Kashf Journal of Multidisciplinary Research
Vol: 02 - Issue 11 (2025)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

THE GROWING ROLE OF MICROBIAL BIOSURFACTANTS IN THE OIL AND GAS INDUSTRY

Marwana Magaji*
Sultan Abdul Rahman College of Health Technology Gwadabawa

Mubarak Musa Bodinga
Sultan Abdul Rahman College of Health Technology Gwadabawa

[*]***Corresponding Author:*** magajimarwana123@gmail.com

Article Info

Abstract

The world's energy needs are still growing, but so is the pressure on industries to operate sustainably. This has pushed the petroleum sector to look for innovative and environmentally friendly solutions. One of the most promising answers comes from nature itself: microbial biosurfactants. These are surface-active molecules produced by microorganisms that offer a powerful and green alternative to the synthetic chemicals used today. This review brings together what we know about the main types of biosurfactants—like rhamnolipids and surfactin—and the microbes that create them. We explore their many uses across the oil and gas industry, focusing on how they can help recover more oil, clean up spills, and maintain equipment. We'll also break down how they work and discuss the real-world challenges of producing them on a large scale. The conclusion is clear: biosurfactants have tremendous potential to make the petroleum industry more efficient and far less polluting. It is necessary to enhance its compatibility in different types of formations, especially to achieve good results in special reservoirs. By controlling the oil displacement cost, it can achieve the goal of reducing costs, increasing efficiency, and further improving crude oil recovery.

Keywords:

Biosurfactant, Microbial Enhanced Oil Recovery, Oil Spill Cleanup, Rhamnolipids, Green Technology, Hydrocarbon Degradation.

1. INTRODUCTION

The petroleum industry is stuck between a rock and a hard place. It needs to extract more oil from aging, difficult fields while also reducing its environmental footprint. The standard chemical surfactants used for decades, though effective, are part of the problem. They're often made from petrochemicals, can be toxic, slow to break down in the environment, and don't always work well in the high-temperature, high-salt conditions of oil reservoirs (Saharan et al., 2011).

This is where biosurfactants come in. These versatile molecules, made by bacteria, yeasts, and fungi, are a sustainable and high-performance solution. They are biodegradable, generally non-toxic, and remain stable under the harsh conditions where synthetic surfactants fail (Banat et al., 2010). This article will explore how these remarkable biological molecules are produced and how they are poised to transform key areas of the petroleum industry.

Today, human life is extremely dependent on fossil fuels and related hydrocarbon products, viz., kerosene, gas, petrol, and diesel (Silva et al., 2014; Geetha et al., 2018). Among the several fossil fuels, crude oil has played an important role in the industrial revolution since the dawn of civilization to secure the world's energy supplies (Geetha et al., 2018; Bachari et al., 2019). The global oil resource consumption statistics show an increasing trend from the last century to 2019 (36390.5 Mbbl). The primary source of energy is expected to rise sharply in the future, and oil prices will rise (Schulz, 2016). The global crude oil consumption trend from 2000 to the present is increasing as forecasted consumer demand increases in the future (Figure 1). The graph recorded a decline In 2020 due to a global coronavirus pandemic and an extensive shutdown. However, global energy demand is expected to increase in the coming decades (Sonnichsen, 2021).

Around the world, the increasing universal energy demand required a strong energy supply response in addition to limited fossil fuel resources. To regulate the scarcity, researchers are developing techniques to improve the oil recovery from the existing reservoirs. In addition, recognizing alternative resources is paramount to easing the dependence on fossil fuels in the future (Hirasaki et al., 2011; Wei et al., 2014; Ardabili et al., 2019; Nikolova and Gutierrez, 2021). According to the International Energy Agency, oil production is steadily trending toward heavy or ultra-heavy oil production rather than medium to light oil. In countries like China, Canada, Venezuela, Mexico, and the USA, heavy crude oil accounts for about half of the recoverable petroleum resources. Therefore, the development of significant uses for this resource is rapidly becoming an important technology (Ceron-Camacho et al., 2013).

