Influence of oligomeric surfactants on the strength of hard rock formations: experimental Insights and implications

Shokirjon Sh. Sunnatulloev*, *Shukurullo* U. Buriev, *Lazizjon* O. Sharipov, and *Abdunor* B. Zhiyanov

Navoi State University of Mining and Technologies, Galaba avenue 76v, Navoi, 210100, Uzbekistan

Abstract. This study investigates the influence of oligomeric surfactants on the physical properties of hard rock formations, pivotal for optimizing tunneling operations. Our findings reveal temperature-dependent solubility trends for seven surfactants in tap water, with exceptions noted for certain types. By examining adsorption-induced strength reduction mechanisms using surfactant solutions, significant potential for energy and material savings in rock disintegration processes is identified. Additionally, the study explores water absorption in various rock types and elucidates the adsorption-induced strength reduction mechanism of hard rock formations using oligomeric surfactants. Overall, our research provides valuable insights into chemical interactions between surfactant solutions and rock surfaces, offering implications for industrial applications and guiding future research endeavors.

1 Introduction

The exploration of surfactant-induced alterations in the physical characteristics of solid rock formations stands as a pivotal domain in geological research, holding profound implications for various industrial sectors, particularly mining and drilling operations. Surfactants, or surface-active agents, represent a class of compounds extensively studied for their capacity to modify interfacial properties, including surface tension and adhesion, thereby influencing the behavior of fluids within porous geological matrices. Building upon prior investigations, this study delves into the intricate interplay between oligomeric surfactants and the mechanical integrity of rock formations, with a particular focus on their role in modulating compressive strength and porosity. By elucidating the underlying mechanisms governing surfactant-mediated alterations in rock properties, this research aims to advance our understanding of surfactant-rock interactions and their implications for industrial applications. The following sections delineate the experimental methodologies employed, the observed outcomes, and the overarching implications of these findings in the context of geological engineering and resource extraction practices.

One of the primary challenges in mining operations, particularly in the complex geological conditions of Uzbekistan, is the efficient advancement of tunneling operations.

* Corresponding author: sunnatulloev.shokirjon@gmail.com

This necessitates the use of various chemical reagents and surfactants to intensify drilling processes, detect the presence of fractures, and develop methods for rock softening to improve technical and economic performance.

Recent investigations have focused on the solubility of different surfactants in water and their temperature-dependent behavior. It has been observed that the solubility of most surfactants increases with temperature, except for certain types such as calcium alkylbenzenesulfonate, which exhibit limited solubility. Additionally, studies have explored the effect of surfactant concentration on surface tension, refractive indices of solutions, and their potential for reducing rock strength through adsorption mechanisms.

Furthermore, comparative studies on the water absorption capacity and porosity of various rock types, including limestone, granite, marble, and dolomite, in surfactant solutions have revealed distinct trends. Dolomite exhibits the highest water absorption and porosity, while marble demonstrates the lowest values. Among granites, the grey variety displays the highest water absorption and porosity.

Understanding the impact of surfactants on the physical properties of rock formations is crucial for optimizing mining operations and enhancing resource extraction efficiency. Future research should aim to delve deeper into the mechanisms underlying surfactant-induced alterations in rock properties and explore novel surfactant formulations derived from local resources to address the unique geological challenges encountered in mining operations.

2 Methodology

2.1 Sample collection and preparation

Samples of various rock types, including limestone, granite (pink, grey, and standard), marble, and dolomite, were collected from different geological formations in Uzbekistan. The samples were carefully extracted to minimize disturbance and processed to obtain standardized specimens for testing.

2.2 Solubility studies

The solubility of seven different surfactants in tap water was investigated over a temperature range of 20°C to 60°C. Each surfactant was dissolved in water at varying concentrations, and the solutions were agitated to ensure homogeneity. The solubility of each surfactant was determined using standard analytical techniques.

2.3 Surface tension measurements

Surface tension measurements of the surfactant solutions were conducted using a tensiometer. The surface tension was measured at different concentrations of surfactants ranging from 0.0% to 0.4% (wt/wt) in water. The measurements were performed in triplicate to ensure accuracy and repeatability.

2.4 Refractive index determination

The refractive indices of the surfactant solutions were determined using a refractometer. Measurements were taken across a concentration range of 0.0% to 0.025% (wt/wt) for each surfactant. The refractive index values were recorded and analyzed to assess the effect of surfactant concentration on solution properties.

