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PREVENTION OF CRYSTALLISATION OF ASPHALT-RESIN-PARAFFIN DEPOSITS UNDER THE INFLUENCE OF A PERMANENT MAGNETIC FIELD

During the operation of oil production wells, significant losses occur due to asphalt-resin-paraffin deposits (ARPD) in the pores of reservoirs and lift pipes. Understanding the detection and technology for combating ARPD is an urgent scientific, technical, and practical task, as this factor affects the wells' operability and ultimate productivity.

Keywords: *oil products pipeline transportation, high-viscosity oil, paraffin deposition, permanent magnetic field.*

Introduction

The authors of the article in recent years have studied the features of oil and gas reservoirs and the physicochemical characteristics of oil fields in the Carpathians. From practical considerations, we believe various methods to prevent the formation of asphalt-resin-paraffin deposits (ARPD) are currently available, including thermal, physicochemical, and mechanical action. However, finding a universal method is impossible.

The formation of paraffin deposits reduces the oil production from production wells in the fields. It is due to the deposition of oil-bearing rocks in the pores and an oily or solid dark-coloured mass known as paraffin (ARPD) in the columns of wells and the riser pipes, which reduces the maintenance period of wells, raises labour and material costs, and increases the cost of extracted products.

Asphalt-resin-paraffin deposits are highly dispersed suspensions of paraffin crystals and asphaltenes in oils and resins. They have the properties of amorphous bodies with certain hardness, depending on the composition and especially on the presence of water, sand, inorganic salts, alkaline earth metal carbonates, and other mechanical impurities. Petroleum paraffin is a mixture of solid hydrocarbons of two groups, which differ sharply from each other in properties: paraffins $C_{17}H_{36}$–$C_{35}H_{72}$ and ceresins $C_{36}H_{74}$–$C_{55}H_{112}$. The melting point of the first is 27–71°C, and for the second, it is 65–88°C. At the same melting point, ceresins have a higher density and viscosity. The paraffin content in oil sometimes reaches 13–14% or more.

The concept of detection and technology to combat ARPD in oil production, to this day, is an important scientific, technical, and practical task because this factor directly affects the efficiency and final productivity of wells.

Paraffins in oil under formation conditions are in a dissolved state. Chemically, paraffins are resistant to various chemical reagents. Oils in the same area contain less paraffin and more resinous substances. The content of paraffin in the oils of the same field increases with the depth of occurrence. The melting point of solid paraffinic hydrocarbons is higher the greater their molecular weight is. The density of paraffins in the solid state ranges from 865 to 940 kg/m^3, while in the molten state, it varies from 777 to 790 kg/m^3. The solubility of paraffin in organic liquids is high, decreases with increasing molar mass, and increases with increasing temperature [1].

Literature Review

There is a considerable amount of research on the mechanism of formation of paraffin deposits in wells. Many authors have significantly contributed to solving theoretical and practical issues of paraffin deposits, namely: V. I. Lesin [1], P. P. Galonskiy [2], B. V. Kopei, O. O. Kuzmin, S. Y. Onyshchuk [3], N. Y. Kruglytskyi [4], B. A. Mazepa [5], G. A. Mansoori [6], V. I. Klassen [7] et al.

These scientists have studied the mechanism of paraffin formation and deposition, regularities of paraffin deposition on different surfaces, and features and profiles of deposition on pump and compressor pipes (PCP) and oil pipelines.

To date, researchers have identified the following factors that contribute to the formation of paraffin released from oil, deposited, or forming plugs in wells:

– adsorption processes occurring at the boundary solid (metal) – paraffin, which are natural properties of paraffin deposits containing resinous substances;

– the presence of products of formation destruction, mechanical impurities on the surfaces of deposits when introduced from the surface during technological operations, corrosion products of metals, among others;

– surface roughness, which is the basis for the adhesion of paraffin crystals, around which aggregate deposits begin to grow;

– the velocity of the gas-liquid mixture, which can ensure the deposition of crystals on the surface of solids or, conversely, their detachment from the surface and removal to the wellhead;

– electrokinetic phenomena that cause electrification of both the pipe wall surface and the surface of paraffin crystals, which enhances the adhesion of paraffin to metal;

– flow structure, which affects the deposition of paraffin. The highest deposits occur in the laminar regime when the gas is in a dispersed phase [8, 9, 10, 11].

