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REDUCING THE FORMATION OF ASPHALTENE DEPOSITS AND INCREASING THE FLOW RATES OF OIL WELLS

Purpose. Reducing the formation of asphaltene deposits in the bottom-hole zone of wells and increasing their flow rate.

Methodology. The purpose of the work is achieved by conducting theoretical and experimental studies on the formation of asphaltene and paraffin deposits in the bottom-hole zone of the oil reservoir and identifying patterns of their dissolution by pumping heated low-boiling oil components containing carbon atoms C_6-C_9 in molecules into the well.

Findings. The experimental studies conducted under laboratory conditions showed high solubility of asphalt-resin and paraffin compounds in low-boiling oil components. To prevent the deposition of asphaltene deposits in the bottom-hole zone of wells, the turbulent nature of oil movement is necessary, which is achieved by increasing reservoir pressure when water or gas is injected into the oil reservoir. It is also necessary to have a reservoir pressure above the saturation pressure of oil with gas. Effective methods are recommended to reduce the formation of asphaltene deposits in the oil reservoir in the bottom-hole zone and to restore the production rates of producing wells by pumping heated low-boiling oil components containing carbon atoms C_6-C_9 in molecules into the well. It has been experimentally established that when the temperature of the specified solvent changes from 20 to 800 °C, the time of complete dissolution of the asphalt-resin compound (bitumen) in the form of balls with a diameter of 5 mm is within 0.20−3.0 hours, and in reservoir conditions with a temperature of 60−80 °C − significantly less for 0.2−0.25 hours. This indicates that before pumping low-boiling oil components containing C_6-C_9 carbon atoms in the molecules, they must be preheated to reservoir temperature. A method is also proposed for treating the bottom-hole zone of an oil reservoir with a complex solution including low-boiling oil components containing carbon atoms C_6-C_9 in molecules, hydrochloric and fluoric acids.

Originality. Effective methods are proposed to reduce the formation of asphaltene and paraffin deposits in the bottom-hole zone of the oil reservoir and to restore the production rates of producing wells by pumping heated low-boiling oil components into the well, as well as a complex solution with the inclusion of acids.

Practical value. A technique has been developed to improve technological processes to reduce the formation of asphalt-resin-paraffin deposits and to establish rational parameters of the installation for producing low-boiling oil components containing carbon atoms C_6-C_9 in industrial conditions. Using the results of research in oil fields allows you to restore the initial permeability and thereby increase the flow rate of oil wells by 20−30 %.

Keywords: *oil, reservoir, wells, flow rate, asphaltenes, resins, paraffins, deposits*

Introduction. The experience of many field exploitation shows that as oil is withdrawn from the deposits and the formation pressure declines, there is an intensive precipitation of organic and mineral deposits in the bottom-hole zone. This is primarily due to the high content of heavy hydrocarbons such as asphaltenes, resins and paraffins in the oil produced. So, for example, depending on the horizon of the oil reservoir, oil at the Kazakhstani field "Uzen" is characterized by a high content of paraffin hydrocarbons up to 18 % and asphaltene-resinous substances up to 19 %, which cause its high pour point — up to 35 °C, complicating the processes of production, field gathering, processes of commercial preparation of oil [1]. The factors influencing the conditions for the formation of asphalt-

resinous and paraffin deposits in the bottomhole zone of an oil reservoir, and effective methods for restoring production wells are considered below.

Literature review. The authors of [2] indicate that solid deposition during production, transport, and storage of crude oils leads to significant technical problems and economic losses for the oil and gas industry. The thermodynamic equilibrium between high-molecular-weight components of crude oil, such as asphaltenes, resins, and waxes, is an important parameter for the stability of crude oil. Once the equilibrium is disturbed due to variations in temperature, pressure, and oil composition during production, the solubility of highmolecular-weight waxes decreases. The review [3] critically examines the state of research and the prospects for the emergence and characteristics of paraffins, which are formed in oil wells and pipelines. Several approaches for detecting paraffin wax and

managing wax formation damage during oil recovery were discussed. This review also highlighted the effects of temperature and crude oil type on wax formation.

In the study [4], a report was made on various interactions of asphaltenes with water under reservoir conditions during waterflooding. Molecular dynamics simulation results for oil/water systems have shown that asphaltenes become less soluble in oil when water partially mixes with the oil phase. All model asphaltenes containing nitrogen and/or oxygen atoms in their structure tend to associate. It was shown that the asphaltene-water hydrogen bond is the driving force for asphaltene aggregation. One of the effective methods to reduce the formation of asphalt-resinous and paraffin deposits in the bottomhole formation zone due to the water cut of the produced oil is the creation of water isolation zones below and above the productive formation [5]. To do this, the production string and cement stone are perforated in the indicated intervals, and then gel-forming reagents and plugging materials are injected through the formed radial channels. The results of computer modeling of the formation of a cone of bottom water and the results of laboratory studies to evaluate the effectiveness of gel-forming reagents and grouting materials are also presented [6]. Thus, complete sealing of the annular spaces of well bottoms from aquifers is ensured.

