”. Apesar de o problema da formação de depósitos orgânicos existir há mais de 60 anos, ele ainda é relevante hoje. Atualmente, para impedir a formação de ARPD, inibidores divididos em métodos baseados no uso de agentes umectantes, modificadores, depressores e dispersantes são amplamente utilizados na prática de campo. A composição de inibidores geralmente inclui surfactantes e, de acordo com a experiência de campo, surfactantes não iônicos, a saber, poliésteres, são amplamente utilizados para impedir a formação de ARPD. No entanto, pouco se sabe sobre inibidores com um efeito combinado, por exemplo, possuindo propriedades dispersoras de depressores em relação à ARPD. A partir do exposto, o trabalho visa desenvolver um inibidor combinado com propriedades dispersoras de depressores para impedir a formação de ARPD. A propriedade de dispersão do reagente desenvolvido em relação às partículas de asfalteno foi determinada usando métodos capilares e foto colorimétricos. Os estudos foram conduzidos para determinar o impacto do reagente no ponto de congelamento. Foi realizada uma avaliação quantitativa do processo de sedimentação usando a instalação “haste fria”, e foram apresentados os resultados de estudos da resistência à corrosão desenvolvida por inibidor de reagente de ARPD. A temperatura da saturação do óleo com parafina foi determinada por 2 métodos. O método direto - observação visual (microscópio Axio Lab A1) e o método indireto - reogoniometria para determinar a viscosidade cinemática do óleo (analisador de viscosidade HVM-472 (Walter Herzog GmbH, Alemanha)). Assim, foi desenvolvido um inibidor de ARPD (IN-1) compreendendo um copolímero de etileno com α-olefinas ou polímeros de ésteres de ácidos acrílico, metacrílico ou cianoacrílico, um emulsificante de emulsões de óleo em água invertidas e um solvente. O inibidor desenvolvido, com propriedades de dispersão do depressor, é capaz de reduzir o ponto de congelamento de óleo no inverno e desacelerar a precipitação de cristais de parafina em equipamentos de poços e na zona de formação de fundo de poço (BHFZ).

Palavras-chave: *depósitos de asfalto-resina-parafina, reagentes tensoativos, inibidor, zona do fundo do poço, razão de floculação*

ABSTRACT

Currently, most oil fields are under the late stage of development, which is associated with some challenges during the production of reservoir products, including the formation of asphalt-resin-paraffin deposits (ARPD) in the “well – bottom-hole formation zone” system. Even though the problem of organic deposits creation has existed for more than 60 years, it is still relevant today. Currently, to prevent the formation of ARPD, inhibitors divided into methods based on the use of wetting agents, modifiers, depressors, and dispersants are widely used infield practice. The composition of inhibitors often includes surfactants, and according to field experience, non-ionic surfactants, namely, polyesters, are widely used to prevent the formation of ARPD. However, little is known about inhibitors with a combined effect, for example, possessing depressor-dispersing properties concerning ARPD. Proceeding from the above, the work is aimed to develop a combined inhibitor with depressor-dispersing properties to prevent the formation of ARPD. The dispersing property of the prepared reagent for asphaltene

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particles was determined using capillary and photocolorimetric methods. The studies were conducted to assess the impact of the reagent on the freezing point. A quantitative assessment of the sedimentation process using the “Cold rod” installation was performed, and the results of studies of the developed ARPD reagent-inhibitor corrosion resistance were presented. Two methods determined the temperature of oil saturation with paraffin: the direct approach – visual observation (Axio Lab A1 microscope) and the indirect approach – rheogoniometry to determine the kinematic viscosity of oil (HVM-472 viscosity analyzer (Walter Herzog GmbH, Germany)). Thus, an ARPD inhibitor (IN-1), comprising a copolymer of ethylene with α-olefins or polymers of acrylic, methacrylic, or cyanoacrylic acid esters, an emulsifier of inverted oil-in-water emulsions and a solvent, was developed. The developed inhibitor, having depressor-dispersing properties, is capable of reducing oil-freezing point in winter and of slowing down the precipitation of paraffin crystals in well equipped and in the bottom-hole formation zone (BHFZ).

