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Determination of the Minimum Measures in the Well to Prevent the Formation of Asphalt-Resin-Paraffin Deposits

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Определение минимальных мероприятий в скважине по предотвращению образования асфальтосмолопарафиновых отложений

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well, oil production, asphaltene resin paraffin deposits, complicated fund, asphaltenes, ceresins, resins, paraffin, methods of ARPD control, ARPD prevention, reagents, inhibitors, solvents, research, efficiency assessment.

An analysis of the formation of asphaltene resin paraffin deposits is presented, the criteria for assigning wells to subgroups of the complications type are considered, and a classification of complications in oil production is proposed. Oil is a complex and varied mixture of various hydrocarbons, both light and heavy, in thermodynamic equilibrium under reservoir conditions. In some fields, oil production is not accompanied by the formation of asphaltene resin paraffin deposits on the downhole pumping equipment, while in others it is complicated by them.
Methods of preventing the deposition of asphaltene resin paraffin deposits and methods of dealing with them are considered, the research work to substantiate the use of chemical reagents to prevent the formation of complications in oil-producing wells is presented, the minimum measures are presented for subgroups of the proposed classification of the stock complicated by asphaltene resin paraffin deposits. The methods for determining the effectiveness of the asphaltene resin paraffin deposits inhibitors, developed in the PermNIPIneft branch of LLC LUKOIL-Engineering, were briefly presented, being the basis for the studies carried out. The results of the studies on the selection of reagents and determination of their effectiveness for the production well stock complicated by asphaltene resin paraffin deposits were considered. It was found that during wells operation where the physicochemical properties changed, the effectiveness of the inhibitor significantly decreased and did not reach the efficiency criterion of 75%. So, in oil production a periodic check (at least once every three years) is required to assess the effectiveness of the selected reagents, as well as analyze changes in such parameters of the processed object as: change in the physicochemical properties of the fluid; geological and technical measures at the well; significant increase, decrease in production; involvement or isolation of interlayers, production facilities; changes in reservoir, bottomhole pressure during operation.
Approaches for wells are proposed: where, as a result of research, the criterion of the effectiveness of chemical reagents has not been achieved, it is necessary to select other methods to avoid complications.

Ключевые слова:
скважина, добыча нефти, асфальтеносмолопарафиновые отложения, осложненный фонд, асфальтены, церезины, смолы, парафин, методы борьбы с АСПО, предотвращение АСПО, реагенты, ингибиторы, растворители, исследования, оценка эффективности.

Представлен анализ образования асфальтеносмолопарафиновых отложений, рассматриваются критерии отнесения скважин к подгруппам вида осложнений и предложена классификация осложнения при добыче нефти. Нефть представляет собой сложную и разнообразную смесь различных углеводородов, как легких, так и тяжелых, находящихся в термодинамическом равновесии в пластовых условиях. На некоторых месторождениях добыча нефти не сопровождается образованием асфальтеносмолопарафиновых отложений на глубинно-насосном оборудовании скважин, тогда как на остальных осложнена ими.
Рассмотрены методы предотвращения асфальтеносмолопарафиновых отложений и методы борьбы с ними, представлена проделанная исследовательская работа по обоснованию применения химических реагентов для предотвращения образования осложнения в нефтедобывающих скважинах, определены минимальные мероприятия для подгрупп предложенной классификации осложненного асфальтеносмолопарафиновыми отложениями фонда. Кратко приведены методики определения эффективности действия ингибиторов асфальтеносмолопарафиновых отложений, разработанные в филиале «ПермНИПИнефть» ООО «ЛУКОЙЛ-Инжиниринг», на основе которых выполнялись исследования. Рассмотрены результаты исследований по подбору реагентов и определению их эффективности для осложненного асфальтеносмолопарафиновыми отложениями добывающего фонда скважин. Выявлено, что на протяжении работы скважин там, где меняются физико-химические свойства, эффективность ингибитора значительно снижается и не достигает критерия эффективности в 75 %. Так, в процессе добычи нефти необходимо периодически, не реже одного раза в три года, проверять эффективность подобранных реагентов, а также анализировать изменения таких параметров работы обрабатываемого объекта, как: изменение физико-химических свойств флюида; проведение геолого-технических мероприятий на скважине; значительное увеличение, уменьшение дебита; приобщение или изоляция пропластков, эксплуатационных объектов; изменения пластового, забойного давления в процессе эксплуатации.
Предложены подходы по скважинам: там, где в результате исследований не достигнут критерий эффективности химических реагентов, необходимо подбирать другие методы борьбы с осложнением.