The research [7] describes important methods that were used to reduce or soften paraffin deposits in hydrocarbon production systems around the world, such as chemical, mechanical, thermal methods or a combination of them, microbial treatment, cold flow, cold oil recirculation method, choke method, cooling method, wax eating method, magnetic fluid conditioning method, Eco-wave TM treatment, ultrasonic wave treatment, bacterial treatment and spiral flow method. However, the authors of this paper note that many oil companies are still incurring high costs from wax deposits and are still looking for good solutions to eliminate this problem. The technology of magnetic fields application in prevention of asphalt-resin-paraffin deposits is introduced in the article. The article [8] presents a technology for the use of magnetic fields to prevent asphalt-tar and paraffin deposits. The obtained results of the magnetic treatment of the extracted fluid make it possible to use it in oil wells equipped with pumping units, as well as in non-pressure production or in wells operated by an electric submersible pump and in oil pipelines. Oil well treatment with xylene is the most common asphaltene removal method in Iran [9]. In this work [10], the parameters of solubility and the onset of precipitation of polar fractions of heavy oils from Brazilian fields were studied and evaluated using a simplified system of n-heptane/toluene mixtures.

However, petroleum solvents and petrochemical wastes are not readily available in the field due to their high cost. The composition of petrochemical production wastes is dominated by heavy high-molecular components of aromatic hydrocarbons and resinous substances, which do not completely dissolve organic deposits in the pores and cracks of the oil-bearing formation. It is practically impossible to provide all wells in the fields with petroleum solvents due to the limited number of relevant specialized petrochemical industries and the high cost of solvents for asphalt-tar and paraffin deposits.

When treating the bottomhole formation zone with hot-oil, it is also impossible to achieve high solubility of organic deposits, since in the composition of the produced oil, in addition to aromatic hydrocarbons, there are a large quantity of alkane and naphthenic high molecular heavy hydrocarbons, in which asphaltenes and resins are difficult to dissolve. The share of aromatic hydrocarbons which are a good solvent for organic deposits in the oil usually does not exceed 1−5 %. Therefore, it is necessary to search for other and more effective ways to restore the initial permeability of the bottomhole formation zone and available sources of sediment solvents.

Thus, the analysis of the work performed shows that the conditions for the precipitation of asphaltenes from oil have not been sufficiently studied and measures have been developed to reduce them. Particular attention should be paid to the study on factors affecting the nature of oil flow migration in the perforations of the production string, in the bottom hole and inside the tubing. Therefore, it is necessary to search for other, more effective ways to restore the initial permeability of the bottomhole formation zone and available sources of sediment solvents.

Reducing of asphaltene precipitation in the bottomhole formation zone. Known models of asphaltene molecules show that the process of deposition of deposits from oil is significantly affected by the branched structure of molecules and the nature of the migration of the oil flow on a solid surface. In case if migration of oil flow is laminar, then asphaltenes with long molecules from aromatic rings and alkane chains tend to form hard deposits in the bottomhole formation zone and on the working surfaces of equipment. For preventing this phenomenon, oil must travel in a turbulent nature, and the rock pores and equipment must have smooth surfaces. Unfortunately, it is impossible to change the roughness of rock pores and cracks, but it is possible to create a turbulent nature of oil movement by increasing bottom hole pressure during the injection of water or gas into the reservoir. Let us consider the conditions under which it is possible to create a turbulent nature of the movement of oil and reduce the deposition of asphaltene sediments in the near-wellbore.

The minimum speed of oil travel in the bottomhole formation zone (Fig. 1), at which the precipitation of organic deposits is significantly reduced, can be determined based on Darcy law by formula

$$\vartheta = \frac{k}{\mu dL} dp, \qquad (1)$$

where k is the permeability coefficient characterizing the ability of the rock to pass liquids and gases; μ is the liquid viscosity; dL is the change in the length of the filtration zone; dp is the pressure change.

After integrating the variable parameters dL from the well radius r (or from zero, neglecting the small value of r by comparing R) to the supply contour radius R and dp from the pressure p_0 in the bottomhole to the reservoir pressure p, Darcy's equation for the radial filtration of oil will have the following form

$$\vartheta \int_{D}^{R} dL = \frac{k}{\mu} \int_{p_0}^{p} dp; \quad \vartheta = \frac{k(p - p_0)}{\mu R}. \qquad (2)$$

This formula implies that changing the nature of oil movement can be achieved by changing the reservoir pressure during the injection of water or gas into the reservoir. We substitute the obtained velocity v of oil travel into the well-known formula for determining the Reynolds number and determine the turbulence nature of oil movement from the condition

$$\mathrm{Re} = \rho \frac{vD}{\mu} \geq \mathrm{Re}_{cr}, \qquad (3)$$

where Re is the Reynolds number, ρ is the oil density, v is the rate of oil flow; D is the diameter of the perforation channels of
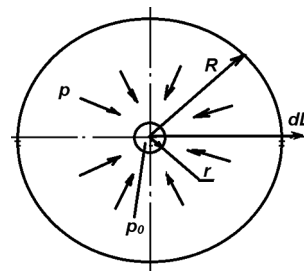

Fig. 1. Scheme of oil movement from the reservoir to the well bottom

the production string; μ is the oil viscosity; $\text{Re}_{cr} \approx 2300$ is the critical value of the Reynolds numbers, below which the laminar nature of oil movement occurs.