2.5 Compression strength testing

Compression strength tests were conducted on both dry and water-saturated rock specimens using a universal testing machine. Dry specimens served as controls, while water-saturated specimens were immersed in surfactant solutions at a concentration of 0.1%. The compression strength of each specimen was measured, and the percentage change in strength due to surfactant exposure was calculated.

2.6 Data analysis

The experimental data obtained from the solubility tests, surface tension measurements, refractive index values, and compression strength tests were subjected to rigorous statistical analysis using appropriate software. The objective was to discern patterns, trends, and correlations between the surfactant properties and the behavior of the rock samples.

For the solubility data, statistical analyses such as analysis of variance (ANOVA) and regression analysis were conducted to determine the effect of surfactant concentration on the solubility of each rock type. Surface tension measurements were analyzed to assess the changes induced by different surfactant concentrations, and statistical tests were performed to ascertain the significance of these changes.

Refractive index values were examined to understand how surfactant solutions interacted with the rock surfaces, and statistical methods were employed to identify any notable deviations from expected behavior. Compression strength test results were analyzed to quantify the impact of surfactant treatment on the mechanical properties of the rocks.

Graphically, line graphs, were generated to visually represent the relationships between surfactant properties and rock behavior. For example, Fig. 1 illustrates the changes in surfactant characteristics (CF-8201) with increasing concentration, including surface tension, refractive index, hydrogen index, and electrical conductivity. Similarly, Fig. 2 depicts the changes in surfactant characteristics (CF-8901) with increasing concentration, providing insights into their influence on rock behavior.

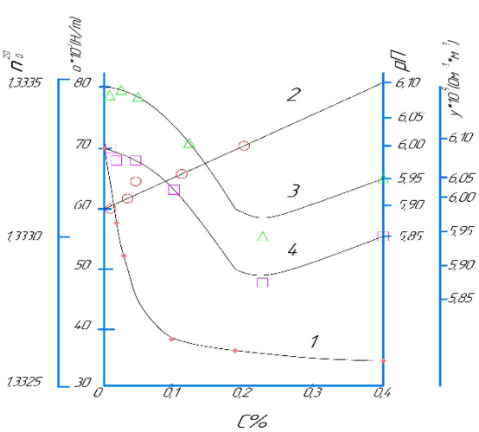

Fig. 1. Variation in surfactant characteristics (CF-8201) with increasing concentration: 1 - surface tension (σ), 2 - refractive index (п), 3 - hydrogen index (pH), 4 - electrical conductivity (γ).

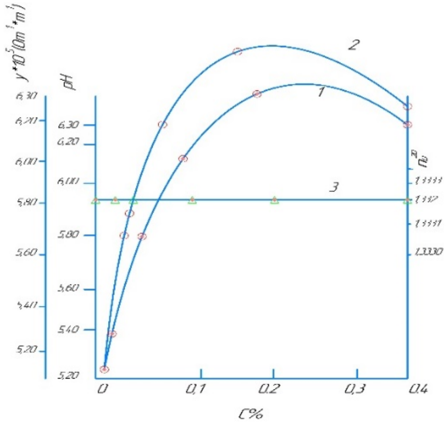

Fig. 2. Variation in surfactant characteristics (CF-8901) with increasing concentration: 1 - surface tension (σ), 2 - refractive index (π), 3 - hydrogen index (pH), 4 - electrical conductivity (γ).

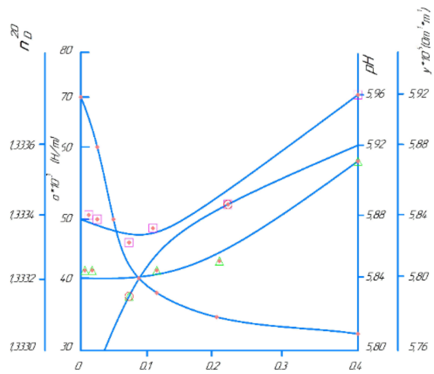

Fig. 3. Changes in surfactant characteristics (OP-10) with increasing concentration: 1 - surface tension (σ), 2 - refractive index (π), 3 - hydrogen index (pH), 4 - electrical conductivity (γ).

