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INVESTIGATION OF THE DISRUPTIVE ACTIVITY OF SURFACTANTS ON OIL FILMS

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Annotatsiya: Ushbu tadqiqot sirt-faol moddalar (SFM) ning neft plyonkalariga ta’sirini va ularning neftni tozalash samaradorligini o‘rganadi. SFM turli sanoat va ekologik jarayonlarda, jumladan, neft qazib olish samaradorligini oshirish (EOR) va neft to‘kilishlarini bartaraf etishda muhim rol o‘ynaydi. Tadqiqotda SFM eritmalarining neft plyonkalariga ta’sir mexanizmlari tahlil qilinib, sirt tarangligini kamaytirish va plyonkalarni buzish dinamikasini tushunishning ahamiyati ta’kidlangan. Tajribaviy tahlillar 0,5% SFM eritmalari yordamida 25°C haroratda o‘tkazilib, natijalar SFM ning suvga nisbatan neft plyonkasini tozalashda ancha samarali ekanligini ko‘rsatdi. Sinovdan o‘tgan SFM orasida PAVKM eng yuqori samaradorlikni ko‘rsatib, 500 soniya ichida 98,3% neft plyonkasini yo‘q qilishga erishdi. Tadqiqotda, shuningdek, SFM konsentratsiyasining neft tozalash samaradorligiga ta’siri ko‘rib chiqilib, maksimal natijalarga erishish uchun optimal konsentratsiyalar aniqlangan. Ushbu natijalar SFM asosida neft qazib olish va ekologik tozalash texnologiyalarini takomillashtirishga muhim hissa qo‘shadi.

Kalit so‘zlar: neft plyonkalari, sirt taranglik, gidrofil-liofil balans, sirt erkin energiyasi, mitsella, sirt faol moddalar, kinetika, dinamika.

Аннотация: Исследование рассматривает разрушительное действие поверхностно-активных веществ (ПАВ) на нефтяные плёнки, с акцентом на их эффективность в удалении нефти. ПАВ играют ключевую роль в различных промышленных и экологических применениях, включая повышение нефтеотдачи (EOR) и ликвидацию разливов нефти. В работе изучены механизмы взаимодействия растворов ПАВ с нефтяными плёнками, подчёркивая важность понимания снижения межфазного натяжения и динамики разрушения плёнок. Экспериментальный анализ проводился с использованием 0,5% растворов ПАВ при 25°C, результаты показали, что ПАВ значительно превосходят воду в удалении нефтяных плёнок. Среди протестированных

ПАВ наибольшую эффективность продемонстрировал PAVKM, достигнув 98,3% удаления нефтяной плёнки за 500 секунд. В исследовании также подчёркивается влияние концентрации ПАВ на эффективность удаления нефти, при этом были выявлены оптимальные концентрации для максимальной эффективности. Эти результаты способствуют развитию усовершенствованных технологий на основе ПАВ для добычи нефти и очистки окружающей среды.

Ключевые слова: нефтяные плёнки, поверхностное натяжение, гидрофильно-лиофильный баланс, поверхностная свободная энергия, мицелла, поверхностно-активные вещества, кинетика, динамика.

Abstract: The study investigates the disruptive activity of surfactants (SAAs) on oil films, focusing on their efficiency in oil removal. Surfactants play a crucial role in various industrial and environmental applications, including enhanced oil recovery (EOR) and oil spill remediation. The research examines the mechanisms through which surfactant solutions interact with oil films, emphasizing the importance of understanding interfacial tension reduction and film rupture dynamics. Experimental analysis was conducted using 0.5% surfactant solutions at 25°C, with results indicating that SAAs significantly outperform water in oil film removal. Among the tested surfactants, SAA-KM demonstrated the highest efficiency, reaching 98.3% oil film removal within 500 seconds. The study also highlights the impact of surfactant concentration on oil removal efficiency, with optimal concentrations identified for maximum effectiveness. These findings contribute to the development of improved surfactant-based technologies for oil extraction and environmental cleanup efforts.

Key words: oil films, surface tension, hydrophilic-lipophilic balance, surface free energy, micelle, surfactants, kinetics, dynamics

INTRODUCTION. The investigation of interactions between oil films and aqueous surfactant solutions is critical for several reasons. Modern methods for cleaning water surfaces and soil from oil and petroleum products, as well as improving the efficiency of oil extraction and processing, depend on a deep understanding of the mechanisms governing these interactions. With the increasing scale of oil extraction, transportation, and refining, there is a pressing need to improve technologies for oil spill mitigation and contaminated site remediation.