Figure 2

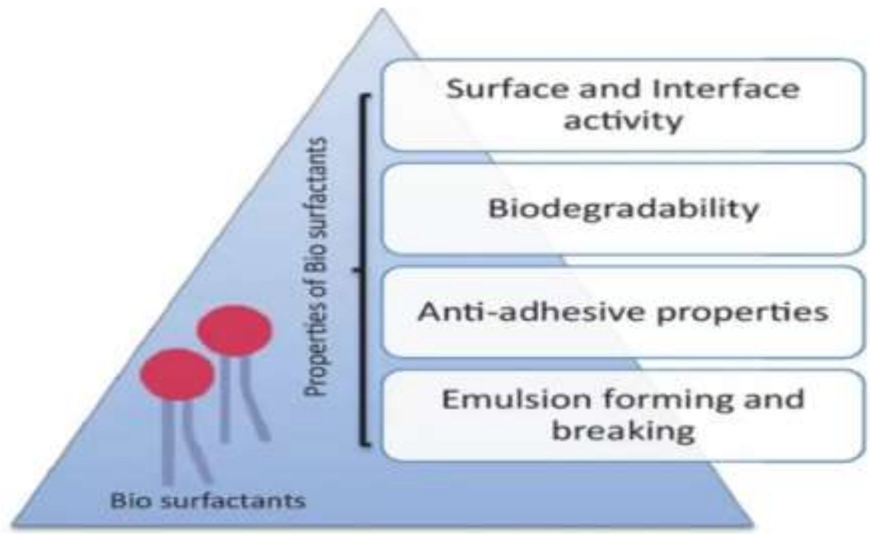

Figure 2. Properties of biosurfactants (Sharma et al., 2022).

1. **Meet the Players: Biosurfactants and Their Microbial Makers**

Biosurfactants are grouped based on their chemical makeup and which microbe produces them. The most important ones for oil and gas applications include:

Glycolipids (Sugar-Fat Molecules): This is the most well-researched group.

Rhamnolipids: Famous products of the bacterium Pseudomonas aeruginosa, these are superb at emulsifying and mobilizing crude oil.

Sophorolipids: Made by yeasts like Starmerella bombicola, they are notable for being produced in large quantities.

Trehalolipids: Produced by Rhodococcus and related bacteria, they are particularly good at emulsifying a wide range of oil components.

Lipopeptides (Protein-Fat Molecules):

Surfactin: Produced by Bacillus subtilis, this is one of the most powerful natural surfactants known, capable of drastically reducing surface tension (Varjani & Upasani, 2017).

Polymeric Biosurfactants:

Emulsan: A large, complex molecule from Acinetobacter bacteria that creates incredibly stable mixtures of oil and water.

Getting a good yield of these compounds depends heavily on choosing the right microbe and fine-tuning its growing conditions what it eats, the temperature, and the acidity of its environment.

2. How Biosurfactants Are Changing the Game in Oil and Gas

Getting More Oil Out of the Ground (Microbial Enhanced Oil Recovery)

In using natural pressure and water flooding to recover oil, up to two-thirds of the original oil can still be left behind, trapped in the tiny pores of the rock by strong capillary forces. Microbial Enhanced Oil Recovery (MEOR) is a third-stage method that uses microbes and their products, like biosurfactants, to free this trapped oil (Lazar et al., 2007).