Based on the above formulas (2 and 3), it is possible to determine the lowest value of the reservoir pressure *p,* above which the turbulent nature of oil movement is ensured and the formation of asphaltene sediments in the bottomhole formation zone does not occur

$$\vartheta = \frac{k(p - p_0)}{\mu R} = \mu \frac{\text{Re}_{cr}}{\rho D}; \quad p = \mu^2 \frac{R\,\text{Re}_{cr}}{k\rho D} - p_0.$$

It can be seen from the above formulas that the process of asphaltene sediments precipitation is significantly influenced by oil viscosity and reservoir pressure. This suggests that one of the main conditions for preventing asphaltene sediments precipitation in the bottomhole zone is to achieve reservoir pressure higher than the saturation pressure by injection water or gas into the reservoir.

One of the factors influencing the required reservoir pressure and increasing the flow rate of production wells is the injectivity of injection wells. In many cases, it is reduced due to the use of formation water with suspended clay particles in the process of maintaining formation pressure. We have received a patent of the Republic of Kazakhstan for a new method of purification [11] of formation water from suspended clay particles, the use of which does not reduce the permeability of the oil reservoir and the injectivity of injection wells, as well as the flow rate of production wells. Rational parameters and modes of operation of technological equipment for the implementation of this method have been determined [12].

This method consists in supplying formation water through the inlet to the lower compartment of the device, which leads to sequential injection of fluid from the bottom up. The liquid rises through a perforated baffle and a layered filter of granular material, each layer of which has a certain particle size. The bottom and top layers have the maximum overall dimensions of the particles, while the minimum overall dimensions of the particles are in the middle layer. As a result, suspended solids do not clog the filter pores, but settle and accumulate in the lower wedge-shaped part of the unit. The filtered water from the tank is discharged through the outlet pipe. The lower outlet pipe allows the accumulated particles to be removed periodically. After filtration, water, cleared of suspended solids, is sent to maintain reservoir pressure.

Efficient technology for removing asphalt and paraffin deposits. We received a patent [13] of the Republic of Kazakhstan for a method for removing asphaltene deposits from the bottomhole formation zone with low-boiling oil components heated to a temperature not lower than formation oil with a carbon content of $C_6–C_9$. in molecules. In group $C_6–C_9$, hydrocarbons include aromatic hydrocarbons such as benzene, toluene and xylene, which are good solvents for asphaltenes, resins and paraffins. Heating of low-boiling oil components above the reservoir temperature and injection into the bottomhole zone accelerates the dissolution of asphaltic-resinous deposits. Low-boiling oil components can be obtained under field condition from degassed oil.

Of these components of oil containing carbon atoms $C_6–C_9$. in molecules, aromatic hydrocarbons such as benzene, toluene and xylene have the highest boiling point from 80 to 176 °C. Arenes with the content of carbon atoms C_{10} and higher in molecules with a boiling point of 218 °C and higher dissolve asphaltenes and resins insufficiently due to their low chemical activity. Low-boiling oil components containing $C_6–C_9$ carbon atoms in molecules are the most effective solvents for asphalt-resin and paraffin deposits and they can be obtained by simple distillation at a temperature of 180–210 °C.

High performance technology for the removal of asphaltene deposits from the well bottom zone using low-boiling oil components is as follows. The well is plugging with a displacement fluid and circulation is established. Solvent (low-boiling oil components) is pumped into the bottomhole formation zone *1* (Fig. 2) through tubing *2* and perforations *3* of well *4* from reservoir *5* using pump *6*. The solvent from low-boiling oil components is preheated in furnace *7* to a temperature of 60–80 °C (not lower than reservoir temperature). The volume of liquid displaced from the well is measured in the annular space.

The solvent of asphaltic-resinous deposits is delivered by tank truck. The amount of the first solvent portion injected is calculated so that it fills the pipes and the annular space from the tubing shoe to top of the formation. Hereon, the annulus is closed and the entire volume of the solvent is pumped through. After the petroleum solvent injection, the well is closed on the 'impregnation' and maintained to respond to organic sediments and redistribution of saturation in the well bottom zone. In the bottomhole formation zone and the well bottom, under the influence of injected low-boiling oil components containing $C_6–C_9$ carbon atoms in molecules, asphaltene compounds in dissolved form become more moveable. After exposure, the particles of asphaltene deposits together with the solvent are brought out from the well. Then the well is put into product selection mode, in which the operation is carried out at the level of the design profitable flowrate.

