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Mechanism and Mitigation Strategies of Asphaltene, Resin and Paraffin Deposition in Oilfield Equipment

Abstract

The article analyzes the existing technologies applied against asphaltene-resin-paraffin deposits (ARPD) formed in oilfield equipment and presents the results of scientific research conducted in the direction of developing more efficient methods to prevent these deposits. The formation of ARPD occurs due to the precipitation of paraffin, resin, asphaltenes and mechanical impurities present in crude oil onto the surfaces of equipment and pipelines as a result of changes in reservoir pressure and temperature. These deposits lead to a decrease in production, failure of technological equipment, shorter maintenance intervals and increased energy and material consumption. Since traditional methods such as cleaning with hot oil and steam are ineffective in deep wells, preference is given to chemical reagents, particularly paraffin deposition inhibitors and complex substances with depressor content. The article explains the composition and formation mechanism of ARPD, the role of surface-active components and analyzes the mechanism of action and advantages of chemical methods. As a result, it is shown that the development of new reagents based on synergistic principles is an effective and promising approach in combating ARPD.

Keywords: *Asphaltene, resin, paraffin deposits, paraffin precipitation inhibitors, depressant, well bottom zone, annular space*

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Neft mədən avadanlıqlarında asfalten, qatran və parafin çöküntüsünün mexanizmi və zərərini azaltma strategiyaları

Xülasə

Məqalədə neft-mədən avadanlıqlarında yaranan asfalten-qatran-parafin çöküntülərinə (AQPÇ) qarşı tətbiq edilən mövcud texnologiyalar təhlil olunur və bu çöküntülərin qarşısını almaq üçün daha səmərəli üsulların işlənməsi istiqamətində aparılan elmi-tədqiqat işlərinin nəticələri təqdim edilir. AQPÇ-lərin formalaşması lay təzyiqi və temperaturun dəyişməsi nəticəsində neftin tərkibindəki parafin, qatran, asfalten və mexaniki qarışıqların avadanlıq və boruların səthinə çökməsi ilə baş verir. Bu çöküntülər hasilatın azalmasına, texnoloji avadanlıqların sıradan çıxmasına, təmir müddətlərinin qısalmasına və əlavə enerji-maya sərfinə səbəb olur. Ənənəvi üsullar kimi isti neft və buxarla təmizləmə dərin quyularda effektli olmadığından, kimyəvi reagentlərə, xüsusilə parafinçökmə inhibitorları və depressor tərkibli kompleks maddələrə üstünlük verilir. Məqalədə AQPÇ-nin tərkibi, yaranma mexanizmi və səthi fəal komponentlərin rolu izah olunur, kimyəvi üsulların təsir mexanizmi və üstünlükləri analiz edilir. Nəticədə, sinergetik prinsiplərə əsaslanan yeni reagentlərin hazırlanmasının AQPÇ-yə qarşı mübarizədə effektiv və perspektivli yanaşma olduğu göstərilir.

Açar sözlər: *asfalten, qatran, parafin çöküntüləri, parafinçökmə inhibitorları, depressor, quyu-dibi zona, həlqəvi fəza*

Introduction

One of the main challenges during the operation of paraffinic oil wells is the methods for combating asphalt-resin-paraffin deposits (ARPD). ARPD absorbs onto the surfaces of downhole zones, subterranean equipment, and pipes as a result of temperature and pressure drops. They accumulate in the downhole zone, oil field equipment, and pipes, leading to decreased system productivity, reduced efficiency of pump units, and other negative consequences.

Along with paraffin, asphalt-resin particles also separate from the oil and deposit on these surfaces. It should be noted that currently, oil production departments mainly use hot oil, and sometimes steam, to clean lift pipes from ARPD in oil fields. To find more efficient methods for this purpose, it is essential to conduct numerous laboratory studies. For conducting targeted research, reviewing existing literature is required.

Experiment: Studies show that ARPD and salt deposition are affected by pressure and temperature in the formation and near-wellbore area. At high pressures (30–110 MPa) and temperatures (100–240 °C), the rock lithology influences deposition behavior: resins dominate in static conditions, while asphaltenes are more prominent in dynamic flow. The crystallization temperature of paraffins indicates their solubility and molecular characteristics (Kang, Lee, Lim 2014).

Research

A method for separating ARPD into major groups has been proposed. Temperature changes along the well closely follow the geothermal gradient (except in high-flow or water-cut wells). A 100 °C difference in paraffin crystallization onset implies that gas-rich crude forms ARPD less and at greater depths compared to oil with low gas content (Sousa, Matos, Guerreiro, 2019).