Keywords: *asphalt-resin-paraffin deposits, surface-active reagents, inhibitor, bottom-hole zone, flocculation ratio.*

АННОТАЦИЯ

На сегодняшний день большинство нефтяных месторождений находятся на поздней стадии разработки, которая сопровождается рядом осложнений при добыче пластовой продукции, в том числе образованием асфальтосмолопарафиновых отложений (АСПО) в системе «скважина-призабойная зона пласта». Несмотря на то, что проблема формирования органических отложений существует уже более 60 лет, на сегодняшний день она является актуальной. Сегодня широко используются в промысловой практике ингибиторы для предотвращения образования АСПО, которые подразделяются на методы, основанные на применении смачивающих добавок, модификаторов, депрессаторов и диспергаторов. В состав ингибиторов зачастую входят поверхностно-активные вещества, и как показывает промысловый опыт, неионогенные ПАВ имеют широкое применение для предупреждения образования АСПО, а именно полимеры сложных эфиров. Однако, на сегодня мало известно ингибиторов, обладающими комплексным действием, например, депрессорно-диспергирующими свойствами по отношению к АСПО.. Диспергирующая способность разработанного реагента по отношению к асфальтеновым частицам определялась с помощью двух методов: «капиллярный» и фотоколориметрический. Проводились исследования по определению влияния реагента на температуру застывания. Была проведена количественная оценка процесса осадкообразования на установке «Холодный стержень», а также представлены результаты исследований антикоррозионных свойств разработанного реагента-ингибитора АСПО. Температура насыщения нефти парафином определялась 2 метода: прямой метод – визуальная оценка (микроскопа Axio Lab A1) и косвенный метод – реологические исследования по определению кинематической вязкости нефти (Анализатор вязкости HVM-472 (Walter Herzog GmbH, Германия)). Таким образом, был разработан ингибитор АСПО (ИН-1), содержащий сополимер этилена с α-олефинами или полимеры сложных эфиров акриловой, метакриловой или цианакриловой кислот, эмульгатор обратных водонефтяных эмульсий и растворитель. Разработанный ингибитор обладает диспергирующими и депрессорными свойствами, способный уменьшить температуру застывания нефти в зимнее время и выпадение кристаллов парафина в скважинного оборудовании и ПЗП.

Ключевые слова: *асфальтосмолопарафиновые отложения, поверхностно-активные вещества, ингибитор, призабойная зона пласта, коэффициент флокуляции.*

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1. INTRODUCTION:

To date, the development of the oil industry in the Russian Federation is characterized by a significant decrease in oil production. This is since most of Russia’s oil fields are under the late stage of development. Oil production is often associated with unwanted formation of organic deposits, such as asphalt-resin-paraffin deposits, in the BHFZ, on the walls of underground well equipment, and in the above-ground lines of the oil and gas gathering and processing system. Although the problem of organic deposits formation has existed for more than 60 years, it is still relevant today (Struchkov, 2018).

The formation of ARPD occurs in two ways. It can be either with the formation and growth of paraffin crystals on a solid surface or the formation and growth of paraffin crystals in the flow of reservoir fluid, with their subsequent adhesion to a solid surface. Paraffin crystals cannot form solid deposits. The binding elements during the formation of solid deposits are asphaltenes, resins, and mechanical impurities, included in ARPD composition. The composition and strength of deposits depend on the composition and properties of reservoir fluid, geological, physical, and technological conditions of an oil field development. In oil production, the composition of ARPD mainly consists of 40 - 60% solid paraffin and less than 10% microcrystalline paraffin, 10 - 56% resins and asphaltenes, water, sand, and inorganic salts (Dubey *et al.*,2017).

ARPD, in well equipped and the BHFZ, are formed at the change in thermobaric conditions when the reservoir is cooled, resulting from the injection of cold water. A decrease in pressure below the pressure of oil saturation with gas results in the vigorous evolution of gas directly in the BHFZ, an increase in oil density, a decrease in phase permeability, and the formation of ARPD. Besides, the creation of ARPD is affected by the reservoir fluid flow rate, change in the composition of oil during its degassing, state of tubing, and many other factors (Sychugov *et al.*, 2019).