Surfactants are widely used in oil extraction, refining, and environmental technologies due to their ability to reduce surface tension and modify surface properties. This facilitates the disruption of stable oil films and aids in oil removal from the environment. Furthermore, the application of surfactants in enhanced oil recovery (EOR) techniques is a promising approach that significantly increases the recovery of hard-to-extract oil reserves.

LITERATURE ANALYSIS AND METHODS. The washing action of aqueous solutions of surfactants (surface-active agents) is widely utilized in various technological processes and household applications. Research on this phenomenon is actively conducted to identify reagents with the highest efficiency for specific contaminants and to develop new detergents. However, the scientific principles underlying this process, first formulated by P. Rebinder in 1935 [1], have remained largely unchanged to this day. The only theoretical equation used to interpret the washing action of SAAs is the expression for the change in Gibbs free surface energy before and after the detachment of an oil particle from a solid surface [1–4]. Most studies on the washing mechanism focus on fabric laundering, as reviewed in [5].

Oil companies do not give sufficient attention to the significance of the washing action of aqueous surfactant solutions injected into reservoirs for oil recovery. As a result, the mechanism of oil extraction from reservoirs is still described solely within the framework of hydrodynamic models, and the use of SAAs to enhance oil recovery is based only on their ability to reduce interfacial tension at the oil-water boundary [7–10]. However, several studies, including monographs by L. K. Altunina [11] and G. A. Babalyan [12–13], as well as other works [14–19], indicate that interactions between surfactant solutions and oil films within rock pores should significantly influence oil extraction.

Moreover, in [11–13], it is noted that the process of residual oil removal should be accompanied by the rupture of the oil film. However, the stage of continuous film rupture is typically excluded from consideration since the initial state of the washing process is often assumed to be an oil (or petroleum) contamination in the form of a droplet on a solid surface—already a result of prior film rupture [18–19].

Therefore, the development of an experimental methodology for studying this interaction, along with its theoretical foundations, as undertaken in this study, is highly relevant. This is particularly important today, as the majority of global oil production comes from fields that have surpassed their production peak. As a result, strategies for maximizing oil recovery are becoming increasingly critical to meet the global demand for energy carriers. According to various experts, the oil recovery factor (ORF) in all oil-producing countries remains unsatisfactory, ranging from 25% to 40%. As of 2013, the global average ORF was estimated at 30–35% [20], meaning that more than half of the oil remains trapped in reservoirs. Notably, even a 1% increase in the global ORF could significantly expand recoverable oil reserves. Addressing this challenge requires a fundamental investigation of the interaction between surfactant solutions and oil films, particularly the ability of surfactant solutions to remove these films. The high practical demand for such research, combined with the insufficient study of the underlying mechanisms, defines the objectives and key tasks of this study.

Thus, studying the interaction between aqueous surfactant solutions and oil films contributes to the development of more efficient, cost-effective, and environmentally friendly technologies in the oil industry and in oil spill response systems.

The relevance of studying the interaction between aqueous surfactant solutions and oil films arises from the need to enhance their efficiency in removing petroleum-based contaminants. This is important both for reducing environmental impact and improving the economic efficiency of industrial processes. Assessing the effectiveness of these interactions involves analyzing numerous factors, including the type and chemical structure of surfactant molecules, temperature, water composition, surfactant concentration, oil characteristics, and the duration of oil film formation.

To simplify the study of these factors, reagents with high washing activity were used. Surfactants were selected based on a comparative analysis of their washing performance in 0.5% aqueous solutions prepared with distilled water. The tests were conducted against oil films from the Fergana oil field under identical film formation conditions.

The method for determining the efficiency of oil film removal from a glass surface involves measuring the percentage of film removal by reservoir water from the walls of a glass test tube over time. A 100% benchmark corresponds to the removal of half of the total tube surface area.

The testing procedure consists of the following steps:

1. The test tube is filled with 25 mL of oil and allowed to sit for 20 minutes.
2. The oil is then poured into a flask, and the tube is half-filled with a surfactant solution or test water (reservoir water).
3. The remaining space in the tube is refilled with oil from the flask.
4. The tube is sealed, inverted, and a stopwatch is activated to record the time required for the oil film to be washed away.

RESULTS AND DISCUSSION. The results of the study on the effect of surfactant solutions on oil film removal from glass surfaces are presented in Figure 1.