Aim and Objectives

The subject of the study is the peculiarities of the influence of magnetic induction of the Magnetic Anti-Paraffin Device (MAD-XH) on highly paraffinic oils during their transportation in pump and compressor pipes (PCP).

The object of the study is the design of technological requirements for constructing the structural scheme of the Magnetic Anti-Paraffin Device (MAD-XH).

The article aims to develop and study a model of transportation of high-viscosity oil by applying the technology of the action of the permanent magnetic field MAD-XH on paraffin oils to prevent the formation and deposition of paraffin during the transportation of oil through pipelines of different diameters.

The practice of paraffin oil production in the fields shows the main places of paraffin deposits to be well pumps, risers in wells, discharge lines from wells, and tanks of industrial collection points. The most intensive paraffin deposition occurs on the inner surface of well risers. In the discharge lines, paraffin formation intensifies during winter, when the air temperature drops significantly below the gas and oil flow temperature.

Discussion of Results

Numerous industrial studies have shown that the distribution nature of paraffin deposits in risers of different diameters is approximately the same.

The thickness of sediments gradually increases from the place of their formation at a depth of 500–900 m and reaches a maximum thickness at a depth of 50–200 m from the wellhead, then decreases to 1–2 mm in the wellhead (Fig. 1). Comparative analysis of deposits in PCP shows that even similar characteristics of oil differ significantly in the composition of asphalt-resin-paraffin deposits [12, 13]. Moreover, they are different at different selection points and change over time. PCP studies conducted at the Boryslav field confirm this. The distribution of ARPD is as follows: from the mouth to a depth of 200 m, PCP are clear; 200–600 m – dry solid deposits; 600–800 m – covered with both solid and viscous sedentary sediments; 800–1000 m – mobile deposits; more than 1000 m – PCP are clear [13, 14].

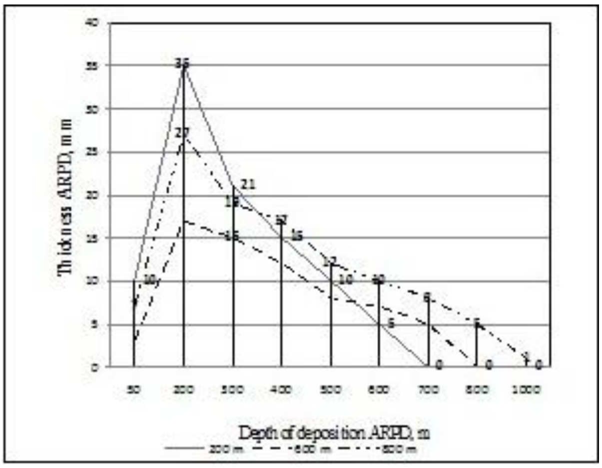

Fig. 1. Deposits in risers of wells, discharge lines, and reservoirs

Table 1 presents the analysis of deposits in the risers of wells, discharge lines, and reservoirs.

We have established that:

– the content of paraffin in the mass of sediments increases from bottom to top, reaching a maximum at the wellhead; the remaining volume includes oil, resinous substances, water, and mechanical impurities;

– the melting point of paraffin decreases from bottom to top, i.e., in the lower part of the lift, more refractory crystals fall out;

– for the period of complete waxing, paraffin deposition in pipes makes up 0.5–1.0% (by mass) of the amount of extracted oil and 6–15% (by mass) of paraffin accumulated in oil;

– in Devonian gushing wells, the deposition of solid paraffin occurs under a pressure of 3.5–4.0 MPa and temperature of 20–24°C, and the beginning of intense paraffin formation occurs in the area with a pressure of 2.5–2.6 MPa and temperature of 17–18°C;

– the hydrophilic nature of the surface leads to a decrease in the intensity of paraffin adhesion. The surface wettability is affected by the degree of water dispersion in oil. With increasing dispersion of emulsions, the wettability of the surface deteriorates;

– the properties of paraffins themselves affect the intensity of deposits. Thus, the higher the refractoriness of paraffin, the stronger the adhesion of crystals to each other and their ability to stick.