Preventing the formation of ARPD during oil production is carried out in two ways: 1) removal of already formed deposits; 2) preventing scaling. Methods for removing ARPD include thermal methods (steam injection, flushing with hot oil or water as a heat carrier, the use of electric furnaces, induction heaters, etc.), mechanical methods (the use of scraping tools, scratchalizers mounted on rods), chemical methods (the use of organic solvents or detergents to remove ARPD) (Zhang *et al.*, 2019).

The most widely used methods for removing ARPD are chemical methods of removal, namely, the use of organic ARPD solvents. When choosing the most efficient way for removing ARPD, the composition, structure, and properties of these deposits must be accounted for. Nonetheless, the existence of extensive diversity of techniques for removing ARPD fails to completely solve the problem of the formation of ARPD in well equipment (Turbakov *et al.*, 2014).

The standard classification renders possible to specify the following methods for preventing the formation of ARPD: the use of protective coatings (coating of pipes with epoxy resins, finely crushed glass, bakelite varnish, resins, the use of glass-reinforced plastic rods); physical methods (vibrational, ultrasonic methods, exposure to magnetic, electric and electromagnetic fields); chemical methods (wetting agents, modifiers, depressors, and dispersants) (Cuesta *et al.*, 2013; Mali *et al.*, 2014).

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 more round, 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 increase the thermal conductivity of oil and slow down the process of paraffin crystallization (Babalyan *et al.*, 1983).

To prevent the formation of ARPD in oil fields, a chemical method for protecting down-hole equipment, based on the use of specially selected chemical reagents – ARPD inhibitors, which are surfactants of ionic or non-ionic classes, is used. Ionic surface-active reagents (surfactants) are divided into cationic and anionic. Anionic surfactants dissociate in water into ions (positively charged cation and negatively charged anion). Negatively charged anion has surface activity. The most typical anionic surfactants, used in the oil industry, are alkyl aryl sulfonates (sulfonyl), alkyl sulfonates, alkyl sulfates, etc. Cationic surfactants also dissociate in water into ions, but in contrast to anionic surfactants, cations, positively charged ions, have surface activity. Examples of cationic surfactants include as follows: aliphatic amines – salts of hydrochloric acid, imidazoline derivatives, etc. Non-ionic surfactants do not dissociate in water into cations and anions. Nonylphenol ethoxylates, ethoxylated fatty alcohols, and acids block copolymers of ethylene and propylene oxides (disolvans, separols), amines are used as non-ionic surfactants (Babalyan *et al.*, 1983; Bikkulov *et al.*, 1997; Rogachev *et al.*, 2000).

Reservoir water often has a high content of alkaline-earth metal chlorides (calcium, magnesium). Therefore, in contrast to anionic surfactants, non-ionic surfactants, which do not chemically react with alkaline-earth metal salts, are often used in oil fields (Dubey *et al.*, 2017; Fang *et al.*, 2014).

Currently, surfactants are widely used in field practice, with various dosing techniques being applied, and according to field experience and patent research data, nonionic surfactants, namely, polyesters are widely used to prevent the formation of ARPD. Proceeding from the above, we have analyzed known and practically applied ARPD inhibitors, and as a result a reagent was developed and tested for its inhibiting property with respect to ARPD. The results of these tests, inter alia, confirmed its inhibiting property. The test results made it possible to optimize the composition of the new reagent and proved its high performance in preventing the formation of ARPD compared to other known inhibitors (RF patent No. 2388785, RF patent No. 2027730, RF patent No. 2104391, etc.). The new ARPD reagent-inhibitor was assigned a reference designation of IN-1.

A copolymer of ethylene with α-olefins or polymers of acrylic, methacrylic or cyanoacrylic acids esters represented by general formula (-CH_2-CR'(COOR)-$)_n$ (R' = H — acrylates, R'= CH_3 — methacrylates, R'= CN — cyanoacrylates); an emulsifier of inverted oil-in-water emulsions and a solvent were chosen as components included in the composition of IN-1. These components were chosen due to their wide applicability and high efficiency in terms of preventing the formation of ARPD.

A copolymer of ethylene with α-olefins (polyvinyl acetate) with a molecular weight of 500-100000 has depressor properties. The dispersant used is an emulsifier of inverted oil-in-water emulsions Yalan E-2 brand A (conc.), manufactured according to TU 2458-00122650721-2009 with rev.1. The solvent serves as a binding element to better dissolve the two components.