As is known, in the bottom-hole zone in the pores of the oil reservoir, not only asphalt-resinous and paraffin deposits are formed, but also mineral deposits in the form of small particles of rock and salts. They can only be dissolved with acidic solutions, such as aqueous solutions of hydrochloric and fluoric acids. In this regard, we propose a method for treating the bottom-hole zone of an oil reservoir with a complex solution, including low-boiling components of oil containing carbon atoms $C_6–C_9$ in molecules, hydrochloric and fluoric acids. At the same time, thin oil films are formed on the surfaces of porous and fractured rock, along which the acid solution moves deep into the reservoir. This significantly increases the efficiency of cleaning the bottom-hole zone of the oil reservoir and the surface of process equipment from organic and mineral deposits.

Technology for producing low-boiling oil components under field conditions. The technological scheme for obtaining low-boiling oil components with the content of $C_6–C_9$ carbon atoms in molecules under field conditions by simple distillation from degassed oil is shown in Fig. 3. The initial degassed oil I is supplied with a pump *1* through the heat exchanger *2* in the furnace *3*, where it is heated to the boiling point of aromatic hydrocarbons with a carbon content of C_9 (up to 200 °C). From the furnace, the heated oil is fed into a two-section installation *4* of cylindrically shaped through the inlet nozzle *5*. In the working chamber *6* of the installation oil is subjected to a simple single-stage differential distillation. In such case, the liquid phase II will be enriched with high-boiling oil components with a carbon content of more than C_9 in molecules and is bring out by a branch pipe *7*, and the gas phase — low-boiling oil components with a carbon content below C_9 in mole-
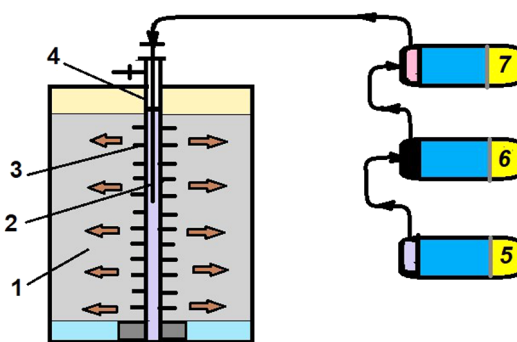

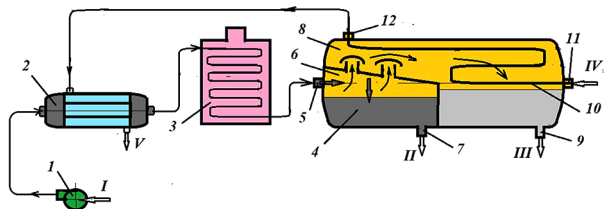*Fig. 2. Scheme of injection of low-boiling oil components into the well*

Fig. 3. Technological scheme for obtaining low-boiling oil components under field conditions

Fig. 4. Scheme of the setup using an Engler distillating flask

cules are directed through the side slots of the tray into the working quenching chamber *8*.

In the second working chamber *8*, the high-boiling oil components III with a carbon atom content of more than C_9 are cooled and bring out in the form of a liquid through the branch pipe *9*. Inside the second working chamber *8* there is a tubular cooler *10*, which has a branch pipe *11* for cold water input and a branch pipe *12* for bringing out heated water. Cold water IV enters the tubular cooler *10* through the inlet elbow and takes on heat from the vapour phase of oil. Then the heated water is brought out from the cooler with the output nozzle *12*. With a view to economy of thermal energy, the water V heated in the second working chamber is sent to the heat exchanger *2*, where it gives off its heat to the original oil. To heat the oil, you can use a standard furnace, which provides a temperature within 200−210 °C and the required capability of the two-section unit.

The required surface area of a tubular cooler of a two-section unit can be determined by formula

$$Q = FKdt,$$

where Q is the amount of heat that the gas phase of hydrocarbons gives off to the water flow to heat it; K is the heat exchange factor; dt is the change in water temperature.

Upon integration of the variable parameter dt from the initial t_1 to the final t_2 water temperature, the formula for the required surface area of the tubular cooler will be as follows

$$Q = FK\int_{t_1}^{t_2}dt; \quad p = \mu^2\frac{R\,\mathrm{Re}_{cr}}{k\rho D} - p_0.$$

The amount of heat transferred from the gas phase of hydrocarbons to water is calculated by formula

$$Q = G(J_2 - J_1),$$

where G is water mass rate; J_2 and J_1 are the final and initial enthalpy of water.

Thus, the proposed technologies for removing asphaltene deposits and obtaining a new effective solvent − low-boiling oil components can significantly reduce the cost for restoring the bottomhole formation zone permeability and increase well production rates.