During production and transportation, asphaltic and paraffin masses adsorb onto rock surfaces, tubing, and equipment. Molecular diffusion is considered the main mechanism of wax deposition, though other processes (e.g., Brownian motion of solid paraffins) may contribute. Asphaltene deposition has been modeled under flow conditions through permeability tests, density analysis, pore structure studies, and soxhlet extraction. ARPD presents complex rheological, structural, chemical, and colloidal properties, further complicated by the wide variety of their compositions. Mostly organic, these deposits are insoluble and non-dispersible in crude oil under operating conditions. (Soto-Castruita, Ramrez, 2015).

Typically dark brown or black, ARPD is a solid mass with high viscosity, which decreases significantly with heat. Natural polar surfactants and oil emulsions concentrate within ARPD, enhancing their adhesion to metal surfaces and penetration into cracks, wear points, corrosion sites, and porous materials. These poorly soluble, dense substances tend to settle under gravity or centrifugal forces and interact with oil-rock, oil-metal, and oil-water interfaces (Huang, Zheng, & Fogler, 2015).

The properties of ARPD (Asphaltene-Resin-Paraffin Deposits) structural groups are not constant and vary depending on the nature of the petroleum products involved. Surface-active fractions extracted from asphalt–bitumen–fraction complexes (ABFC) exhibit higher surface activity than similar fractions obtained directly from crude oil. ARPD contains significantly more natural surfactants than oil itself, which strongly influences the colloid-chemical properties of the deposits.

Although asphaltenes have weak surface activity, they play a crucial role in stabilizing “water-in-oil” emulsions, along with resins, carbene–carbide compounds, and finely dispersed mineral particles. These compounds largely define the rheological and viscosity-related behavior of ARPD.

Surfactant concentrations in ARPD are extremely high—2–3 orders of magnitude above the critical micelle concentration (CMC). Most surfactants exist in free (molecular or colloidal) or bound states, not as micelles. When ARPD is diluted with cyclohexane (which breaks down high-

molecular aggregates), the interfacial tension at the water boundary decreases sharply, reaching a minimum at specific ARPD concentrations. This elevated surfactant activity increases water dispersion within ARPD and enhances emulsion stability. Maximum activity in cyclohexane occurs at concentrations 2–3 times lower than in crude oil, indicating that oil contains fewer active surfactants (Robustillo, Coto, & Juan, 2012).

Water content in ARPD may vary compared to crude oil, but the dispersion of water differs. In crude oil, "water-in-oil" emulsions are polydisperse with relatively large droplets; in ARPD, water is found mostly in a highly dispersed phase.

Microscopic studies reveal two types of ARPD microstructure:

- Type I: Polydisperse suspensions of mostly solid particles in oil.
- Type II: Coarse reverse emulsions, where water droplets are firmly embedded within thick layers forming the structural skeleton.

Sampling location	Thickness	Composition ATPD,%			Organic part ATPD, %			
		organic substances	minerals	water	oil	tar	Asphaltenes	Carbenes, carboids
Surface of tubing	1-16	59,8	12,4	27,8	68,7	18,2	5,9	4,7
Outer layer of tubing	1-16	67,0	8,6	24,4	71,2	18,0	5,9	4,3
Inner layer of tubing	0-1	65,9	16,2	17,9	53,0	27,7	6,3	12,2
Bottom of the tank	170	81,5	6,2	12,3	62,5	31,4	5,6	0,5
Inner layer of the tank bottom	0-1	66,7	11,4	21,9	55,9	32,8	9,2	2,1

Both types share similar group composition and solubility in organic solvents. However, Type II forms mechanically strong spatial structures, making them more resistant to leaching by aqueous or detergent-based solvents.

Removal of the more amorphous Type I deposits is complicated by their tendency to emulsify. Besides the structural characteristics, ARPD's mechanical properties are also critical. Their mineral content consists of rock particles of varying size, metal oxides, and organometallic compounds—present in far higher amounts than in crude oil (Demirbas, 2016).

ARPD is a highly complex dispersed system, containing:

- Molecularly dispersed components,
- Colloidal particles,
- Large insoluble solids with adsorbed resins and surfactants,
- Water-in-oil emulsions stabilized by various emulsifiers.

A table summarizes the key physicochemical properties of ARPD collected from various equipment surfaces.