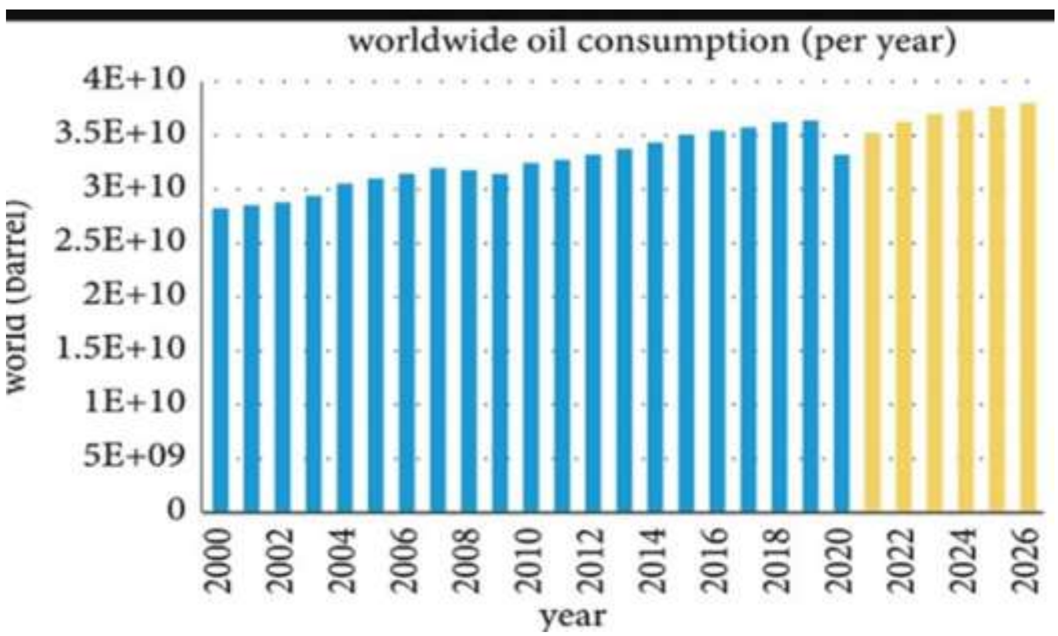

Figure 1. Global consumption of crude oil per year Sonnichsen, 2021

Biosurfactants help in three key ways:

1. **Reducing Stickiness:** They gather at the point where oil, rock, and water meet, drastically reducing the interfacial tension. This loosens the grip the rock has on the oil, allowing it to flow more easily.
2. **Breaking Oil into Droplets:** They break up large, trapped oil globs into tiny, mobile droplets that can be swept along by the water being injected into the reservoir.
3. **Changing the Rock's Preference:** They can make the rock surface more "water-wet," which helps peel oil away from the rock, much like dish soap releases grease from a pan.

a. Cleaning Up Oil Spills (Bioremediation)

When oil spills occur, biosurfactants act as a powerful cleanup tool by making the oil more available to natural microbes that can eat it (Singh et al., 2022). They dissolve and emulsify the oil, breaking large slicks into tiny droplets. This dramatically increases the surface area, making it easier for oil-eating bacteria to access and digest the pollution. They can also stimulate the growth of these natural oil-degrading microbial communities, speeding up the cleanup process significantly. This method has been used successfully on contaminated beaches, soil, and groundwater.

b. Maintaining Equipment and Infrastructure

Cleaning Storage Tanks: Over time, storage tanks build up a thick, sludgy mix of oil, water, and solids at the bottom. Biosurfactants can be used to liquefy and emulsify this sludge, allowing it to be pumped out and even enabling the recovery of usable oil.Keeping Pipelines Clear: They can be added to cleaning solutions to prevent waxy paraffins and asphaltenes from building up inside pipelines, ensuring smooth flow and reducing downtime for maintenance.

c. The Road Ahead: Challenges and Opportunities

Biosurfactants aren't yet used everywhere. The main hurdle is cost; they are currently more expensive to produce than synthetic surfactants. The path forward involves: Driving Down Costs: The biggest focus is on making production cheaper by:

1. **Using Waste Feedstocks:** Feeding microbes low-cost or even waste materials like molasses, agricultural waste, or used cooking oil.
2. **Engineering Better Microbes:** Using biotechnology to create super-producer strains and optimizing the fermentation process itself (Singh et al., 2022).· Proving They Work in the Real World: For oil recovery, we need more large-scale field tests that prove biosurfactants are effective and stable under the extreme heat, pressure, and saltiness of actual oil reservoirs.· Building Trust: Gathering more safety and environmental data will be key to getting regulatory approval and convincing the industry to fully embrace this new technology.

