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Employing Surfactin: A Bio-Surfactant Play Amazing Role in Microbial Enhanced Oil Recovery (MEOR)

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Abstract

As microbial enhanced oil recovery (MEOR) is the recent promising oil extraction technique, it is known for optimizing the oil extraction process from depleted reservoirs that have been already utilized by primary and secondary oil recovery techniques. In this method a comprehensive species of microbes or their metabolites are involved that biosurfactants are the most promising ones than others. Biosurfacts include a large group of surface active metabolites that produced by microorganisms and have some unique properties which give them the ability to fulfill some surface activities, like; surface tension (ST) reduction or interfacial tension (IFT) reduction between two phases. Surfactin is such a biosurfactant that partake in MEOR process by reducing IFT and ST leading to alteration oil mobility, changing in reservoirs wettability, emulsification process and result to enhance oil recovery. Surfactin is lipopeptide biosurfactant that firstly discovered by Arima et al. in 1968, and it is produced by *Bacillus spp.* and own unique chemical structure that named it cyclic lactone ring. Surfactin reduces the IFT and ST of water considerably from 72 to 27 mN/m with aconcentration of 1 x10^{-4} g/L, that shows its greater effectiveness than several other biosurfactants. Surfactin owns numerous noble properties that change it to a precious candidate in MEOR process. Findings show, this biosurfactant demonstrated lower toxicity, higher surface activity, more sustainability, and a great stability in tough conditions.

Key Words; Biosurfactant, Interfacial Tension (IFT), Surface Tension (ST), Surfactin, Emulsification, Wettability Alteration, Microbial Enhanced Oil Recovery (MEOR), Mobility Control

Introduction

Microbial enhanced oil recovery, that also known as tertiary oil recovery process, is one of the most crucial oil recovery techniques for extracting the trapped oil in the reservoirs, that has not been extracted by primary and secondary oil recovery techniques [1]. This technique implements microbes or their metabolites, like; biosurfactants, biopolymers, bioacids, solvents, enzymes and biogases, for altering the properties of the formation for improving oil extraction process. These metabolites are produced by different groups of microorganisms' *ex-situ* or *in-situ* that take part in MEOR [2]. One of the significant group of microbial metabolites that play a crucial role in MEOR, are biosurfactants. These are the surface active agents that enhance oil recovery process, by decreasing interfacial tension between two phases (water/oil), alter the formation wettability from oil-wet to water-wet because of the unique chemical structure that they own [3]. When we study the chemical structure of these molecules we will find out

two different regions in their composition; one hydrophilic head that reacts with aqua phase and one hydrophobic tail containing hydrocarbon chain that reacts with oleous phase, leading to create an interfacial layer and results to decrease interfacial tension or surface tention. Among all wellknown biosurfactants, surfactin is more studied, popular and important in MEOR process [4], [2]. This is a lepopeptide biosurfactant that produce by a wide range of microbes, specially; Bacillus spp., and due to the following properties, like; high surface activity, versatility, stability, and low toxicity, it is an extremely popular biosurfactant that is broadly used in MEOR technique all around the world [5].

What is surfactin?

It is a cyclic lipopeptide biosurfactant and it was discovered by Arima et al. [6] in 1968 and it possesses a unique chemical structure of a cyclic peptide chain containing seven amino acids, besides, a hydroxyl fatty acid chain that has 13-16 carbon atoms. These aforementioned parts of this chemical give it a cyclic lactone ring structure (see figure 1) [7], [8]. Due to this unique chemical structure it has an amphiphilic nature that allows it to reduce IFT and ST significantly, and makes it able to assemble in the nanostructure. These two valuable functionalities give it a great potency to demonstrate physicochemical characteristics like foaming and emulsifying. Another advantage of surfactin over other biosurfactants and chemical surfactants is it lower value of critical micelle concentration (CMC), which makes it more interesting for implementing in various fields. Because this low CMC causes to get the expected result with less quantity of this biosurfactant than other [9], [10].