This work aimed to develop a combined inhibitor with depressor-dispersing properties to prevent the formation of ARPD. Thus, an ARPD inhibitor (IN-1), comprising a copolymer of ethylene with α-olefins or polymers of acrylic, methacrylic, or cyanoacrylic acid esters, an emulsifier of inverted oil-in-water emulsions and a solvent, was developed. The developed inhibitor, having depressor-dispersing properties, is capable of reducing oil-freezing point in winter and of slowing down the precipitation of paraffin crystals in well equipped and the BHFZ.

2. MATERIALS AND METHODS:

The “capillary” method, which qualitative characteristic is the flocculation ratio, was used to assess the effect by the developed IN-1 inhibitor reagent on asphaltenes in oil. The technique involves applying a drop of solution through a narrow capillary on filter paper, capable of trapping large dispersed particles in the center of a spreading drop. By visual inspection of the spot on the paper, after absorbing a drop of oil, it is possible to conclude whether or not there are aggregates of asphaltene particles. Uniform coloring of the spot confirms the absence of such aggregates and heterogeneous coloring witnesses in favor of their presence. By variation in the spot type, when the IN-1 is added in oil, its effect on asphaltenes can be assessed (Khabibullin *et al.*, 1992).

Degassed oil with a density of 916 kg/m^3, oil viscosity of 97.2 MPa·s, with the following content of resins (12.5%), paraffins (3.7%), and asphaltenes (1.69%) was chosen as the object of the research.

The dispersing ability of the IN-1 reagent relative to asphaltene particles can also be assessed via the photocolorimetric method. The studies were performed using the UNICO 2100 spectrophotometer (United Products and Instruments, USA). From the entire wavelength spectrum (300-1000 nm), an average length (500 nm) was chosen to build a graph for the dependence of light absorption coefficient and optical oil density on the IN-1 reagent concentration in oil.

The studies performed were aimed to determine the IN-1 reagent effect on such a key technological parameter of paraffin oil as the congealing point. he studies were carried out according to the state standard GOST 20287 (method B), without dehydration and pre-heating the product to a temperature of (50 ± 1)°C. An oil model, with paraffin content of 5 wt.%, was used as paraffin oil. The reagent was added in oil in the amount of 0.1 to 1.5 wt.%.

The sedimentation process quantitative assessment was carried out using the “Cold finger” installation. To assess the IN-1 reagent performance, paraffin oil with a density of 916 kg/m^3 was used. Before the experiment, “cold fingers,” before being lowered in oil, were treated with petroleum ether and then with acetone. Oil with the IN-1 reagent was poured into metal cups. The studies were implemented by adding the IN-1 reagent in oil in the amount of 0.1 to 1.5 wt.%. For comparison purposes, reagent-free oil was used. The volume of oil in the cups was chosen in such a manner that the “cold fingers” were immersed in oil by at least one-half. The bath temperature was set at 37°C, the “cold finger” temperature was 12°C, and the duration of a single experiment made 60 minutes.

To study the developed ARPD reagent-inhibitor corrosion resistance, an oil model with varied IN-1 content (from 0.1 to 2 wt.%) was used. The model of oil, typical for oil fields of the Republic of Tatarstan, was used. The study of the ARPD inhibitor corrosion resistance was carried out under the state standards GOST 9.908-85, GOST R 9.905-2007, and GOST R 9.907-2007. The permissible corrosive activity for St-20 steel, according to a static test at 20°C, should not exceed 0.2g/m^2·h. The experiments were carried out at room temperature (20°C) and reservoir temperature (37°C).

There is no uniform standard for measuring the temperature of oil saturation with paraffin. Therefore, two methods for determining this parameter were used during the study, including a direct method – a visual estimation, and an indirect method – rheogoniometry for determining the kinematic viscosity of oil.

The IN-1 reagent was dissolved in oil at different concentrations (from 0.1 to 1.5 wt.%). For its complete dissolving, oil was heated to 60°C. Then oil samples with the IN-1 were gradually cooled from 60°C to 18°C. The microstructure of oil with the reagent was studied using an Axio Lab A1 microscope at a magnification of 400 times. The IN-1 reagent-free oil sample was used as a check specimen for comparison purposes. The experiments were carried out for paraffin oils with a paraffin content of 5 wt.% and 7 wt.%.