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Introduction

Oil is a complex and varied mixture of various hydrocarbons, both light and heavy, in thermodynamic equilibrium under reservoir conditions. In some fields, oil production is not accompanied by the formation of asphaltene-resin-paraffin deposits on the gas pumping equipment (GPE), while in others it is complicated by them.

The diagram of the distribution of wells complicated by asphaltene-resin-paraffin deposits (ARPD) of the stock in the context of oil and gas producing companies (OGPCs) of LUKOIL PJSC is shown in Fig. 1.

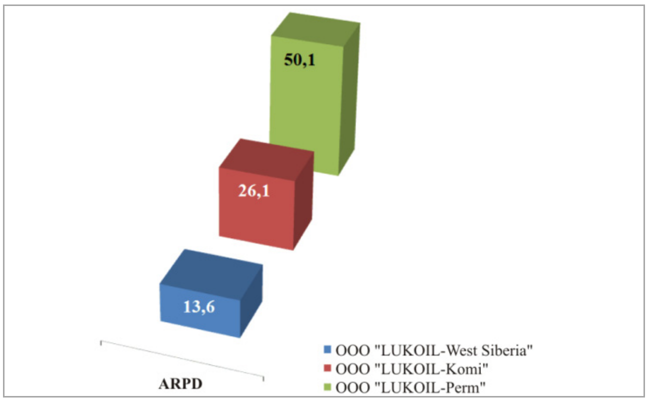


Fig. 1. The share of wells from the stock complicated with ARPD across OGPCs of LUKOIL PJSC as of January 01, 2020

Oilfield ARPD are a mixture of high molecular weight compounds consisting of paraffin, ceresin, resins, and asphaltenes.

Asphaltenes are, under standard conditions, powdered black substances with a molecular weight of 1.500 to 10.000. The more dissolved asphaltenes the reservoir oil contains, the higher the level of its viscosity is. They dissolve in aromatic hydrocarbons, chloroform, and carbon disulfide.

Resins are liquids or plastic substances of high density and viscosity with a molecular weight of 450 to 1.500. Their density is close to one. They dissolve in saturated and aromatic hydrocarbons.

Ceresins are a mixture of solid alkanes with the number of carbon atoms per molecule varying from C35 to C55. They dissolve in pentane, hexane, heptane, and other hydrocarbons.

Paraffins are a mixture of solid hydrocarbons (solid under normal conditions) with the number of atoms per molecule varying from C16 to C35. They dissolve in saturated hydrocarbons such as pentane, hexane fraction, heptane.

ARPD begin to precipitate (crystallize) in oil at the stage of lifting to the surface, mainly when the oil temperature drops below the temperature of its saturation with paraffin. In addition, under certain temperature and pressure conditions, asphaltenes begin to deposit in the formation and clog the bottomhole formation zone. When the temperature and pressure conditions change, the violation of stability leads to the co-crystallization of asphaltenes, resins, and paraffins released from oil, and the formation of various types of ARPD both on the walls of the production string (PS) and on the GPE of production wells.