Laboratory research. Experimental studies were carried out for assessment of feasibility of low-boiling oil components with the content of $C_6–C_9$ carbon atoms in molecules as a solvent of asphaltene deposits. Low-boiling oil components were obtained in two laboratory facilities, the first of them was created according to the traditional scheme and the second − by analogy with the recommended scheme (Fig. 3) of an industrial installation.

The first laboratory setup (Fig. 4) consists of a cylindrical body *1*, inside which there is Engler distillating flask *2* with oil, a mesh cell *3* and a flexible electric heater *4*. The space between the cylindrical body and the mesh cell is filled with silica sand *5*. Electric current is supplied to the electric heater through a transformer (laboratory transformer) *6* allowing one to adjust electrical voltage and the oil heating temperature within 20−210 °C. The voltage transformer is equipped with a voltmeter. The upper tube of the flask is closed with a rubber
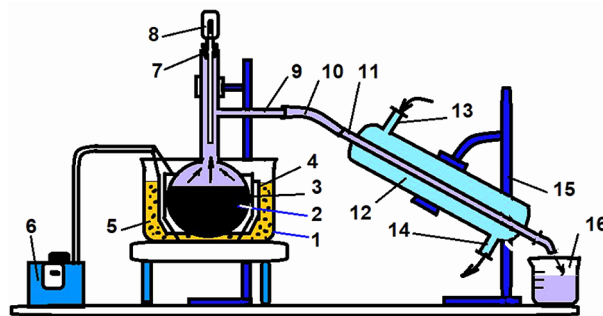
cork *7* at the center of which a thermometer *8* is installed to measure the temperature inside the flask.

The side tube *9* of the flask communicates through a flexible silicone tube *10* with the inner tube of the glass refrigerator *12*. The outer tube of the refrigerator has an inlet elbow *13* for supplying cold water and an outlet nozzle *14* for bring out heated water. The refrigerator is fastened to upright *15*. Under the outlet port of the inner tube of the refrigerator there is a beaker *16*.

Laboratory setup works as follows. The Engler distillating flask is filled with oil in a volume about 70 % of overall volume of the flask, taking into account the volume expansion of oil when it is heated to 200 °C. The space between the outer and inner tubes of the refrigerator *12* is supplied through the inlet elbow *13* flowing cold water. To heat the oil, an electric current is connected through a transformer to a heater element. By adjusting the electrical voltage with the help of a transformer, the temperature inside the flask is brought to 200 °C, at which low-boiling oil components containing $C_6–C_9$ carbon atoms in molecules evaporate and are directed through the side tube of the flask into the inner tube of the refrigerator. Here the vaporized gas phase of oil is condensed and low-boiling oil components with the content of $C_6–C_9$ carbon atoms in molecules in liquid state enters the receiving beaker.

The second laboratory experimental setup (Fig. 5) is an analogue of industrial equipment to produce low-boiling oil components under field conditions with the content of $C_6–C_9$ carbon atoms in molecules. It consists of a horizontal cylindrical reactor *1* filled with degassed oil and equipped with an electric heater *2*, a thermometer *3*, a pressure gauge *4*, outlet *5* and *6* inlet nozzle.

The reactor interior is connected through a tube *7* and a cock *8* with a working chamber *9*, the upper part of which is perforated. The working chamber is installed inside the quenching chamber *10* and has an outlet pipe *11* for draining low-boiling oil components. The working chamber is equipped with an outlet pipe *12* for draining high-boiling oil components. Inside the quenching chamber there is a coil *13* with inlet *14* and outlet elbow *15*.

The installation works as follows. The cylindrical reactor is filled with oil through the inlet spout. Under these circumstances, the outlet pipe of the reactor is in the open position. After filling with oil, the reactor is heated to the boiling point of aromatic hydrocarbons at 200 °C. Cold water is passed through the quenching chamber coil. Then the valve of the connector tube is opened, through which the heated oil from the reactor enters the working chamber. In the working chamber, low-boiling oil components evaporate and exit through the perforations into the quenching chamber. High-boiling components in the form of liquid are brought out through the outlet pipe of the working chamber. In the quenching chamber, vaporous low-boiling oil components are converted into liquid and brought out through the outlet connection.