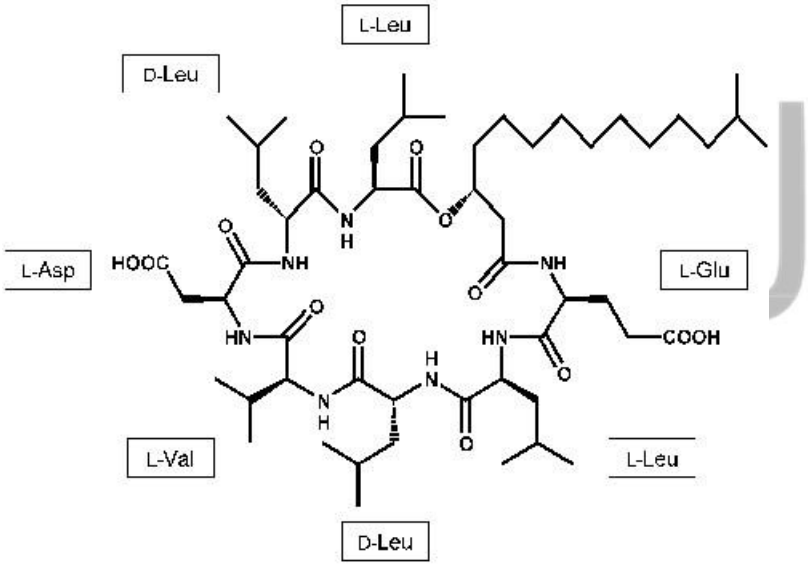

Figure 1. *Sarfactin structure [11]*

As we already mentioned, surfactin is produced by certain strains of bacteria, specially by Bacillus subtilis strains. This biosurfactant attracted too much attention among other biosurfactants because of its wide range of application in different industries, as well as in oil recovery industry [12]. As it exhibits great surface activity, it reduces the IFT and ST that cause to obtain a considerable importance in MEOR process. The main source of surfactin is *Bacillus subtilis* a bacterium that inhabits in soil. Surfactin is produced in high yield by fermentation of *B.subtilis* strains in a proper medium like Landy medium containing molasses as carbon source, yeast powder as nitrogen source, suitable pH (between 6-8) and proper temperature (around 16 °C) for growing and producing surfactin optimally, as a secondary metabolite [13].

What is the role of surfactin in MEOR process?

As it is commonly found out, biosurfactants play a vital role in MEOR process. They enhance oil recovery process and cause to extract much more oil from the reservoirs. These compounds fulfil this

vital task by three following mechanisms; 1- Reduce the water/oil interfacial tension and make the water to displace the oil more effectively. 2- Create a stable emulsion of oil in water that cause to increase the contact area between oil and water and removal of more oil by water in the reservoir. 3- Alter the wettability of the reservoir rocks from oil-wet to water-wet that results to adsorb more water and displace the trapped oil [14]. Surfactin as other biosurfactants has all these precious properties. In addition, in some cases its effectiveness is higher than other biosurfactants. For instance, its surface activity is greater than others, that leads to easier displacement of oil in the reservoir. Furthermore, it has a considerable emulsifying properties that disperse and solubilize the oil for making them more vulnerable to microbial degradation and lead to enhanced oil recovery. Likewise, it is used in selective plugging process for redirecting the water flow from high permeability regions to poor permeability zones for enhancing oil recovery. Besides, it enhances the capillary number by reducing water/oil IFT and promotes the flow of oil over the rock pores. And the last but not the least, surfactin plays a crucial role in biodegradation enhancement of residual oil by contributing as a nutrient source for microorganisms in the reservoir. It helps the grow and reproduction of microorganisms that take part in breaking down of hydrocarbons with high molecular weight [15], [2].

Another positive prospective of surfactin is its advantages over chemical surfactants that make it more suitable candidate than chemical surfactants. Here we can name some of these advantages in the following aspects; its eco-friendliness and low toxicity, improved surface activity, lower critical micelle concentration, greater emulsification capability, and its stability under rigorous conditions (extreme pH level, temperature, and salinity) [14]. Several studies show that surfactin reduces the surface tension and interfacial tension in oil reservoirs considerably, for example; from 72 to 27 mN/m at a concentration 1 $x10^{-4}$ g/L [5], [16]. While, rhamnolipid, that is produced by Pseudomonas spp. can optimally reduce the ST and IFT from 72 to 35.26 mN/m with concentration of $1.27x10^{-2}$g/L [17]. Also it reduced the IFT of medium crude oil from 42.3 mN/m to 6.9 mN/m and of a light crude oil from 36.4 to 3.8 mN/m [18]. Furthermore, crude surfactin also showed a great potential application in MEOR process that is substantially cost-effective because of unnecessity of purification in comparison with other biosurfactants and chemical surfactants [5]. With all these positive properties it was found out that applying surfactin caused to recover 9.2% more oil from the reservoirs [19].