The following factors influence the intensity of ARPD formation:

– decrease in pressure in the bottomhole area and the associated imbalance in the gas-liquid system;

– intensive degassing;

– temperature decrease along the wellbore as it approaches the wellhead;

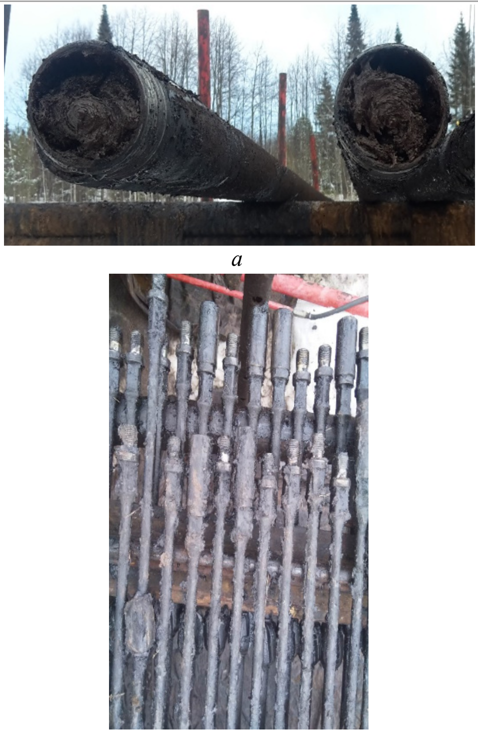
– change in the speed of movement of the gas-liquid mixture, which can cause either the separation of paraffin crystals from the surface of the GPE, or, on the contrary, their precipitation;

– changes in the composition of each phase of the mixture and the ratio of the phases' volumes;

– roughness of the GPE surface;

– adsorption processes due to the presence of resinous components with high adhesion to metal surfaces in oil.

The listed factors change continuously from bottomhole of the well to wellhead. Therefore, the presence and nature of deposits are not constant. The ARPD formation occurs mainly due to a decrease in temperature and pressure, degassing in the process of oil lifting along the wellbore. The solubility of asphaltene-resin-paraffin substances (ARPS) decreases, the crystallization of paraffin and the precipitation of ARPS on the surface of oilfield equipment begin. As they accumulate, the productivity of the wells decreases until complete cessation of oil production.



a

b

Fig. 2. ARPD: *a* – inside pumping and compressor pipes (PCP); *b* – on sucker rods (SR)

Fig. 2 shows examples of ARPD on the elements of production wells' GPE.

Assignment of Wells to Subgroups of the Complication Type

Oils are subdivided into the following types by the mass content of paraffins, resins, and asphaltenes.

By the content of paraffins, the oil can be:

– low-paraffin – ≤ 1.5 %;

– paraffin – > 1.5 % ≤ 6.0 %;

– high-paraffin – > 6.0 %.

By the content of resins and asphaltenes, the oil can be:

– low-resinous – ≤ 5.0 %;

– resinous – > 5.0 % ≤ 15.0 %;

– highly resinous – > 15.0 %.

Table 1

Subgroups by category of ARPD complication

Subgroup		
A1	A2	A3
Calculations in software products using the results of laboratory studies of the physicochemical properties of well products and geological and technical data on the production target highlight the tendency of oil to precipitate ARPD	Types of oil produced: – heavy highly resinous paraffin oil; – heavy highly resinous high-paraffin oil; – bituminous highly resinous paraffin oil; – bituminous highly resinous high-paraffin oil	Dynamometry results, decreased productivity of the pumping unit, increased pressure in flow lines, dragging of the SR string, sticking of the scraper, sticking of the pumping unit
Wells where ARPD are observed on the GPE (based on the results of GPE lifting and disassembly)	Revealing the facts of premature failures of any type of GPE due to ARPD	Revealing the facts of premature failures of any type of GPE due to ARPD during the implementation of all planned measures to deal with and prevent complications