The indirect method for determining the temperature of oil saturation with paraffin via rheogoniometry involved determining the kinematic viscosity of oil with and without adding the IN-1 at a gradual decrease in temperature. The experiment was carried out using the viscosity analyzer HVM-472 (Walter Herzog GmbH, Germany) according to the state standard GOST 33-2000 (ISO 3104-94), ASTM D445. The determination of the kinematic viscosity of oil with the reagent was implemented within the temperature range from 60°C to 20°C. The IN-1 reagent-free oil sample was used as a check specimen for comparison purposes. A paraffin oil model was used (5 wt.% of paraffin). The reagent concentration in oil made 0.2 wt.%.

3. RESULTS AND DISCUSSION:

The dispersing ability of the studied ARPD inhibitor relative to asphaltene particles was determined by two independent methods, i.e. “capillary” and photocolorimetric methods (Tica *et al*., 2019, Rahman *et al*., 2017; Ma *et al*., 2019; Shatalova *et al*., 2014;).
The results of studying the IN-1 reagent effect on asphaltenes in oil using the “capillary” method are presented in Figure 1.

As is seen from Figure 1, when the IN-1 reagent is added to oil, with the increase in its concentration (from 0 to 4 wt.%), the flocculation ratio of asphaltenes in oil decreases, which witnesses in favor of a decrease in the size of their particles resulting from the dispersing effect of this reagent.

The results of studying the dispersing ability of the IN-1 reagent relative to asphaltene particles using the photocolorimetric method are presented in Figure 2.

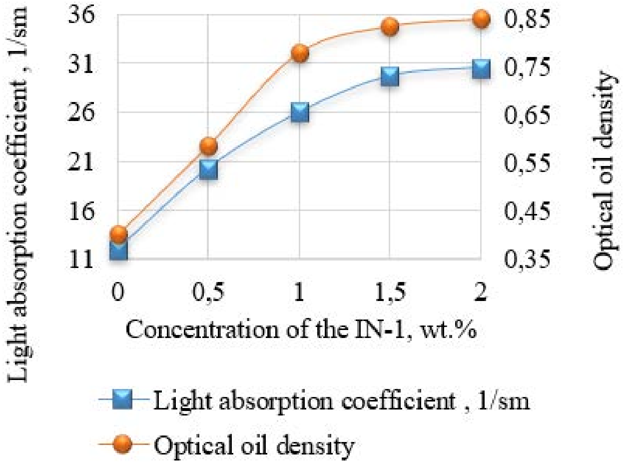

***Figure 2.** Dependence of light absorption coefficient and optical oil density on the IN-1 reagent concentration in oil*

As is seen from Figure 2, oil optical density increases upon adding the ARPD inhibitor, which is due to an increasing degree of dispersion of the main light-absorbing particles in oil – asphaltenes. The results of studying the IN-1 reagent effect on the congealing point of oil are presented in Table 1.

Based on the research findings, it can be concluded that the IN-1 reagent has high depression ability, it's adding in paraffin oil under consideration in the amount of 0.1 wt.% to 1.5 wt.% results to a significant decrease in oil congealing point (by an average of 10°C), approximating it to the average ambient temperature during winter, typical for the main oil-producing regions of the Russian Federation.

The results of studying the sedimentation process using the “Cold finger” installation are presented in Table 2. As is seen from Table 2, the developed ARPD IN-1 inhibitor in oil composition can prevent the sedimentation process by 8.3-45.8%, depending on its weight content in oil. One of the requirements applicable to ARPD inhibitors is their low corrosive activity relative to the metal surface. The results of determining the corrosion rate are presented in Table 3.

As is seen from Table 3, the values of corrosion rate at temperatures of 20°C and 37°C do not exceed the specified standard. When adding the IN-1 in oil, its ability to inhibit the corrosion rate was revealed (at 20°C, by 2.3 times; at 37°C, by 3.3 times). The ARPD inhibitor in combination with oil can be recommended for fields with a reservoir temperature of 37°C (for example, Romashkinskoye field).