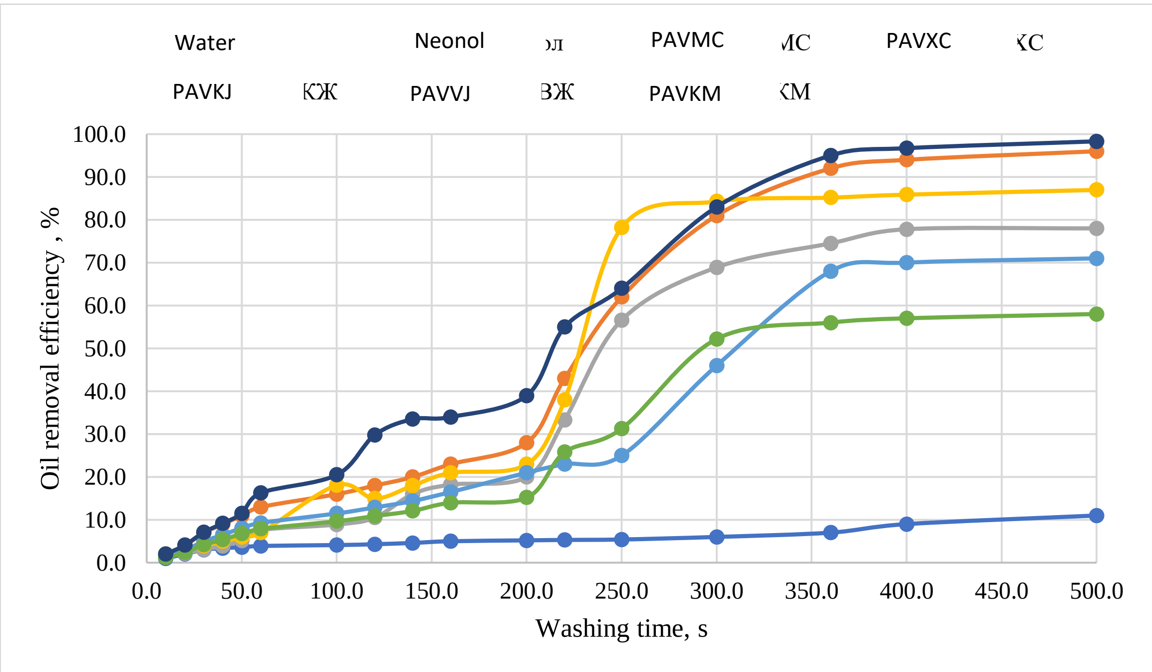

Figure 1. Kinetics of oil film removal in a 0.5% surfactant solution at 25°C

An analysis of Figure 1, which illustrates the kinetics of oil film removal from a glass surface in 0.5% solutions of various surfactants at 25°C, allows for scientific conclusions regarding the effectiveness of all tested surfactants compared to water. All the surfactants under consideration demonstrate significantly greater efficiency in removing the oil film than pure water. This is evident from the results: for instance, at 500 seconds, water removed only 11%

of the oil film, whereas the surfactants achieved considerably higher removal rates, ranging from 58% to 98.3%.

Among the tested surfactants, PAVKM exhibits the highest efficiency, reaching 98.3% removal at 500 seconds. This suggests that its composition contains components that interact more actively with the oil film, potentially due to the optimal length and structure of its hydrocarbon chain or a more favorable hydrophilic-lipophilic balance (HLB).

For all surfactants except PAVKM, a noticeable deceleration in removal rate is observed after 300 seconds of the experiment, whereas PAVKM continues to demonstrate a stable and high removal rate up to 500 seconds.

Based on the data, it can be inferred that Neonol - based surfactants (Neonol) and PAVKM are the most effective, making them the preferred candidates for applications requiring rapid and efficient oil film removal.

These findings provide valuable insights for selecting the most suitable surfactants for industrial applications, particularly in the cleaning and remediation of oil-contaminated surfaces.

The results of the study on the effect of surfactant concentration on oil removal efficiency are presented in Figure 2.