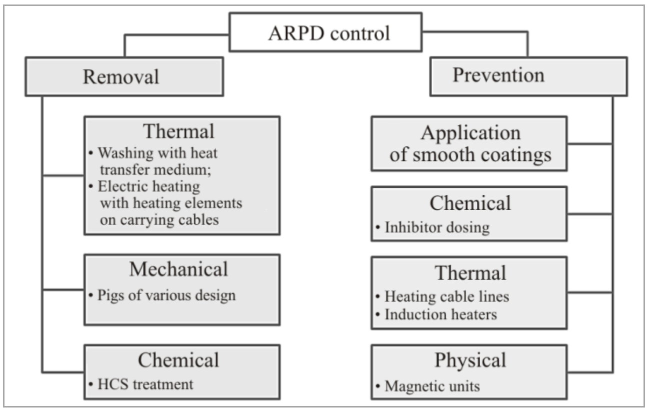


Fig. 3. Basic methods of dealing with ARPD

By density, oils are subdivided into the following types:
– extra light – ≤ 0.830 g/cm^3;
– light – > 0.830 g/cm^3 ≤ 0.850 g/cm^3;
– medium – > 0.850 g/cm^3 ≤ 0.870 g/cm^3;
– heavy – > 0.870 g/cm^3 ≤ 0.895 g/cm^3;
– bituminous – > 0.895 g/cm^3.

To classify the complications in the operation of ARPD production wells, the following criteria are usually used:

1. Oil types: heavy highly resinous paraffin, heavy highly resinous high-paraffin, bituminous highly resinous paraffin and bituminous highly resinous high-paraffin (a more paraffin-rich type of oil).
2. Calculations in software products using the results of laboratory studies of the physicochemical properties of well products and geological and technical data on the production target highlight the tendency of oil to precipitate ARPD.
3. Dynamometry results, decreased productivity of the pumping unit, increased pressure in flow lines, dragging of the SR string, sticking of the scraper, sticking of the pumping unit.
4. Wells in which ARPD are observed on the GPE (based on the results of GPE lifting and disassembly)
5. Revealing the facts of premature failures of any type of GPE due to ARPD.
6. Revealing the facts of premature failures of any type of GPE due to ARPD during the implementation of all planned measures to deal with and prevent complications.

According to the criteria, subgroups were formed based on the categories of ARPD complications (Table 1).

Methods of Dealing with Complication

There are two focus areas in dealing with ARPD in oil production:
– precautions and prevention of deposits;
– removal of already formed deposits.

Basic methods of dealing with deposits are shown in Fig. 3.

Application of Smooth Coatings

This is a method of covering the inner surface of PCP with wax-resistant materials – enamels, epoxy resins and others, the use of fiberglass PCP. The use of enamels, epoxy resins and fiberglass PCP makes it possible to reduce the volume of operations for PCP dewaxing using hot flushing and chemical treatments.

Thermal Methods

Thermal methods for preventing ARPD include the use of various heaters – linear heaters (heating cable lines), induction devices for local heating. Compensation of heat losses in the well using heating cable lines is the most versatile method, which also reduces the viscosity of emulsions.

One of the main methods for removing ARPD is flushing wells with a heat carrier. Hot oil or hot water with the addition of surfactants (SAA) is used as a heat carrier. The essence of the method is that the heat carrier (heated oil or water) is pumped into the annulus of the well, heats the ARPD located in the pumping and compressor pipe (PCP), and the completely or partially melted deposits are carried away through the pipe wall into the flow line with the fluid flow. Heating the PCP from outside leads to the fact that even if the deposits fail to liquefy completely, they can be carried away with the flow, since the molten layer of deposits no longer has sufficient adhesion properties to hold on to the PCP surface. When oil is used as a heat carrier, the effective removal of paraffin deposits is achieved not only due to the thermal effect but also due to the dissolution of the paraffin mass with hot oil. However, during further transportation of oil saturated with paraffin at a high temperature, secondary paraffin precipitation in the pipeline takes place due to a decrease in the flow temperature. In this case, the process of secondary deposit formation can be so intense that after several flushes with a heat carrier, a paraffin plug may form in the flow line. Similar cases are possible when flushing the well with hot water.