The installation works as follows. The cylindrical reactor is filled with oil through the inlet pipe. In this case, the outlet pipe of the reactor is in the open position. After filling with oil,
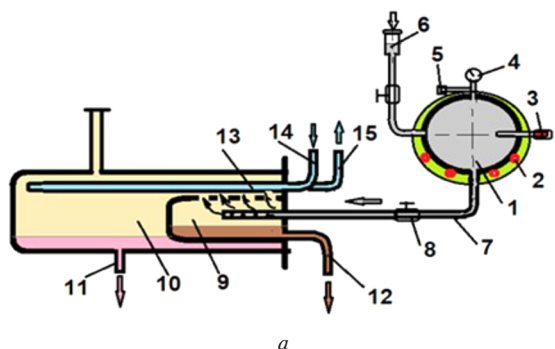
a

b

Fig. 5. Scheme (a) and general (b) view of the installation for obtaining low-boiling oil components by the analogy with industrial equipment

Fig. 6. Scheme (a) and general view (b) of the equipment for evaluation solubility of solid bitumen in low-boiling oil components containing C_6-C_9 carbon atoms in molecules

the reactor is heated to the boiling point of aromatic hydrocarbons of 200 °C. Cold water is passed through the coil of the cooling chamber. Then the valve of the connecting tube is opened, through which the heated oil from the reactor enters the working chamber. In the working chamber, low-boiling oil components evaporate and exit through the perforations into the cooling chamber. High-boiling components in the form of a liquid are discharged through the outlet pipe of the working chamber. In the cooling chamber, the vaporous low-boiling components of the oil turn into a liquid and are discharged through the outlet pipe.

In the performance of an experiment, oil with a kinematic viscosity of 30 mm²/s at 20 °C (ASTM D 445-2011) and 10 mm²/s at 50 °C (ASTM D 445-2011) was accepted. Low-boiling oil components with the content of C_6-C_9 carbon atoms in molecules having a boiling point of up to 200 °C, were obtained on the mentioned above laboratory setup. At a temperature of 200 °C, cut of aromatic hydrocarbons such as benzene, toluene and xylene evaporate from oil, in which asphaltenes and resins are readily soluble.

As an asphaltic-resinous compound (sediment), solid bitumen was adopted, containing about 25 % of asphaltene and 35 % of resin, and spherules of 5 mm in diameter were made from it. A 30 ml plastic cylindrical transparent can *1* (Fig. 6) with a mesh partition *2* contains a solvent − low-boiling oil components *3* in a volume of 70 percent of the can volume. Upon *I* the vertical position of the can, a spherule *4* of solid bitumen is placed on a mesh partition located above the level of the solvent. All cans are closed from 1800 below and from above with rubber corks *4* and *5*.

Then the cans are turned 180° and placed in water container. The desired temperature inside the cans is created by heating water using an electric heater located under the container. In this case, within a given period, the change in a ball diameter of solid bitumen is recorded in the process of its dissolution in low-boiling oil components. The solubility of solid
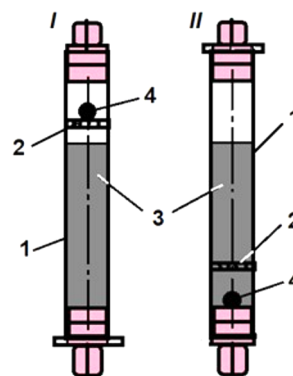
bitumen in low-boiling oil components, respectively, in reservoir (60−80 °C) and atmospheric conditions was estimated as the difference δ of the original diameter of 5 mm of a bitumen ball and its diameter d_0 in solution process at time range of $B = 0.25$; 0.50; 1.0; 1.5; 2.0 and 2.5 hours, i. e. as the intensity of solubility of the bitumen ball $\delta = 5 - d_0$ in the solvent. The measurement summaries of the solubility of the bitumen ball δ at a temperature of $T = 20$; 40; 60 and 80 °C of the solvent and the dissolution time B (hours) are presented in Table 1.

To establish the dependence of the solubility δ of the bitumen ball on the temperature T (°C) of the solvent and the time of dissolution B (hours) of the bitumen, the mathematical method of rotatable design was used [5]. When coding factors, their interval and levels of variation were taken into account; they are listed in Table 2.

The connection of the named and coded values was found with the help of proportion

$$x_1 = (T - 40)/10; \quad x_2 = (B - 1.2)/0.4.$$

Table 3 lists the ranges of variation in the factors denoted by named (T and B) and coded x_1 and x_2 (working matrix) values, as well as the experimental values obtained of the inten-

Table 1

The results of measurement of the intensity of solubility of the bitumen ball in low-boiling oil components with the content of C_6-C_9 carbon atoms in molecules

Test number	Solvent temperature T, °C	The intensity of the solubility of the bitumen ball δ (mm) in time B (hours) of its presence in the solvent					
		0.25	0.5	1.0	1.5	2.0	2.5
1	20	2.0	2.5	3.0	3.5	4.0	4.5
2	40	3.5	4.5	>5.0	>5.0	>5.0	>5.0
3	60	5.0	>5.0	>5.0	>5.0	>5.0	>5.0
4	80	>5.0	>5.0	>5.0	>5.0	>5.0	>5.0

Table 2

Interval and levels of factors variation

Factors	Variation levels					Variation interval
	−1.414	−1	0	+1	+1.414	
T, °C − solvent temperature, x_1	26	30	40	50	54.1	10
B, hours − bitumen dissolution time, x_2	0.6	0.8	1.2	1.6	1.8	0.4