These factors interact with each other in the well, weakening and, in most cases, enhancing the processes of paraffin release from the mixture and their deposition on pipes and equipment.

According to most scientists, the determining factor influencing the formation of paraffin is the decrease in temperature along the wellbore.

Table 1

Analysis of deposits in risers of wells, discharge lines, and reservoirs

Conditions of formation of ARPD	Riser pipes diameter, mm			Discharge lines. Distance from the fitting, m		Reservoirs
	62	73	89	1.5	4	
Thermodynamic conditions in risers during regular operation of the well at the depth of the beginning of paraffin deposits:						
pressure, MPa	3.6	4.4	3.8			
temperature, °C	20	24	24.5			
The same, at the depth of the deposition of hard paraffin:						
pressure, MPa	2.6	2.6	2.5			
temperature, °C	18	18	17			
Time of full waxing, hours						
time, hours	76	118.5	142			
Paraffin melting point, °C, at depths, m:						
0	68	–	68	65	62.5	53.8
200	72	73	69			
400	75	74	74			
600	77	75	75			
Paraffin content in paraffin mass, %, at depths, m:						
0	58	–	61	43	39.4	30.4
200	43.6	43.6	48			
400	41.5	46	41			
600	34	–	34			
Asphaltene content, %	–	2.08	–	2.2	2.9	1.48
Resin content, %	–	7.18	–	7.5	7.4	–
Density at 20°C, kg/m^3	–	917	–	–	–	930

The nature of the temperature distribution along the length of the well depends on:

– heat transfer from the moving fluid along the wellbore to the surrounding rocks;

– expansion of the gas-liquid mixture.

The heat transfer intensity depends on the temperature difference between the liquid and the surrounding rocks at a certain depth and the thermal conductivity of the annular space between the risers and the production string.

With the annular space filled with gas, the heat transfer is less than when filled with liquid.

At a pressure in the wellbore above the saturation pressure, all the gas is in a dissolved state, and cooling, in this case, is caused by the heat transfer to the environment.

The cooling of the gas-oil mixture, caused by the gas expansion and its work to raise the liquid, is several times less than the cooling due to heat transfer to the surrounding rocks [15, 16]. The results of studies presented in Table 2 confirm this.

Consequently, the temperature along the wellbore is determined mainly by the heat transfer conditions and, hence, the well's flow rate.

Table 2

Comparison of test results

Depth, m	Pressure, MPa	Total temperature gradient, °C/100 m	Temperature gradient caused by the expansion of the gas-oil mixture, °C/100 m
1400	11.5	1.5	0.14
900	7.5	1.9	0.17
600	5.0	2.1	0.34
200	2.3	1.8	0.55

It is important to note that the stated considerations relate to the interval of one hundred wells, where the pressure is higher than 2.0 MPa. Here is the release of dry gas (methane). As the pressure increases, the solubility of the gas increases, and at the same time, the amount of heat expended on the evaporation of gases emitted from oil containing large amounts of ethane and propane grows.

Calculations show that gas release at pressures below 1.0 MPa is associated with better cooling, and the release of heavy gas at low pressure contributes to a higher reduction in paraffin solubility in oil than the release of dry gas [17].

A significant disadvantage in the product extraction of ‘Boryslavnaftohaz’ Oil and Gas Production Division (OGPD) is the presence of paraffin deposits and, as a result, a reduction in the maintenance period of wells during their operation. Therefore, based on the changes in the composition and structure of ARPD, the methods of combating them should change over time.