In order to prevent the formation of deposits during the secondary paraffin precipitation from the solution, it is necessary to introduce into the heat carrier either a paraffin inhibitor or a surfactant that has the property of dispersing the resin-paraffin mass. These reagents, as a rule, are selected in the laboratory, taking into account the properties of oils and the conditions of the field in the wells of which these methods and reagents are supposed to be applied.

Specialized enterprises have developed methods for electric heating of downhole equipment with pipe-type heating elements on load-carrying cables to remove paraffin plugs in order to restore circulation.

Mechanical Methods

Removal of ARPD mechanically is carried out using scrapers of various designs. During well operation using pumping units with a submersible electric motor (SEM) and a free-flow method, the PCP is cleaned with scrapers, which are lowered on a wire. On wells equipped with sucker rod pumps (SRP), centralizing scrapers are used. These are fixed on the rods at certain intervals and cut off the ARPD from the PCP walls. The cut deposits are carried to the surface with the fluid flow.

Physical Methods

The method is based on the use of magnetic devices and the effect of a magnetic field on the fluid. The mechanism for preventing deposits is as follows: the water-in-oil emulsion entering the well contains iron impurities in typical concentrations of 10–100 mg/l; these impurities are formed mainly as aggregates of ferromagnetic microcrystals of iron (FMI). When the oil flow passes through the magnetic field area, the FMI aggregates are destroyed into individual submicron particles. Since each aggregate contains from several hundred to several thousand microparticles, the destruction of aggregates leads to a sharp, from 100 to 1000-fold, increase in the concentration of paraffin crystallization centers. As the speed of the radial displacement of inclusions is proportional to their volume, then with a 100-time increase in the number of crystallization centers, the average size of paraffin crystals will decrease by the same factor, and the rate of paraffin transfer to the pipeline wall will decrease by a factor of 100 as well. As a result of the aggregate destruction, paraffin crystals fall out in the form of a finely dispersed, voluminous, stable suspension, and the growth rate of deposits decreases in proportion to a decrease in the average size that precipitated together with resins and asphaltenes into the solid phase of paraffin crystals, that is, also by a factor of 100. A magnetic device for a specific well must be selected by examining the effect of the magnetic field on the produced fluid.

Chemical methods

One of the most widespread methods of preventing ARPD is the dosed supply of ARPD inhibitors. The produced inhibitors also contain drag reducers, substances that lower the crystallization temperature of paraffin, and modifiers (dispersants), substances that reduce the structural bond and solidity of deposits. Inhibitors also have some detergent and dissolving properties. The composition and properties of oil and reservoir fluids of each oil field differ from those of other fields. Even within the same field, depending on where the well is located – in the center or the periphery, the oil composition and properties can vary significantly. Therefore, it is necessary to select the appropriate inhibitor for each well individually. The choice of inhibitor is made on the basis of laboratory and field tests. The effectiveness of the applied inhibitor according to the results of laboratory tests should be at least 75 %. This reagent will help to increase the well cleaning interval, but does not exclude operations to remove ARPD. When using an inhibitor with an efficiency of 95 % or more, ARPD are not formed.

The dosage value per ton of oil produced is determined for each inhibitor. The amount of dosage, in turn, depends on the method of inhibitor injection to the well product.

Dosing devices such as wellhead reagent supply units (WRSU) or subsurface dispensers (SD) mounted below the pumping unit are used as a means of dosing the inhibitor into the annulus of the well or directly to the intake of the pumping unit using downhole pipelines.

Hydrocarbon solvents (HCS) are used to eliminate ARPD in downhole and oilfield equipment. As a rule, in most cases, ARPD solvents are used when other methods and procedures fail to yield a positive effect. For example, with deep ARPD in the PCP, in the PS or in the operating elements of the pumps.