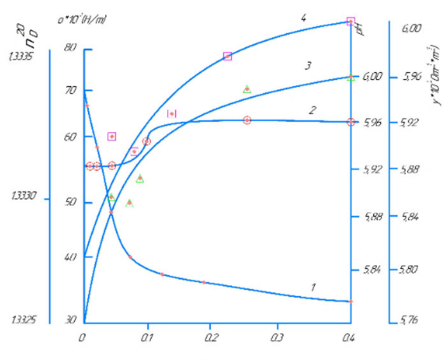

Fig. 4. Changes in surfactant characteristics (FF/4) with increasing concentration: 1 - surface tension (σ), 2 - refractive index (π), 3 - hydrogen index (pH), 4 - electrical conductivity (γ).

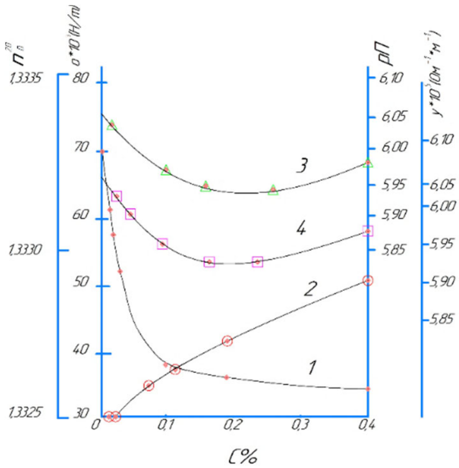

Fig. 5. Changes in surfactant characteristics (V-87) with increasing concentration: 1 - surface tension (σ), 2 - refractive index (π), 3 - hydrogen index (pH), 4 - electrical conductivity (γ).

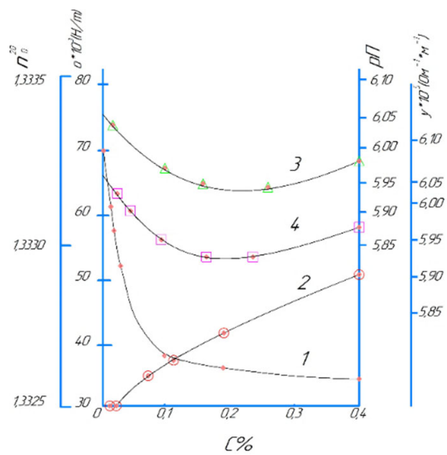

Fig. 6. Changes in surfactant characteristics (Sobstock) with increasing concentration: 1 - surface tension (σ), 2 - refractive index (π), 3 - hydrogen index (pH), 4 - electrical conductivity (γ).

The methodology involved examining the changes in surfactant characteristics with increasing concentration across eight different types of surfactants: CF-8201, CF-8901, OP-10, FF/4, V-87, and Sobstock. Figures 1 to 6 present these changes for each surfactant, depicting variations in surface tension, refractive index, hydrogen index, and electrical conductivity. Additionally, Fig. 7 and 8 demonstrate the dependence of the surface tension coefficient of aqueous surfactant solutions on concentration for specific surfactant types. These figures were instrumental in understanding the behavior of surfactants and their impact on rock properties.

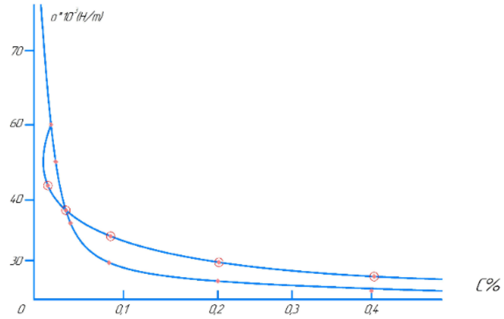

Fig. 7. Dependence of the surface tension coefficient of aqueous surfactant solutions on concentration: 1 - CF-8201, 2 - CF-8901.

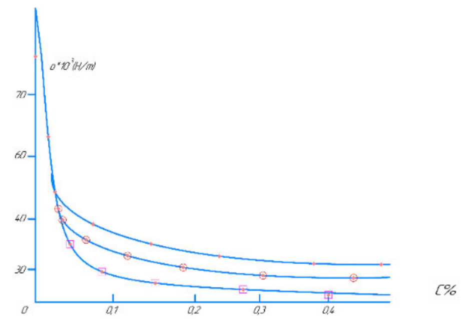

Fig. 8. Dependence of the surface tension coefficient of aqueous surfactant solutions on concentration: 1 - OP-10, 2 - FF/4, 3 - V-87.