Second-order rotatable design matrix

Test number	Factors		Working matrix		Criteria of factor evaluation
	T, °C	B, hours	x_1	x_2	δ, mm
1	50	1.6	1	1	5.0
2	50	0.8	1	−1	4.8
3	30	1.6	−1	1	4.2
4	30	0.8	−1	-1	3.2
5	6.3	1.2	−1.414	0	3.3
6	25.86	1.2	1.414	0	5.0
7	54.14	0.63	0	−1.414	4.2
8	40	1.76	0	1.414	5.0
9	40	1.2	0	0	5.0
10	40	1.2	0	0	5.0
11	40	1.2	0	0	5.0
12	40	1.2	0	0	5.0
13	40	1.2	0	0	5.0

sity of solubility of the bitumen ball δ. The values of the regression coefficients were calculated and equations were obtained that describe the solubility change in the bitumen ball δ from two factors: the solvent temperature x_1 (T) and the time of bitumen dissolution x_2 (B): in coded values

$$\delta = -5.0001 + 0.6004x_1 + 0.2914x_2 - 0.2x_1x_2 - \\ -0.4480x_1^2 - 0.2231x_2^2;$$

in natural value

$$\delta = -9.8518 + 0.4784T + 6.0751B - 0.05TB - \\ -0.0044T^2 - 1.3944B^2.$$

Fig. 7 shows the dependence graphs of the solubility of the bitumen ball δ at temperatures of T = 20; 40; 60 and 80 °C of solvent and dissolution time B = 0.25; 0.50; 1.0; 1.5; 2.0 and 2.5 hours.

It can be seen from the graphs that upon the temperature changes from 20 to 80 °C, the time of complete dissolution of bitumen in the form of a ball with a diameter of 5 mm is within 0.20−3.0 hours, and under reservoir conditions (60−80 °C) − significantly fewer, within 0.2−0.25 hours. This suggests that in the process of injection of low-boiling oil components containing C_6−C_9 carbon atoms in the molecules, it is necessary
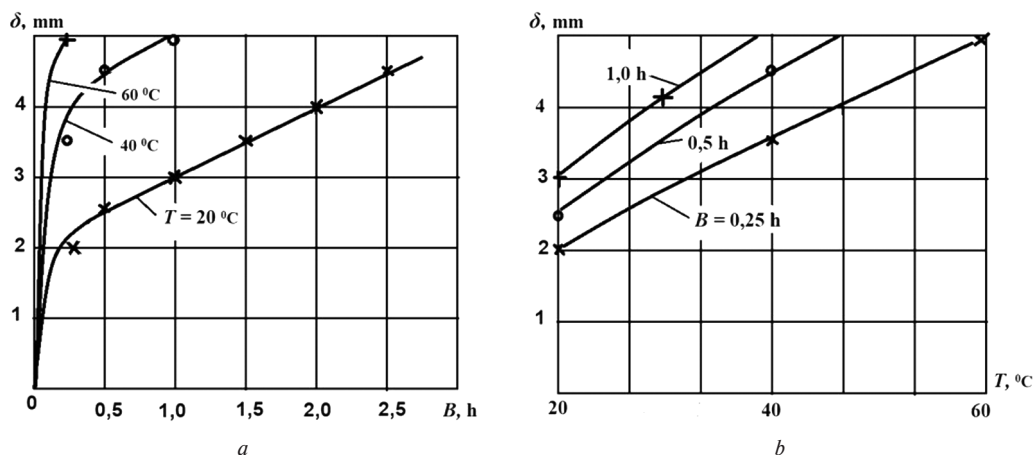
to preheat them to the reservoir temperature. The residence time and the volume of the solvent in the formation are determined depending on the contamination level of the bottomhole zone with asphaltic-resinous deposits.

Conclusions. The following conclusions are drawn.

1. The process of asphaltene precipitation from oil is significantly influenced by the branched structure of asphaltene and resins molecules, as well as the nature of migration of oil flow on a solid surface. In case if oil flow is laminar, then asphaltenes with long molecules from aromatic rings and alkane chains tend to form hard deposits. For preventing this phenomenon, oil must travel in the well bottom zone in a turbulent nature, and equipment must have smooth surfaces.

2. Reducing the asphaltene precipitation in the bottomhole zone can be achieved by an increase in the reservoir pressure by injecting water or gas into the reservoir at which the turbulent nature of oil movement is ensured. It should also be noted that one of the main conditions for preventing the precipitation of organic sediments in the bottomhole zone is the preservation of the reservoir pressure above the saturation pressure.

3. A new effective method for removing asphaltic-resinous deposits from the bottomhole formation zone using low-boiling oil components heated up to a temperature not lower than the oil reservoir with the content of C_6−C_9 carbon atoms in molecules is proposed. This hydrocarbon group includes aromatic hydrocarbons such as benzene, toluene and xylene, which dissolve well asphaltenes, resin and paraffin. Heating of low-boiling oil components above the reservoir temperature and injection into the bottomhole zone accelerates the dissolution of asphaltic-resinous deposits.