Challenges and solutions regarding applying surfactin in MEOR

Besides, such advantages of surfactin as biosurfactant in MEOR process, there are some challenges that limit its application in MEOR. Therefore, during implementing this compound in MEOR process these limitations should be considered, they are included; selection of the suitable microbial strain, stability and compatibility of surfactin in rigid condition of the reservoir, and survival of producing microorganisms through the reservoirs [20].

For overcoming these restrictions, first of all we should carefully select the appropriate microorganisms for producing surfactin. *B.sultilis*, *B.licheniformis* and *B.amyloliquefaciens* are some proper candidate for producing optimal amount of surfactin. Meanwhile the selection of the most suitable one might depend on the factors such as stability, cultivation method, application, and yield [21]. In purpose of overcoming the stability challenge there are some suggested solutions, like; 1-formulation of surfactin with other agents to make it more stable against harsh pH, temperature and salinity. 2- Addition of co-surfactant in the formulation to improve the stability and efficiency of surfactin. And, 3- Encopsulation of surfactin to get more stable under rigid conditions [21], [2]. Due to resolving the challenge about surviving of producing microorganisms the following ways are suggested; 1- Introducing enough nutrients for optimizing the growth and reproduction of the microbial strains, for instance; injection of nutrient rich solutions, 2- implying pH tolerant and temperature tolerant strains for overcoming with harsh pH or temperature, and 3- injection of oxygen releasing compounds for supplying sufficient amount of oxygen [22].

Environmental and economic considerations of applying surfactin in MEOR

Surfactin has a number of valuable properties that make it a considerable eco-friendly compound in MEOR process such as 1- biodegradability that means, it is degraded effectively by natural microbes in the nature. So it does not contaminate the environment. 2- low toxicity that declares it does not create considerable risk in nature for other organisms, 3- ability to decrease surface tension that makes it a significant candidate for eliminating oil pollution of the environment, and 4- its production by *B.subtilis* that demonstrates its sustainability [23]. All these properties made it a valuable candidate with potential applications in a wide range of industries, specifically; in MEOR.

Although around 50 years have been passed from the discovery of surfactin it is not cost-effective yet for implementing in many industries. It is estimated, which the surfactin that derived from petro-chemical industry costs around 100-1000 USD/kg that make it uncompetitive with chemical surfactants. But new strategies of production have been invented that promised to decrease its price and make it more economically available than before. One of these strategies is agro-industrial residues that included many techniques and the most effective one is ultrafiltration process [8]. Due to the limitations that production and implementation of microbial surfactin researchers are working to replace this with other products which might be more sustainable. Plant-based biosurfactants and fungi hydrophobins are two potential candidates [24].

Conclusion

Microbial enhanced oil recovery is the most crucial technique for optimizing the extraction of oil from the reservoirs. In this technique a wide range of microorganisms or their metabolites are implied that biosurfactants are a significants group that included a large number of biosurfactant compounds that are produced by bacteria. Surfactin is a strong biosurfactant that plays a very important role in microbial enhanced oil recovery. It has some properties including great surface activity (higher than lots of biosurfactant), versatility (it has a diverse set of applications in different industries), sustainability (it is produced by numerous strains of *B.subtilis*), stability and low toxicity that made it considerable candidate for MEOR projects among other biosurfactants. Besides, it is more suitable than chemical surfactants due to being eco-friendly. Because it is a biodegradable compound that can be biodegraded effectively by large number of microbes. In addition, it is badged friendly than other biosurfactants and thanks to effective application of crude surfactin. Regardless all aforementioned advantages of surfactin, there are still some limitation and considerations regarding to its implementation in MEOR field projects. Some these challenges are like; selection of the proper bacterial strain to produce it, limitations related to growing and reproduction of producing microbes due to tough conditions of the reservoirs, and restrictions for compatibility of produced surfactin in the harsh situation of the reservoir. In spite of all researches that have been done about surfactin there is still a long way to pass for achieving enough knowledge for applying this biosurfactant directly in MEOR projects with high scales.

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