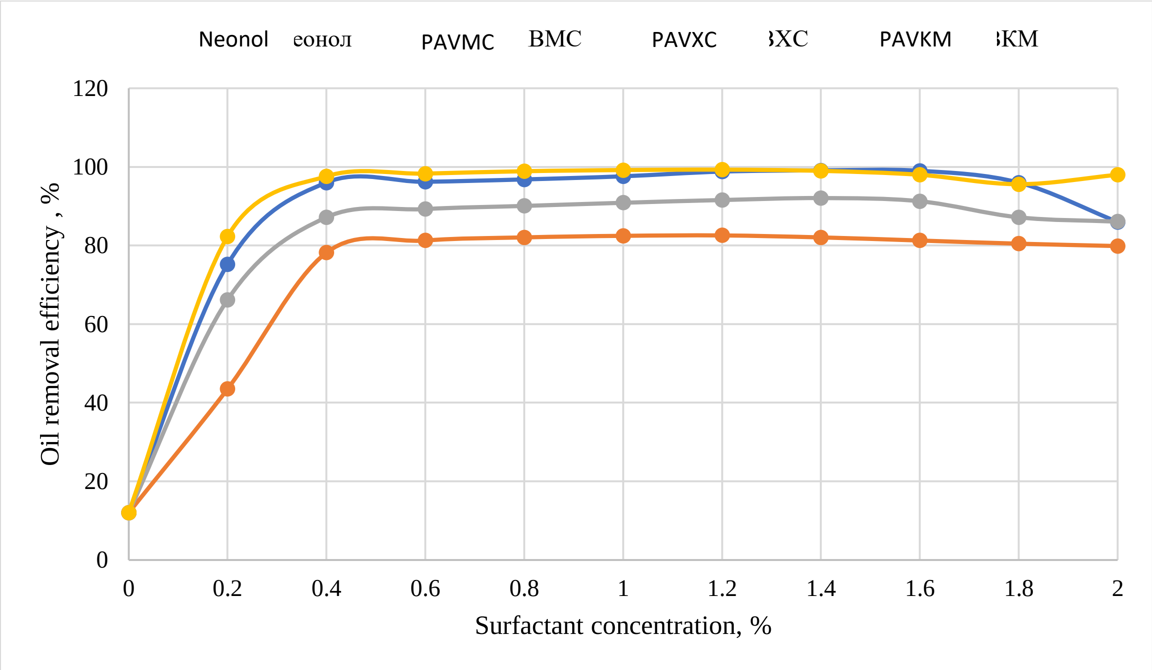

Figure 2. Variation in oil removal efficiency as a function of surfactant concentration over 10 minutes

An analysis of the presented data on the variation in oil removal efficiency as a function of surfactant concentration over a 10-minute exposure reveals that the behavior of different surfactants varies depending on their concentration in solution.

As the surfactant concentration increases to a certain level, oil removal efficiency improves for all tested surfactants. This suggests that a higher surfactant concentration enhances oil film removal, likely due to a reduction in surface tension and improved surface wettability.

However, beyond a certain concentration, further increases in surfactant concentration do not result in significant improvements in oil removal efficiency and may even lead to a decline. For instance, PAVKM maintains high efficiency (over 98%) even at increased concentrations. In contrast, PAVMC, PAVXC, and Neonol exhibit a decrease in oil removal efficiency when their concentration exceeds 1.4–1.6%. This decline may indicate adverse effects of excessive surfactant concentration, such as micelle formation, which can hinder the interaction of surfactant molecules with the oil film.

Upon reaching the critical micelle concentration (CMC), surfactant molecules in solution begin to form micelles. In these structures, the hydrophobic segments of the surfactant molecules are sequestered within the micelle core, reducing the number of surfactant molecules available to interact with the oil film. At high concentrations, the solution may also become more viscous, impeding the movement of surfactant molecules to the surface and reducing their ability to lower interfacial tension between oil and water.

In systems where surfactants compete for surface adsorption, excessive concentrations may lead to molecules displacing one another rather than effectively interacting with the oil. Additionally, at high concentrations, surfactants can form various structural phases, such as liquid crystals, which may interact with oil films less efficiently than individual surfactant molecules or micelles.

Among all tested surfactants, PAVKM demonstrates the highest oil removal efficiency across all concentrations, which may be attributed to its molecular structure or unique interaction mechanisms with oil. Conversely, PAVMS exhibits the lowest efficiency, particularly at higher concentrations.

For most surfactants, a clear relationship between concentration and removal efficiency is observed, with maximum efficiency achieved within a specific concentration range. This highlights the importance of determining the optimal concentration for each surfactant to achieve the best cleaning performance.

These findings underscore the necessity of careful selection and precise dosing of surfactants for effective oil contamination removal, as well as the potential impact of surfactant structural and chemical properties on their cleaning performance.

CONCLUSION. The experimental findings confirm the significant role of surfactants in the disruption and removal of oil films from solid surfaces. Surfactants demonstrate a higher efficiency compared to water, with their effectiveness dependent on concentration, chemical structure, and interaction with oil. The results indicate that PAVKM is the most effective among the tested surfactants, suggesting its potential application in industrial and environmental settings. Additionally, the study emphasizes the necessity of optimizing surfactant concentration to avoid adverse effects such as micelle formation, which can hinder oil removal efficiency. Understanding the interplay between surfactant concentration and oil displacement mechanisms provides valuable insights for enhancing oil recovery techniques and developing efficient oil spill remediation strategies. Future research should explore the long-term environmental impact of surfactant use and investigate novel formulations to further improve oil displacement efficiency.

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