Wax crystals occurrence on the walls of down-hole equipment is possible only after oil cooling to a temperature, below the temperature of oil saturation with paraffin. Reaching the saturation temperature is followed by the precipitation, as a solid phase, of the most high-melting paraffins (ceresins), which intensively begin to form deposits (Bikkulov *et al*., 1997; Struchkov *et al*., 2019; Struchkov *et al*., 2018; Joshi *et al*., 2005; Campbell *et al*., 2003; Shagiakhmetov *et al*., 2018). Therefore, when selecting a reagent for removing and preventing the formation of ARPD, the temperature of oil saturation with paraffin is deemed to be an important parameter.

The dependence of the temperature of oil saturation with paraffin on the IN-1 concentration in oil is presented in Figure 3.

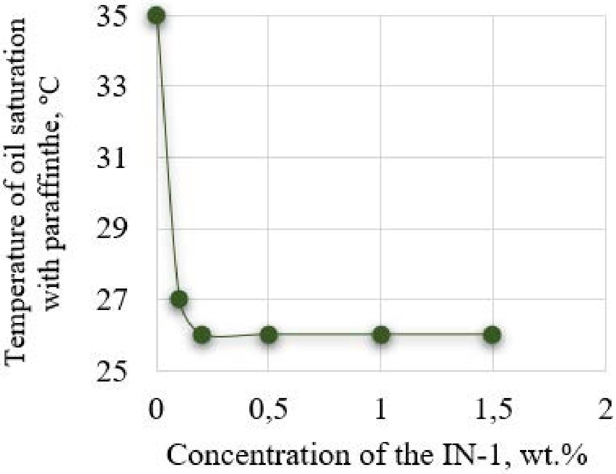

Figure 3. *Dependence of the temperature of oil saturation with paraffin on the IN-1 concentration in oil*

As is seen from Figure 3, 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 wt.%), at which 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. Figure 4 illustrates the micrographs of paraffin oil (7 wt.%) with the IN-1, added in the amount of 0.2 wt.%, and without the IN-1. Micrographs were taken at a temperature of 37°C (average reservoir temperature of Tatarstan fields). As is seen from the micrographs in Figure 4, the introduction of the IN-1 reagent (0.2 wt.%) into paraffin oil inhibits the formation of wax crystals. The results of studying the temperature of oil saturation with paraffin using rheogoniometry are presented in Figure 5.

As is seen from Figure 5, 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 IN-1 reagent in oil, the temperature of oil saturation with paraffin decreases from 35 to 26°C. When the temperature drops below 26°C, there is a sharp increase in oil viscosity due to the structure formation process. To confirm the rheogoniometry results, micrographs of paraffin oil were taken using a microscope with and without adding the IN-1 reagent at temperatures of 25 and 30°C (Figure 6).

As is seen from Figure 6b, at the temperature of 30°C in oil with adding the IN-1 reagent, virtually no solid particles are observed, and when the temperature decreases to 25°C, their occurring is observed (Figure 6a). From Figure 6, it can be assumed that occurring the first solid particles of paraffin in oil with adding the IN-1 reagent takes place at a temperature of 26°C.

As is confirmed by the results of rheogoniometry and microscopical analysis, adding the IN-1 reagent in paraffin oil causes a significant decrease in the temperature of oil saturation with paraffin, therefore the IN-1 reagent can be recommended for practical application as the ARPD inhibitor. Thus, while implementing the laboratory research, the ARPD inhibitor (IN-1), containing a copolymer of ethylene with α-olefins or polymers of acrylic, methacrylic or cyanoacrylic acid esters, an emulsifier of inverted oil-in-water emulsions and a solvent, has been developed. The developed inhibitor has dispersing and depressor properties, capable to reduce the congealing point of oil in winter and precipitation of wax crystals in the well equipment and the bottom-hole zone.

4. CONCLUSIONS:

1. An ARPD inhibitor (IN-1), comprising a copolymer of ethylene with α-olefins or polymers of acrylic, methacrylic or cyanoacrylic acid esters, an emulsifier of inverted oil-in-water emulsions and a solvent, was developed.