As shown in the data, the structural composition and properties of ARPD layers vary depending on their distance from the metal surface. The closer the deposit is to the metal, the higher its content of carbenes, carbides, and mineral compounds. This is due to both the catalytic effect of the metal

and the precipitation process. As a result, the layer in direct contact with the metal differs significantly in properties from the outer layers formed later (Papadimitriou, Romanos 2007).

ARPD formation begins when crude oil contacts the tubing surface at temperatures between 14.2°C and 37.8°C, depending on oil composition. Local cooling near the pipe wall reduces the oil's paraffin solubility, leading to adhesion.

Paraffin crystallization starts with poorly soluble hydrocarbons of relatively high molecular weight. These accumulate near the pipe wall via thermo-diffusion. The resulting layer is typically <0.1 mm thick but highly viscous and strongly adherent due to its amorphous, finely dispersed polycrystalline structure (Kang, Lee, Lim, 2014).

The initial stage of ARPD formation is complex and begins above the paraffin melting point. Polar surface-active components like resins, organic acids, and asphaltenes adsorb on the pipe surface, forming the first adhesion layer. Paraffin then adheres concurrently or subsequently. Once an initial ARPD layer is formed, further adhesion occurs onto this layer, not the pipe itself, through suspended paraffin particles in the oil flow. Adhesion is influenced by water and impurities in the oil. Water may form a continuous film on hydrophilic surfaces, preventing direct oil contact and reducing adhesion. On hydrophobic surfaces, water presence enhances paraffin precipitation. Solid impurities accelerate ARPD aggregation and adhesion rates. Adhesion is also affected by metal surface properties—thermal conductivity, roughness, and oil flow rate. At low flow rates, increasing surface roughness has little effect, but at high flow velocities, adhesion increases, peaks, and then declines. The peak adhesion rate is proportional to adhesion strength and pipe diameter, and inversely proportional to oil viscosity. Understanding ARPD formation mechanisms is crucial for developing effective mitigation strategies (Rogel, Ovalles, 2016).

As oil cools along the wellbore and approaches the wax appearance temperature, paraffin rapidly crystallizes and transitions from a dissolved to a suspended phase. These crystals serve as nucleation centers and deposit on pipe surfaces (Adeyanju, 2013).

Simultaneously, resin-asphaltene particles separate from the oil and deposit. The presence of suspended solids, salts, and water droplets stabilizes these deposits, making removal difficult. Such deposits lower well productivity, cause equipment failure, increase operational costs, and shorten service intervals (El-Dalatony, Jeon, Salama 2019).

Wax deposition in wells is typically managed via thermal, chemical, thermochemical, mechanical, and physical methods. Currently, the Azerbaijani "Azneft" Oil and Gas Production Company mainly uses chemical inhibitors and heat carriers (e.g., hot oil, water, steam, or solvents). However, recent paraffin deposition is occurring at depths of 800–1200 m, beyond the reach of traditional thermal treatments, which are effective only up to ~500 m (Qurbanov, Əlsəfərova, 2005).

At such depths, heat is dissipated not only by warming rock formations but also through the Joule–Thomson effect, where gas expansion causes cooling. This limits heat delivery to deeper zones, making chemical reagents more suitable for deep-well paraffin control.

The overall strategy for managing ARPD focuses on either preventing deposition or inhibiting sediment formation, using (Gabetov, 2005):

- Mechanical cleaning of pipes and equipment,
- Protective coatings on surfaces,
- Thermal treatment of produced fluids,
- Chemical treatment of production fluids.

Chemical agents serve several purposes:

- Break down or prevent stable water-in-oil emulsions,
- Protect equipment from corrosion and scaling,
- Optimize gas–liquid flow structure in low-water gas-lift and compressor wells.

Multifunctional reagents, combining depressants and demulsifies, have been used to improve oil flow and reduce ARPD in wells and pipelines. These reagents enhance rheological properties and reduce wax formation by 25–30% (Van Der Gest, Guersoni, 2018).

Recent research suggests that the effectiveness of surface-active inhibitors correlates with their chemical structure and colloid–chemical parameters. For example, when the water content in oil exceeds 20%, surfactant-based inhibitors show positive results, while polymer-based inhibitors may be less effective.