4. A rational technological scheme for obtaining low-boiling oil components with the content of C_6−C_9 carbon atoms in molecules under field conditions is recommended, which consists in a simple distillation of degassed oil in a two-section installation with separating and quenching working chambers for two petroleum cuts. To heat oil within 200−210 °C, a standard furnace can be used, which provides the required capacity of a two-section unit for simple oil distillation.

5. Laboratory experimental studies showed a high solubility of asphaltic-resinous compounds in a solvent from low-boiling oil components containing C_6−C_9 carbon atoms in molecules. When the temperature of the specified solvent changes from 20 to 80 °C, the time of complete dissolution of the asphaltic-resinous compound (bitumen) in the form of balls with the diameter of 5 mm is within 0.20−3.0 hours, and under reservoir conditions with a temperature of 60−80 °C − significantly fewer, within 0.2−0.25 hours. This suggests that in the process of injection of low-boiling oil components containing C_6−C_9 carbon atoms in the molecules, it is necessary to preheat them to the reservoir temperature.

Fig. 7. Dependence of the solubility of the bitumen ball δ on time B (a) of its presence in the solvent and the solvent temperature (b)

6. Thus, on the basis of theoretical and experimental studies, the possibility of a significant reduction of asphaltene precipitation in the bottomhole zone by choosing a rational value of the injection pressure of water or gas for oil displacement has been substantiated, providing a minimum speed of oil travel with a turbulent nature of travel. A new technology has been proposed for the effective removal of asphaltic-resinous deposits from the bottomhole zone and exploration wells debit increase by treatment with low-boiling oil components containing C_6-C_9 carbon atoms in molecules heated up to a temperature not lower than the oil reservoir.

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Зниження утворення асфальто-смолистих відкладень і підвищення дебітів нафтових свердловин

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Мета. Зниження утворення асфальтенових відкладень у привибійній зоні свердловин і збільшення їх дебіту.

Методика. Мета роботи досягається проведенням теоретичних та експериментальних досліджень процесів утворення асфальтенових і парафінових відкладень у привибійній зоні нафтового пласта й виявленням закономірностей їх розчинення закачуванням у свердловину нагрітої низькокиплячої компоненти нафти, що містять атоми вуглецю C_6-C_9 у молекулах.

Результати. Експериментальні дослідження, проведені в лабораторних умовах, показали високу розчинність асфальто-смолистих і парафінових сполук у низькокиплячих компонентах нафти. Для запобігання відкладенню асфальтенових відкладень у привибійній зоні свердловин необхідний турбулентний характер руху нафти, що досягається підвищенням пластового тиску при закачуванні води або газу до нафтового пласта. Також необхідно мати пластовий тиск вище тиску насичення нафти газом. Рекомендовані ефективні методи зниження утворення асфальтенових відкладень у нафтовому пласті у привибійній зоні й відновлення дебітів свердловин, що добувають шляхом закачування у свердловину нагрітих низькокиплячих компонентів нафти, які містять атоми вуглецю C_6-C_9 у молекулах. Експериментально встановлено, що при зміні температури зазначеного розчинника від 20 до 80 °C час повного розчинення асфальто-смолистого з'єднання (бітуму) у вигляді кульок діаметром 5 мм знаходиться в межах 0,20—3,0 години, а у пластових умовах із температурою 60—80 °C — значно менше протягом 0,2—0,25 годин. Це свідчить про те, що перед закачуванням низькокиплячих компонентів нафти, що містять атоми вуглецю C_6-C_9, їх необхідно попередньо підігріти до пластової температури. Пропонується також спосіб обробки привибійної зони нафтового пласта комплексним розчином, що включає низькокиплячі компоненти нафти із вмістом атомів вуглецю C_6-C_9 в молекулах, соляної та фтористої кислот.

Наукова новизна. Запропоновані ефективні методи зниження утворення асфальтенових і парафінових відкладень у привибійній зоні нафтового пласта й відновлення дебітів видобувних свердловин шляхом закачування у свердловину підігрітих низькокиплячих компонентів нафти, а також комплексним розчином включенням кислот.

Практична значимість. Розроблена методика вдосконалення технологічних процесів для зниження утворення асфальто-смолисто-парафінових відкладень і встановлення раціональних параметрів установлення отримання низькокиплячих компонентів нафти, що містять атоми вуглецю C_6-C_9, у промислових умовах. Використання результатів досліджень на нафтових родовищах дозволяє відновити початкову проникність і цим збільшити дебіт нафтових свердловин на 20—30 %.

Ключові слова: *нафта, пласт, свердловини, дебіт, асфальтени, смоли, парафіни, відкладення*