Emerging technology: petroleum biotechnology

Petroleum biotechnology has the aim of introducing biological processes to produce and refine petroleum to generate value-added by-products with minimum pollution output (Silva et al., 2014). The adaptability of microbes, their metabolism, and their intrinsic capacity to facilitate the transformation of complicated raw materials under harsh conditions such as high salinity, temperature, pH values, pressure, and hydrophobicity allow the improvement of those technologies (Montiel et al., 2009). Among various microbial metabolites, the most promising is a biosurfactant in the oil industry (Silva et al., 2014). Biosurfactants are amphiphilic compounds (hydrophilic and hydrophobic domains are present) that are widely known for multiple functions due to their diverse structures and numerous. Various microbial species are capable of producing surface-active molecules to improve the bioavailability of hydrophobic, immiscible, and mostly inaccessible substrates, facilitating enhanced survival under low humidity conditions. The production of biosurfactants generally occurs in miscible hydrophilic and hydrocarbon

carbon sources in the medium. The process of synthesis becomes attractive when the researcher develops it from waste substrates (Dziegielewska et al., 2013).

The chemical composition of biosurfactants varies greatly depending on the type of microorganism and can be broadly categorized on the basis of their molecular weight and charge. The biosurfactants are classified into two classes: low molecular weight surfactants (which reduce surface tension between two immiscible liquids) and high molecular weight surfactants (which allow the formation of oil-in-water or water-in-oil emulsions). The high molecular weight surfactants are more complex as they consist of heteropolysaccharides, lipopolysaccharides, lipoproteins, and proteins, whereas the low molecular weight biosurfactants are generally made up of exopolysaccharides that are capable of emulsifying immiscible liquids but are less efficient in reducing the surface tension (Uzoigwe et al., 2015). The list of biosurfactants implemented in the petroleum industry is summarized in Table 1.

ow molecular weight biosurfactant			
hamnolipid	*Marinobacter sp., Pseudomonas aeruginosa*	Bioremediation, marine oil spill	Tripathi et al. (2019)
ipopeptide			
urfactin	*Bacillus subtilis*	(Microbial enhanced oil recovery) MEOR	Liu et al. (2015)
ichenysin	*Bacillus licheniformis*	MEOR	Coronel-Leon et al. (2016)
igh molecular weight biosurfactant			
mulsan	*Acinetobacter calcoaceticus*	MEOR	Uzoigwe et al. (2015)
lasan	*Acinetobacter radioresistens*	MEOR Bioremediation	Toren et al. (2001)
phingan	*Sphingomonas spp.*	Oil and gas	Li et al. (2016)
anthan gum	*Xanthomonas campestris*	Oil and gas	Kang et al. (2019)

Table 1. Summary of biosurfactants used in petroleum industries for remediation or enhanced oil recovery.

d. Conclusion

Microbial biosurfactants represent a fundamental shift toward a more sustainable and efficient future for the oil and gas industry. Their unique combination of green credentials—biodegradability, low toxicity—and robust performance under tough conditions makes them ideal for recovering more oil, cleaning up messes, and maintaining equipment. While the price tag remains a challenge, intense research into cost-cutting production methods is quickly closing the gap. Embracing this technology is a clear win-win: it can boost the industry's bottom line while dramatically shrinking its environmental impact, a crucial step toward a circular economy.

References

Banat, I. M., Franzetti, A., Gandolfi, I., Bestetti, G., Martinotti, M. G., Fracchia, L., … & Marchant, R. (2010). Microbial biosurfactants production, applications and future potential. Applied Microbiology and Biotechnology, 87(2), 427–444.

Lazar, I., Petrisor, I. G., & Yen, T. F. (2007). Microbial enhanced oil recovery (MEOR). Petroleum Science and Technology, 25(11), 1353–1366.

Saharan, B. S., Sahu, R. K., & Sharma, D. (2011). A review on biosurfactants: fermentation, current developments and perspectives. Genetic Engineering and Biotechnology Journal, 2011, 1–14.

Singh, P., Patil, Y., & Rale, V. (2022). Biosurfactant production: emerging trends and promising strategies. Journal of Applied Microbiology, 132(5), 3307–3326.