2. The dispersing property of the studied ARPD inhibitor with respect to asphaltene particles was determined using two independent methods, i.e. “capillary” and photocolorimetric. During the study of the impact of IN-1 reagent on

asphaltenes in oil by the “capillary” method, it was revealed that when IN-1 reagent is added to oil with an increase in its content (from 0 to 4 wt.%), the flocculation ratio of asphaltenes in oil decreases, which witnesses in favor of a decrease in the size of their particles resulting from the dispersing ability of this reagent. During the study of the impact of IN-1 reagent on asphaltenes in oil by the photocolorimetric method, it was revealed that when IN-1 reagent was added in an amount of 0 to 2 wt.%, the values of optical density gradually increased. The optical density of oil increases upon adding ARPD inhibitor, which is due to a rise in the dispersion degree of the main light-absorbing particles in oil - asphaltenes.

3. According to the results of studies of the impact of IN-1 reagent on oil-freezing point, it can be concluded that IN-1 possesses high depressor properties, it's adding to the studied paraffin oil in an amount of 0.1 to 1.5 wt.% results to a significant decrease in oil-freezing point (by an average of 10°C), approximating it to an average ambient temperature in winter, typical for the main oil-producing regions of the Russian Federation.

4. When adding IN-1 in oil, it was revealed that IN-1 is capable of slowing down the corrosion rate (at 20°C by 2.3 times, at 37°C by 3.3 times). The ARPD inhibitor, in combination with oil, can be recommended for the fields with a reservoir temperature of 37°C.

5. When IN-1 reagent is added in oil, the temperature of oil saturation with paraffin decreases from 35 to 26°C. When the temperature drops below 26°C, there is a sharp rise in oil viscosity, due to the process of structuring occurring therein. The results of the performed rheogoniometry and microscopic studies witness in favor of the fact that adding IN-1 reagent to paraffin oil results to a noticeable decrease in the temperature of its saturation with paraffin, thereby the IN-1 reagent can be recommended for practical use as an ARPD inhibitor.

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***Table 1.** Variation in the congealing point of paraffin oil, containing the ARPD inhibitor*

No.	Concentration of the inhibitor in oil, wt.%	Congealing point, ºC	Depressor effect ΔT, ºC
1	0	-23	0
2	0.1	-28	5
3	0.5	-32	9
4	1	-39	16
5	1.5	-45	22

***Table 2.** Inhibitory ability of the IN-1 reagent relative to ARPD*

No.	Concentration of the inhibitor in oil, wt.%	Inhibitory ability, %
1	0	–
2	0.1	8.3
3	0.5	25.0
4	1	37.5
5	1.5	45.8

***Table 3.** The results of determining the ARPD inhibitor corrosion rate in oil*

	Temperature, °C	Concentration of the IN-1, wt.%				
		0	0.1	0.5	1	1.5
V_c, g/m^2·h	20	0.0756	0.0325	0.0342	0.0311	0.0318
	37	0.1134	0.0362	0.0369	0.0336	0.0324

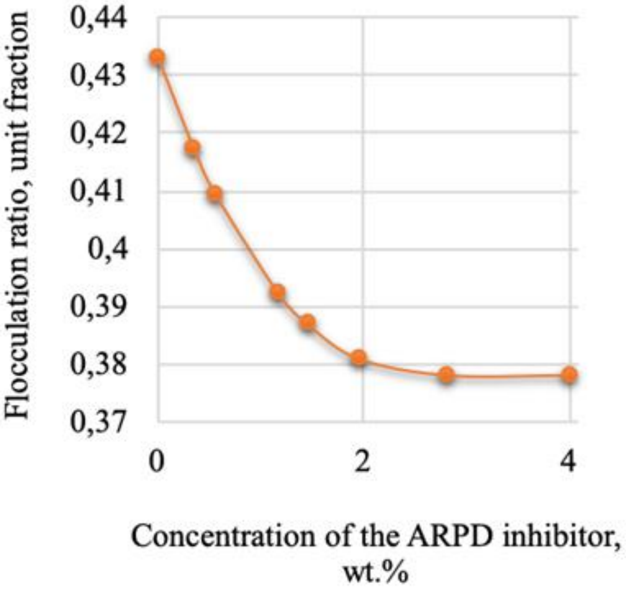

***Figure 1.** Dependence of the flocculation ratio of asphaltenes in oil on the content of the IN-1 reagent therein in different concentrations*