We have proposed a different approach to prevent the formation of paraffin in downhole oil production equipment, which is the use of the magnetic method, the essence of which is to apply a magnetic anti-paraffin device (MAD), that allows for a significant reduction of the viscosity of oil, a growth in the speed of oil through the pipeline, a drastic decrease in the number of paraffin deposits on the pipeline walls, and a threefold increase in the well’s service life [18].

Analysis of MAD operation in modern conditions of oil production. A review of the current experience in applying methods and means of magnetic treatment of liquids in oil production allows us to draw the following general conclusions.

The main application of magnetic treatment is to magnetise the water pumped into the well, which significantly lowers the growth of ARPD and increases the acceptability of wells for preventing and reducing the growth rate of ARPD.

It increases the duration of the inter-cleaning period of wells and, in most cases, their flow rate to improve the corrosion resistance of pipelines and oilfield equipment, which prolongs their service life. In addition to these areas, there are plans to use magnetic treatment to pump oil through main pipelines and to remove ARPD in pipelines and tanks for oil transportation.

The available data on the results of the operation of magnetic devices in oil production and more than 40 years of experience in their use have convincingly proved the high technical and economic efficiency of such devices.

Many years of experience in using magnetic devices in oil production to prevent the deposition of ARPD have demonstrated their greater effectiveness than traditional ones, such as chemical, mechanical, and thermal means of protection.

In addition, these scientists have proven that devices with permanent magnets are the most commonly chosen to prevent and reduce the growth of ARPD with devices placed directly in wells.

Devices used to prevent the ARPD have the most complex, usually multiverse field distributions, long lengths of working channels, and higher gradients of magnetic field strength. Increasing the intensity and gradient are the main areas of improvement of such devices. Table 3 provides information on the operation of paraffin-containing wells of the Boryslav field before using the MAD [19, 20].

According to order No. 3n-8-112 dated April 15, 2002, of OJSC ‘Ukrnafta’ and following the MAP Joint Testing Programme, the first device’s design was used in the ‘Boryslavnaftohaz’ Oil and Gas Production Division (OGPD) [21]. Table 3 presents the data on the operation of the selected paraffin-containing wells of the Boryslav field before applying the MAD.

This device for magnetising the liquid (Fig. 2) consists of a housing pipe (component 1) made of soft magnetic material and a magnetic system mounted on its axis, which is a series of permanently installed along the housing pipeline permanent magnets (component 2) **with alternating directions of magnetisation.**

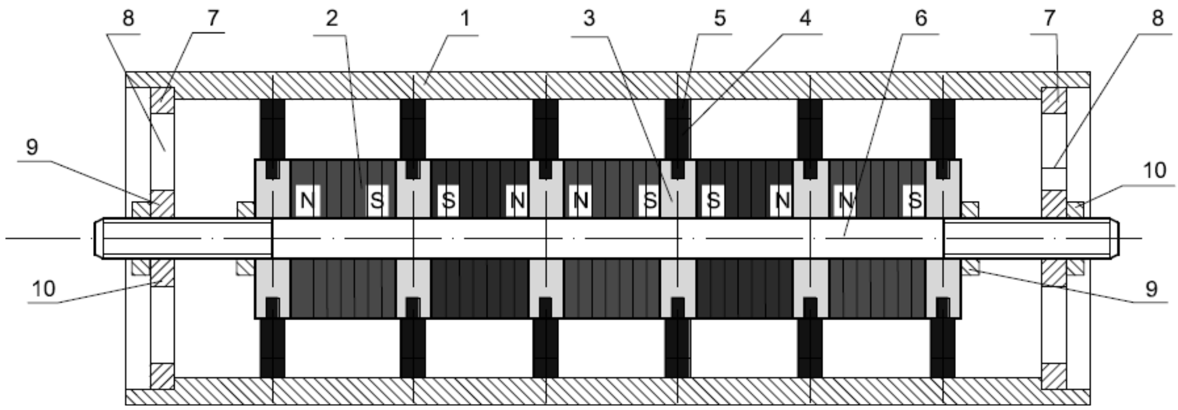

Fig. 2. Scheme of a magnetic anti-paraffin device (MAD) with higher magnetic induction: 1 – pipeline-casing; 2 – pipeline-casing made of permanent magnets; 3 – pole tips; 4 – component rods; 5 – ferromagnetic material; 6 – rod with threading; 7 – profiled disks; 8 – holes; 9, 10 – nuts