Varjani, S. J., & Upasani, V. N. (2017). Critical review on biosurfactant analysis, purification and characterization using rhamnolipid as a model biosurfactant. Bioresource Technology, 232, 389–397.

Amani, H., and Kariminezhad, H. (2016). Study on emulsification of crude oil in water using emulsan biosurfactant for pipeline transportation. Petrol.Sci. Technol. 34, 216–222. Doi: 10.1080/10916466.2015.1118500

CrossRef Full Text | Google Scholar

Ardabili, S., Mosavi, A., and Varkonyi-Koczy, A. R. (2019). "Systematic review of deep learning and machine learning models in biofuels research" in Engineering for Sustainable Future (Berlin, Germany: Springer).Google Scholar

Bachari, Z., Isari, A. A., Mahmoudi, H., Moradi, S., and Mahvelati, E. H. (2019). Application of natural surfactants for enhanced oil recovery-critical review. IOP conf. Environ. Earth Sci 221:012039. Doi: 10.1088/1755-1315/221/1/012039

CrossRef Full Text | Google Scholar

Berninger, J. P., Williams, E. S., and Brooks, B. W. (2011). An initial probabilistic hazard assessment of oil dispersants approved by the United States National Contingency Plan. Environ. Toxicol. Chem. 30, 1704–1708. Doi: 10.1002/etc.532

PubMed Abstract | CrossRef Full Text | Google Scholar

Bryant, R. S., Burchfield, T. E., Dennis, D. M., and Hitzman, D. O. (1990). Microbial-enhanced waterflooding: mink unit project. SPE Reserv. Eng. 5, 9–13. Doi: 10.2118/17341-PA

Ceron-Camacho, R., Martinez-Palou, R., Chavez-Gomez, B., Cuellar, F., Bernal-Huicochea, C., Clavel, J. C., et al. (2013). Synergistic effect of alkyl-O-glucoside and-cellobioside biosurfactants as effective emulsifiers of crude oil in water. A proposal for the transport of heavy crude oil by pipeline. Fuel 110, 310–317. Doi: 10.1016/j.fuel.2014.01.023

Coronel-Leon, J., Marques, A. M., Bastida, J., and Manresa, A. (2016). Optimizing the production of the biosurfactant lichenysin and its application in biofilm control. J. Appl. Microbiol. 120, 99–111. Doi: 10.1111/jam.12992

Dziegielewska, E., and Adamczak, M. (2013). Evaluation of waste product synthesis of surfactants by yeasts. Chem 67:1113. Doi: 10.2478/s11696-013-0349-1

CrossRef Full Text | Google Scholar

Edwards, K. R., Lepo, J. E., and Lewis, M. A. (2003). Toxicity comparison of biosurfactants and synthetic surfactants used in oil spill remediation to two estuarine species. Mar. Pollut. Bull. 46, 1309–1316. Doi: 10.1016/S0025-326X(03)00238-8

PubMed Abstract | CrossRef Full Text | Google Scholar

El-Sheshtawy, H. S., Aiad, I., Osman, M. E., Abo-ELnasr, A. A., and Kobisy, A. S. (2015). Production of biosurfactant from Bacillus licheniformis for microbial enhanced oil recovery and inhibition the growth of sulphate reducing bacteria. Egypt. J. Pet. 24, 155–162. Doi: 10.1016/j.ejpe.2015.05.005

CrossRef Full Text | Google Scholar

Franzetti, A., Gandolfi, I., Raimondi, C., Bestetti, G., Banat, I. M., Smyth, T. J., et al. (2012). Environmental fate, toxicity, characteristics and potential applications of novel bioemulsifiers produced by Variovorax paradoxus 7bCT5. Bioresour. Technol. 108, 245–251. Doi: 10.1016/j.biortech.2012.01.005

PubMed Abstract | CrossRef Full Text | Google Scholar

Gaathaug, A. V., Bjerketvedt, D., Vaagsaether, K., and Nilsen, S. H. (2014). Experimental study of gas explosions in hydrogensulphide-natural gas-air mixtures. J. Combust. 2014:905893, 1–12. Doi: 10.1155/2014/905893