A proposed composition for removing ARPD includes aliphatic hydrocarbons, a polar electrolyte (a by-product of propylene hydrophilization), and light pyrolysis resin. Another formulation was developed for removing ARPD from near-wellbore zones, injection pipelines, and field equipment. This includes inhibitors FLEK-IP-102 and XPP-004 mixed with a 40% solution of depressant additive DP-65 in aviation kerosene, acting as a high-efficiency inhibitor. Compounds containing amide and carboxyl groups not only disperse asphaltenes but also aid in demulsification, preventing deposition, equipment contamination, and corrosion (Ibrahimov, Naibova, 2007).

These chemical agents are recommended for direct injection into the well. One formulation for ARPD removal from storage tanks includes: 30% modified polyethylene polyamines with acrylic acid, 2.5–7.0% solvent-surfactant blend, and the remainder being waste liquid hydrocarbons from isoprene production A robust formula to prevent salt and resin deposits on pipe walls contains: 10–45% powdered technical detergent (PTMS), 18–30% sulfamic acid, and the remainder as petroleum construction bitumen (Sousa, Matos, Guerreiro, 2019).

Another effective ARPD removal agent for field equipment and near-wellbore hydrophilization includes: 33–75% cyclohexane fraction, 20–30% tall or rapeseed oil, 0.01–5% surfactants, 5–30% organic solvent, 0.01–2% fine hydrophobic material, and 1–3% scale inhibitor. Its technical advantage lies in dissolving ARPD, improving cleaning, dispersing, emulsifying, and stabilizing effects — all contributing to reduced oil dilution and increased oil recovery.

The technical result of the work is the prevention of the formation of asphaltenes and paraffins due to its solubility, an increase in the detergent, dispersion, emulsification and stabilizing effect of the composition due to the presence of an increased amount of paraffin, resin and asphaltenes in the sediment, as well as a decrease in oil thickening and an increase in the formation of rocks. To remove ATPD formed during the operation of the vessels, the authors used a 1% solution of acetamide oligomer and phenol formaldehyde in acetone. It was shown that when 110-130 mg/l of the reagent was added to the oil, ATPD was effectively separated from the oil (96-98%). As a result, the freezing point of the oils decreased by 18-220 C and their thermal conductivity improved. The composition, which prevents the growth of ATPD crystals by hydrophilizing the surface of the deep-well pumping equipment, includes a surfactant, an additive and a solvent (Mukkamala, 2006).

According to the method of cleaning the internal parts of mine transport pipes from paraffin deposits, a similar composition is applied to two places of the transport pipe, and the space between them is filled with a large part of light hydrocarbons obtained from a hydro cyclone. Comparative results of the efficiency of various technologies for using the A-98 reagent for cleaning well riser pipes from ARPD are given in. Reagent A-98 is a composition consisting of pyrolysis and gas condensate solvents. The solvent separated during the pyrolysis of petroleum hydrocarbons (fraction 125-1900C) contains 99% aromatic compounds (including 50% xylene), which have a high solubility of all ARPD components. The authors found that the proposed technologies using the A-98 reagent are more efficient than the existing traditional technology using gas condensate (Taqstemirov, & Sizimova, 2007).

PKI reagent reduces the freezing point of oil from 26.40C to 12.80C. The use of PKI reagent allows to increase the time of cleaning wells from paraffin by 2.5-3 times. The reagent is added to the oil in an amount of 200 g\t. To remove ARPD residues during oil production, transportation and storage, a composition consisting of a copolymer of ethylene oxide and propylene oxide, a poorly soluble surfactant, a monoalkyl ether based on a combination of a hydrogen atom and a solvent with polyethylene glycol can be used. Diproxamine 157-65M, the product of their combination with ethylenediamine in methanol, or a mixture of ethylene oxide and propylene oxide with the block copolymer Laprol 4202-2B-30 in methanol and water in a ratio of 4:1, or a block copolymer based on EPO6 and C-O2 alcohols (TsGPKh-780) or a mixture of these block copolymers were used as copolymers of ethylene oxide and propylene oxide (Ağayev, Grebnev, Gurova, 2009).

Conclusions

1. Technologies for combating asphaltene-tar-paraffin deposits formed on the surface of equipment were studied, new technologies were developed, and research was conducted to create more efficient technologies based on them for increasing the efficiency of oil field development, restoring production and protecting equipment in operation.

2. Materials from scientific and technical literature were studied and finally it was confirmed that the most progressive method among the methods of combating ATPD is the chemical method. For this purpose, existing chemical reagents were analyzed and their mechanism of action was explained.

3. As a result, a conclusion was reached on the necessity of developing new formulations against asphaltene-tar-paraffin deposits based on synergistic principles.

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