Table 3

Information on the operation of paraffin-containing wells No. 797, 948, and 1343 of the Boryslav field for using MAD

No. of the well	Year	Operating mode	Oil flow, t/day and night	Waterlogging, %	Type of underground repair of wells	Date of the operation	Washing or treatment of the bottomhole zone	Complication	Inter-repair period
1	2	3	4	5	6	7	8	9	10
797	1997	around the clock	0.15	95	complete repair	26.03.1997	no	no	290.3
	1998	around the clock	0.15	95	complete repair	01.02.1998	no	no	
					complete repair	22.11.1998	no	no	
					pump replacement	14.12.1998	no	no	
	1999	around the clock	0.15	95	complete repair	07.04.1999	no	no	
	2000	around the clock	0.10	95	complete repair	22.07.2000	no	no	
					complete repair	28.11.2000	no	no	
	2001	around the clock	0.11	92	complete repair	26.12.2001	no	no	
	2002	around the clock	0.23	90	MAD installation	18.10.2002	no	no	
	2003	around the clock	0.13	92	complete repair	17.06.2003	no	no	170.0
					pump replacement	10.11.2003	no	some ARPD	
					complete repair	06.12.2003	no	no	
948	1997	around the clock	0.20	90	complete repair	05.02.1997	no	no	297.4
	1998	around the clock	0.15	93	complete repair	10.01.1998	no	no	
					pump replacement	06.06.1998	no	no	
	1999	around the clock	0.20	90	complete repair	07.06.1999	no	no	
					complete repair	22.08.1999	no	no	
	2000	around the clock	0.12	93	complete repair	06.10.2000	no	no	
	2001	around the clock	0.12	93	pump replacement	30.08.2001	no	no	
					complete repair	30.11.2001	no	no	
	2002	around the clock	0.13	91	complete repair	04.05.2002	no	no	
					MAD installation	04.10.2002	no	no	
	2003	around the clock	0.11	94	complete repair	08.10.2003	no	no	not specified
	2004	around the clock			complete repair	24.01.2004	treatment	without ARPD	

Continuation of Table 3

1	2	3	4	5	6	7	8	9	10
1343	1997	around the clock	0.10	93	complete repair	20.06.1997	no	no	383.6
	1998	around the clock	0.10	93	complete repair	15.10.1998	no	no	
	1999	around the clock	0.10	93			no	no	
	2000	around the clock	0.15	90	complete repair	30.11.2000	no	no	
	2001	around the clock	0.11	94			no	no	
	2002	around the clock	0.11	94	complete repair	10.06.2002	no	no	
					MAD installation	20.09.2002	no	no	
	2003	around the clock	0.11	94					not specified

Fig. 2 depicts a magnetic anti-paraffin device with alternating directions of magnetisation, an increased magnetic induction, and permanent magnets having an annular shape and radial magnetisation and placed on a common magnetic circuit. On the outer surfaces of the permanent magnets are fixed pole pieces (component 3), and between the magnets are gaskets of non-magnetic material. The outer surface of the magnetic system with non-magnetic gaskets between the magnets and placed on permanent magnet pole pieces has the shape of a cylinder, and the working channel for the processed liquid is the gap of the annular section between the magnetic system and the housing pipeline. Parts (component 4) of the component rods consist of soft magnetic material, and parts (component 5) are of non-ferromagnetic material. The fixing of the system is possible with a rod located along the axis of the magnetic system (component 6) with threading in the end parts of its length, profiled disks (component 7) with holes (component 8) in the cross-sections for fluid flow and nuts (components 9, 10). This implementation provides the desired parameters of the influencing magnetic field at smaller cross-sectional sizes of the magnetic system, fewer expensive permanent magnets, and a larger cross-section of the working channel [22, 23].