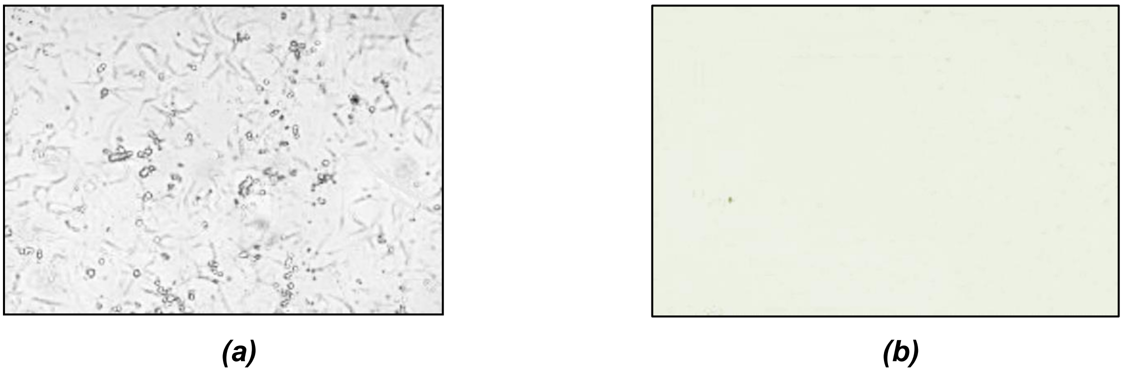

***Figure 4.** Micrographs at a temperature of 37°C (**a**) of oil (7 wt.% of paraffin), without the IN-1; (**b**) of oil with the IN-1, added in the amount of 0.2 wt.%*

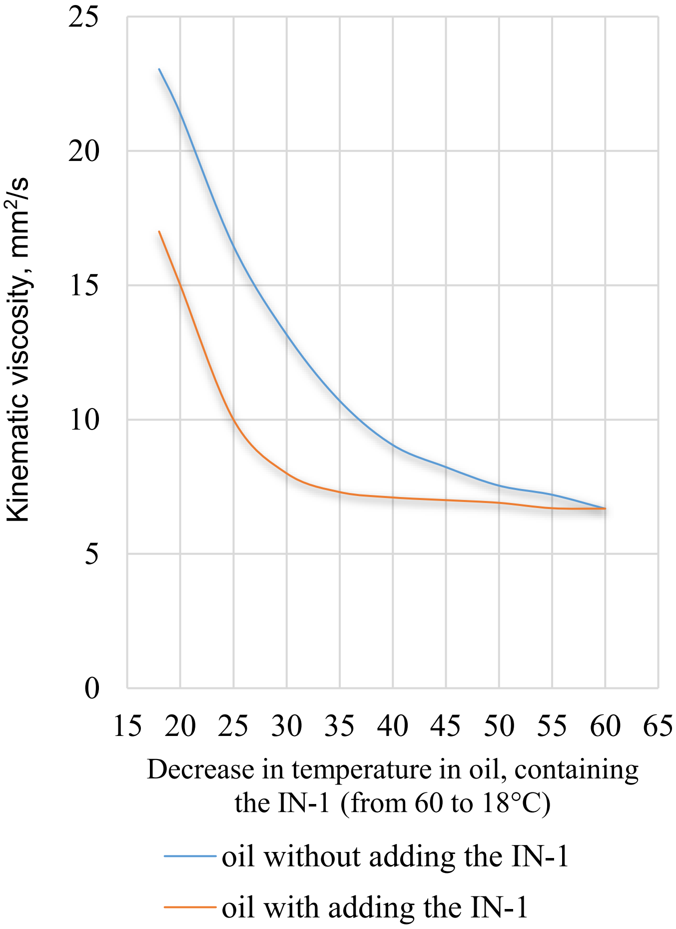

***Figure 5.** Dependence of kinematic viscosity of oil with and without adding the IN-1 on temperature*

(a) ***(b)***

Figure 6. *Micrographs of paraffin oil with adding the IN-1 at a temperature of: (**a**) 25°C; (**b**) 30°C*