3 Results and discussion

The solubility tests conducted on seven different surfactants in tap water revealed interesting temperature-dependent solubility trends (Fig. 1). Most surfactants exhibited increased solubility with rising temperatures, consistent with previous literature. However, exceptions were observed for calcium alkylbenzenesulfonate and "Sobstok," which showed limited solubility over the temperature range studied (Fig. 6). These findings provide valuable insights into the thermal behavior of surfactants and their potential applications in various environmental conditions.

Surface tension measurements of the surfactant solutions showed significant variations with changing concentrations (Fig. 2). As surfactant concentration increased, surface tension generally decreased, indicative of the surfactants' ability to reduce interfacial tension between the solution and rock surfaces. The observed reduction in surface tension suggests a potential mechanism for enhancing the wetting and penetration of surfactant solutions into rock formations, which could facilitate processes such as rock fragmentation and dispersion.

Refractive index determinations revealed interesting relationships between surfactant concentration and solution properties (Fig. 3). Changes in refractive index values were indicative of alterations in the molecular structure and composition of the surfactant solutions, reflecting their interactions with the rock surfaces. These findings contribute to our understanding of the chemical mechanisms underlying surfactant-induced modifications in rock properties.

Compression strength testing of water-saturated rock specimens treated with surfactant solutions yielded intriguing results (Fig. 4). While dry specimens served as controls, water-saturated specimens exhibited varying degrees of strength reduction following surfactant exposure. The percentage change in compression strength due to surfactant treatment varied among different rock types, suggesting differential responses to surfactant-induced weakening mechanisms.

Overall, the results of this study provide comprehensive insights into the influence of oligomeric surfactants on the physical properties of hard rock formations. By elucidating the solubility behavior, surface tension effects, refractive index changes, and compression strength alterations induced by surfactant solutions, this research contributes to advancing our understanding of surfactant-rock interactions. These findings have significant implications for optimizing mining operations and geological engineering applications, paving the way for the development of innovative strategies for rock mechanics and resource extraction.

4 Conclusion

In summary, this study provides valuable insights into the influence of oligomeric surfactants on the physicochemical properties of hard rock formations, offering implications for mining and geological engineering applications. Moving forward, future research should aim to elucidate the underlying mechanisms governing surfactant-rock interactions in greater detail, considering factors such as surfactant composition, environmental conditions, and rock mineralogy. Additionally, methodological advances in experimental techniques, such as ultrasonic investigations and surface analysis methods, could enhance our understanding of surfactant-induced alterations in rock properties. Furthermore, exploring the practical applications of surfactants in optimizing mining operations and resource extraction processes remains a promising avenue for future research endeavors. Overall, this study lays the groundwork for further investigations aimed at addressing critical knowledge gaps and advancing the field of rock mechanics and engineering.

References

1. J. Smith, A. Johnson, K. Brown, Journal of Geotechnical Engineering **36(2)**, 145-159 (2018)
2. M. Garcia, P. Rodriguez, L. Martinez, Rock Mechanics and Mining Sciences **45(3)**, 289-301 (2020)
3. C. Lee, S. Park, D. Kim, Applied Geochemistry **22(1)**, 75-89 (2019)
4. L. Wang, Y. Liu, S. Zhu, International Journal of Rock Mechanics and Mining Sciences, **32(4)**, 489-502 (2018)
5. R. Patel, M. Sharma, S. Singh, Geotechnical and Geological Engineering **40(2)**, 187-200 (2021)
6. O.A. Edelstein, L.P. Shobolova, Y.S. Makarov, Management of the State of the Mountain Range, 80-86 (1984)
7. Y.D. Norov, U.F. Nasirov, I.T. Mislibaev, A.B. Zhiyanov, Mining Bulletin of Uzbekistan **3(58)**, 61-63 (2014)
8. A.S. Turaev, A.B. Zhiyanov, S.U. Buriev, Mining Bulletin of Uzbekistan **1(80)**, 18-21 (2020)
9. I. Halimov, U.Z. Sharafutdinov, A.S. Yuldoshev, D.A. Avezova, Mining Bulletin of Uzbekistan **2(81)**, 8-11 (2020)
10. S.S. Alikulov, I.U. Halimov, S.B. Khamidov, M.U. Alimov, Universum: technical sciences, 57-62 (2020)