A significant disadvantage of using the MAD, according to Fig. 2, is that this device needs installation under the pump, there is a substantial loss of magnetic induction, and the effect of the magnetic field on paraffin deposits in the tubing will not be direct. The implementation of the MAD took place at the OJSC ‘Ukrnafta’ fields.

Fig. 3 shows a diagram of a magnetic anti-paraffin device with an additional element – threaded coupling – of the modernised technological scheme of MAD-XH.

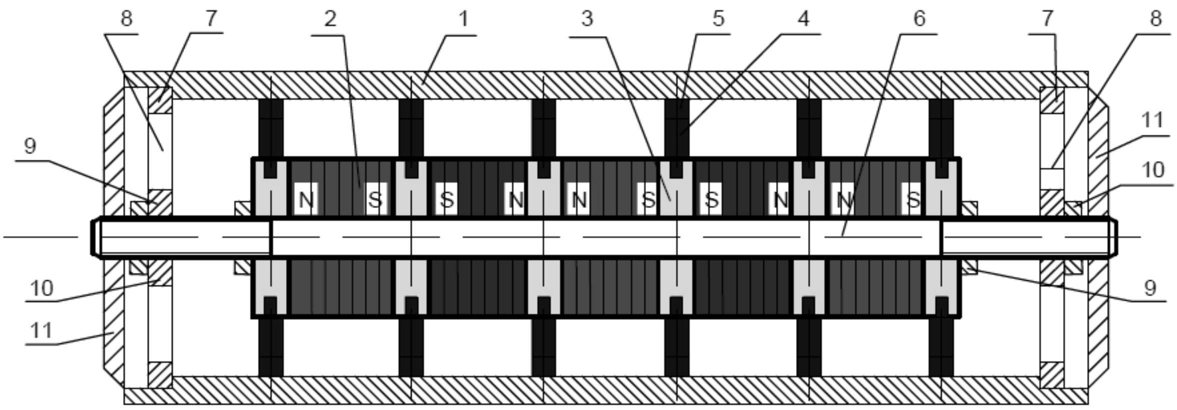

Fig. 3. Scheme of a magnetic anti-paraffin device (MAD-XH) with an additional element such as threaded coupling:
1 – pipeline-casing; 2 – pipeline-casing made of permanent magnets; 3 – pole tips; 4 – component rods;
5 – ferromagnetic material; 6 – rod with threading; 7 – profiled disks; 8 – holes; 9, 10 – nuts;
11 – threaded coupling for fixing the device

The magnetic anti-paraffin device MAD-XH developed by the authors represents a method aimed at magnetising the fluid to significantly increase the maintenance period of tubing equipment for oil wells.

To improve the design and technological solution, increasing the effect of magnetic induction of the magnetic field, we added to the scheme of the existing design of the anti-paraffin device MAD-XH an additional element – threaded coupling (component 11). It makes it possible to install MAD-XH in pump-compressor pipes immediately before the beginning of crystal formation of paraffins, which will increase the effect of the magnetic field to reduce the rate of paraffin formation by an average of 2–3 times.

The advantages of the improved MAD-XH from the existing design of the MAD and prototypes of foreign and domestic production are increased magnetic induction and the manufacture of devices from modern magnetic materials that provide their best efficiency, significantly affecting economic performance [23].

The obtained results allowed the management of the research and design institute of Ivano-Frankivsk OJSC 'Ukrnafta' to recommend using magnetic anti-paraffin devices on wells with high-paraffin oil in the Boryslav field.

Conclusions

The Ivano-Frankivsk Research and Design Institute of OJSC 'Ukrnafta' carried out theoretical and laboratory research for real-world conditions at the oil deposits of the Boryslav field, which proved the effectiveness of the magnetic field as a method of influence on high-paraffin oil to increase the repair (inter-cleaning) period.

Studies have shown three main reasons that affect the formation of asphalt-resin-paraffin deposits, which are:

1) a decrease in the downhole pressure and a violation of the hydrodynamic balance of the gas-liquid system;

2) a decrease in temperature in the formation and wellbore;

3) the composition of hydrocarbons in each phase of the mixture.