Saji, V. S. (2010). A review on recent patents in corrosion inhibitors. Recent Patents Corr. Sci. 2, 6–12. Doi: 10.2174/1877610801002010006

CrossRef Full Text | Google Scholar

Schulz, R. (2016). The reason to expect prolonged USD 30-60/bbl oil. J. Pet. Technol. 68, 42–45. Doi: 10.2118/1016-0042-JPT

CrossRef Full Text | Google Scholar

Shahaliyan, F., Safahieh, A., and Abyar, H. (2015). Evaluation of emulsification index in marine bacteria Pseudomonas sp. And Bacillus sp. Arab. J. Sci. Eng. 40, 1849–1854. Doi: 10.1007/s13369-015-1663-4

CrossRef Full Text | Google Scholar

Sharma, N., Lavania, M., Kukreti, V., Rana, D. P., and Lal, B. (2018). Laboratory investigation of indigenous consortia TERIJ-188 for incremental oil recovery. Front. Microbiol. 9:2357. Doi: 10.3389/fmicb.2018.02357

CrossRef Full Text | Google Scholar

Sharma, N., Lavania, M., and Lal, B. (2022). Biosurfactant: a next-generation tool for sustainable remediation of organic pollutants. Front. Microbiol. 12:821531. Doi: 10.3389/fmicb.2021.821531

PubMed Abstract | CrossRef Full Text | Google Scholar

Silva, R., Almeida, D., Rufino, R., Luna, J., Santos, V., and Sarubbo, L. (2014). Applications of biosurfactants in the petroleum industry and the remediation of oil spills. Int. J. Mol. Sci. 15, 12523–12542. Doi: 10.3390/ijms150712523

PubMed Abstract | CrossRef Full Text | Google Scholar

Silva, S. N. R. L., Farias, C. B. B., Rufino, R. D., Luna, J. M., and Sarubbo, L. A. (2010). Glycerol as substrate for the production of biosurfactant by Pseudomonas aeruginosa UCP0992. Colloids Surf. B Biointerfaces 79, 174–183. Doi: 10.1016/j.colsurfb.2010.03.050

PubMed Abstract | CrossRef Full Text | Google Scholar

Singh, A., van Hamme, J. D., and Ward, O. P. (2007). Surfactants in microbiology and biotechnology: part 2 Application aspects. Biotechnol. Adv. 25, 99–121. Doi: 10.1016/j.biotechadv.2006.10.004

PubMed Abstract | CrossRef Full Text | Google Scholar

Sobrinho, H. B. S., Luna, J. M., Rufino, R. D., Porto, A. L. F., and Sarubbo, L. A. (2013). Assessment of toxicity of a biosurfactant from Candida sphaerica UCP 0995 cultivated with industrial residues in a bioreactor. Electron. J. Biotechnol. 16. Doi: 10.2225/vol16-issue4-fulltext-4

CrossRef Full Text | Google Scholar

Song, W., Ma, D., Zhu, Y., Wei, X., Wu, J., Li, S., et al. (2014). The role of sulphate-reducing bacteria in oil recovery. Int. J. Curr. Microbiol. Appl. Sci. 7, 385–398.

Google Scholar

Sonnichsen, N. (2021). Daily demand for crude oil worldwide from 2006 to 2026, d.d.f.c.o.w.f.t. 2026. Available at: http://www.statista.com

Google Scholar

Toren, A., Navon-Venezia, S., Ron, E. Z., and Rosenberg, E. (2001). Emulsifying activities of purified alasan proteins from Acinetobacter radioresistens KA53. Appl. Environ. Microbiol. 67, 1102–1106. Doi: 10.1128/AEM.67.3.1102-1106.2001

PubMed Abstract | CrossRef Full Text | Google Scholar

Tripathi, L., Twigg, M. S., Zompra, A., Salek, K., Irorere, V. U., Gutierrez T, T., et al. (2019). Biosynthesis of rhamnolipid by a Marinobacter species expands the paradigm of biosurfactant synthesis to a new genus of the marine microflora. Microb. Cell Factories 18, 164–112. Doi: 10.1186/s12934-019-1216-8