Rationale for the Use of Chemical Reagents to Prevent ARPD in Wells

Within the framework of the experimental-laboratory and experimental-industrial tests of reagents for the prevention of ARPD, a complex of studies is carried out to determine the effectiveness of reagent use. Each object is investigated individually. Even at one field, at one production facility, at wells drilled nearby, reagents show different efficiency. This is due to different conditions (physical, chemical) in each individual well, pipeline, device. Also, in the process of oil production, it is necessary to periodically check the effectiveness of the selected reagents at least once every three years, as well as when changing such operating parameters of the production object as:

– change in the physicochemical properties of the fluid;
– carrying out well interventions;
– significant increase, decrease in production;
– involvement or isolation of interlayers, production facilities;
– changes in reservoir, bottomhole pressure during production.

When implementing one of the above points, it is necessary to re-select the applied chemicals. The PermNIPIneft branch has carried out a significant number of studies to determine the effectiveness of ARPD inhibitors to prevent complications in oil production.

Method for Determining ARPD Inhibitors Effectiveness by Cold Finger

This method consists in the comparative assessment of the effectiveness of several ARPD inhibitors or one inhibitor at different concentrations in a dynamic mode typical for specific conditions of oil production or transportation. The method is applicable for oil with a water cut not exceeding 20 %.

The calculation of the effectiveness of paraffin inhibitors (E) is carried out according to the formula:

$$E = \frac{m_0 - m_1}{m_0} \cdot 100\ \%,$$

where m_0 is the weight of paraffin deposits precipitated on the Cold Finger from oil not treated with the inhibitor (comparison cell); m_1 is the weight of paraffin deposits precipitated on the Cold Finger from oil treated with the inhibitor.

The arithmetic mean of two parallel determinations is taken as the measurement result.

Determination of ARPD Inhibitors Effectiveness by Visual Method

This method consists in the comparative assessment of the test results, the selection of the most effective inhibitor in terms of washing off of the oil film, dispersion, adhesion, smearing, and general washing of the flask from ARPD. The method is applicable for oil with a water cut exceeding 20 %.

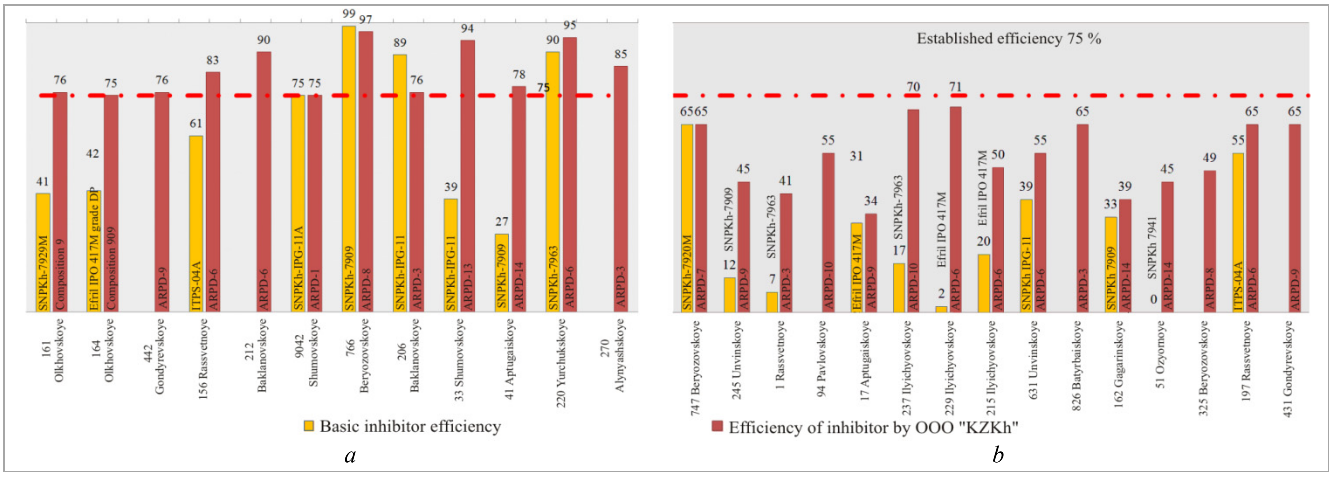


Fig. 4. The effectiveness of basic (previously selected) chemical reagents in comparison with the effectiveness of: *a* – new selections; *b* – new selections that failed to reach the criterion of 75 %