Additionally, intensive gas emission, the change of velocity of the gas-liquid mix and its separate components, and the ratio of the volumes of the phases also affect the formation of ARPD to a certain extent.

The advantage of the developed magnetic anti-paraffin device (MAD) over most foreign and domestic prototypes is the increase in magnetic induction and the production of the device from modern magnetic materials that provide better efficiency, significantly affecting economic performance.

ARPD begin to be deposited, gradually increasing from the beginning of their formation at a depth of 500–900 m, reaching the maximum thickness at 50–200 m from the wellhead, then decreasing to 1–2 mm in the wellhead.

The obtained results allowed the management of the Ivano-Frankivsk Research and Design Institute of OJSC 'Ukrnafta' to recommend using magnetic anti-paraffin devices in wells with high-paraffin oil in the Boryslav field.

Applying MAD can be as effective in gushing wells, during operation with deep-rod centrifugal and diaphragm pumps, and in oil pipelines. The use of MAD, particularly in OJSC 'Ukrnafta', allowed for increasing the inter-repair (inter-cleaning) period by 2–3 times.

The proposed new magnetic anti-paraffin device MAD-XH allows obtaining parameters on large-diameter pipelines that are not worse than those previously achieved only on small-diameter pipelines.

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ЗАПОБІГАННЯ КРИСТАЛІЗАЦІЇ АСФАЛЬТОСМОЛОПАРАФІНОВИХ ВІДКЛАДІВ ПІД ВПЛИВОМ ПОСТІЙНОГО МАГНІТНОГО ПОЛЯ

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Експлуатація нафтовидобувних свердловин на родовищах України ускладнена багатьма факторами. Великі втрати на промислах походять від осадження в порах нафтових порід, в колонах свердловин і в підйомних трубах пластичної або твердої маси темного кольору, відомої під назвою «асфальтосмолопарафінові відкладення» (АСПВ). Поняття процесу виявлення і технології боротьби з АСПВ при видобутку нафти до сьогодні є актуальним науково-технічним і практичним завданням, оскільки цей фактор безпосередньо впливає на працездатність і кінцеву продуктивність свердловин.

Доведено, що для запобігання та зниження зростання АСПВ за допомогою розміщених безпосередньо в свердловинах пристроїв здебільшого використовуються пристрої на постійних магнітах. Використовувані для запобігання АСПВ пристрої мають найскладніші, зазвичай багатореверсні розподіли поля, велику довжину робочих каналів, вищі градієнти напруженості магнітного поля. Збільшення напруженості та градієнта є основними напрямами вдосконалення таких пристроїв.

У пропонованій схемі антипарафінового магнітного пристрою з почерговими напрямами намагніченості, зі збільшеною магнітною індукцією постійні магніти мають кільцеву форму і радіальну намагніченість і розміщені на загальному магнітопроводі. Дослідження показали три основні причини, які впливають на утворення асфальтосмолопарафінових відкладів, а саме: 1) зниження тиску в області вибою, з одночасним порушенням гідродинамічної рівноваги газорідинної системи; 2) зменшення температури в пласті та стовбурі свердловини; 3) склад вуглеводнів у кожній фазі суміші. Можна додати, що інтенсивне газовиділення, зміна швидкості руху газорідинної суміші й окремих її компонентів, співвідношення об'ємів фаз також певною мірою впливають на формування АСПВ.

Застосування магнітних антипарафінових пристроїв (МАП) може бути ефективним як при фонтануванні свердловини, так і при експлуатації її глибинно-штанговими відцентрованими та діафрагмовими насосами, а також на нафтопроводах. Запропонований новий магнітний пристрій МАП-ХН дозволяє отримувати на трубопроводах великого діаметра параметри не гірші, ніж ті, що раніше отримували лише на трубопроводах невеликого діаметра.

Ключові слова: *трубопровідний транспорт нафтопродуктів, високов'язкі нафти, відкладення парафіну, постійне магнітне поле.*