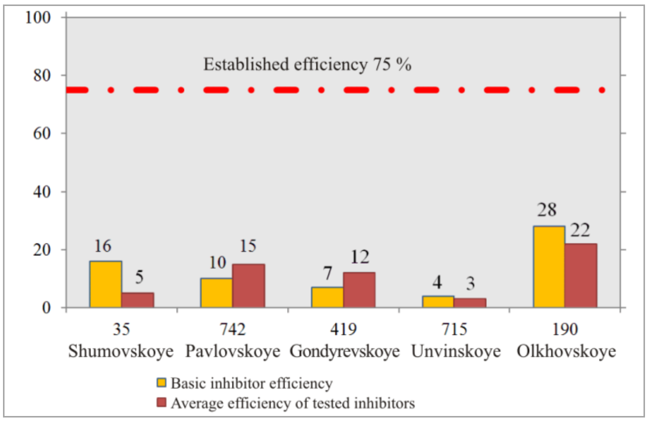


Fig. 5. The effectiveness of basic (previously selected) chemical reagents in comparison with the effectiveness of new selections

The inhibitor efficiency (E, %) is calculated by the formula:

$$E = X_1 - X_2 + X_3 + X_4 + X_5,$$

where according to the tables, following the method, the following is determined:

X_1, % – estimation of oil film washing time;
X_2, % – estimation of ARPD particles dispersion;
X_3, % – estimation of ARPD particles adhesion;
X_4, % – estimation of ARPD particles smearing;
X_5, % – general washing of the flask from ARPD.

The arithmetic mean of two parallel determinations is taken as the measurement result.

Results of the Studies on Determining ARPD Inhibitors Effectiveness

As a result, the studies have shown a decrease in the effectiveness of the basic reagents (Fig. 4).

As can be seen from Fig. 4, the previously selected reagents (basic) at the moment no longer satisfy the criterion of 75 % efficiency. Therefore, the search for effective reagents and the refinement of compositions close to the efficiency criterion continues in this stock.

For some wells, the selection of chemical reagents to prevent ARPD generally does not give effective results for the application of the chemical method of dealing with deposits (Fig. 5).

For such wells, we made a proposal to determine approaches to this group of objects (excluding reagent dosing, changing the way to deal with complications, reagent refinement).

Conclusion

Before implementing measures to remove or prevent complications associated with ARPD on the well, it is necessary to assess the technological efficiency and economic feasibility of using the technology.

The minimum measures for subgroups of the complicated stock are presented in Table 2.

Table 2

Minimum measures for subgroups of the complicated ARPD stock

Subgroup		
A1	A2	A3
Minimum measures		
Mechanical cleaning of PCP by sucker rods with scrapers (sucker rod pump (SRP)) and scrapers (electrical centrifugal pump (ECP), electric screw pump ESP)) using stationary semi-automatic and automatic dewaxing units	Mechanical cleaning of PCP by sucker rods with scrapers (SRP) and scrapers (ECP, ESP) using stationary semi-automatic and automatic dewaxing units	Mechanical cleaning of PCP by sucker rods with scrapers (SRP) and scrapers (ECP, ESP) using stationary semi-automatic and automatic dewaxing units
	The use of a magnetic device (SRP) based on the results of laboratory studies	Dosed supply of ARPD inhibitors based on the results of laboratory studies
	Well flushing with a heat carrier (hot oil or hot water with the addition of surfactants based on the results of laboratory studies) with empirical selection of the well cleaning interval	Introduction of heating cable lines based on the results of thermal calculation
	Treatment of wells with HCS based on the results of laboratory studies with empirical selection of the well cleaning interval	

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