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The influence of surface active compounds synthesized by microorganisms on the environment – an overview

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ABSTRACT

Biosurfactants are surface-active molecules produced by variety of microorganisms like bacteria, yeasts or fungi. They consist of both hydrophilic (polar head) and hydrophobic (non-polar chain) moiety. Such structure allows them to reduce interfacial tension or create microemulsions. Biosurfactants can be produced as a part of cell membrane or extracellular compounds. They show foaming, wetting, emulsifying and dispersing properties. Biosurfactants are characterized by low toxicity, high biodegradability and they do not accumulate in living organisms. Biosurfactants are mostly used in environmental clean-up technologies. However due to many properties biosurfactants find use in various industries, such as: petroleum, pharmaceutical, textile or cosmetic. Microbial surface active compounds can improve the degradation of hydrocarbons from soil and water. Besides they are capable of degrading polycyclic aromatic hydrocarbons (PAHs). Biosurfactants help removing heavy metals like lead, cadmium or zinc, from soil. Rhamnolipids synthesized by bacteria of the *Pseudomonas aeruginosa* are the most commonly used biosurfactants in the remediation process. The aim of this paper is to present different applications of biosurfactants in environmental remediation based on literature review. The paper is based on literature studies.

***Keywords*: Biosurfactants, bioremediation, environment**

1. INTRODUCTION

A wide variety of microorganisms (e.g. yeasts, bacteria and fungi) through microbiological biosynthesis produce surface-active compounds called biosurfactants. They are characterized by the ability to reduce the surface tension of the liquid and at the interface [1]. The biosurfactant molecule, like the synthetic surfactant, has an amphiphilic character – it is constructed of two moieties with different properties in relation to water. The hydrophilic moiety (polar head) shows strong affinity for water and polar liquids. It can contain amino acids, carbohydrate, cyclic polypeptides, alcohol or carboxylic acid [2,3]. Whereas, the hydrophobic part (non-polar chain) exhibits affinity for non-polar liquids. This moiety is mostly composed of long-chain fatty acids or hydroxyl fatty acid [1,4].

Additionally, biosurfactants act as wetting or foaming agents, solubilizers, detergents, dispersants, emulsifier and they can create microemulsion [2]. They also show antioxidant, antimicrobial, antifungal and antibiofilm features [2]. Commonly, the biosurfactant's critical micelle concentrations (CMCs) range from 1 to 200 mg/L and their mass ranges from 500 to 1500 Da [4]. Surfactants of microbial origin can be an alternative to synthetic surfactants, which are widely used in many industries such as: paper, textile, cosmetic, pharmaceutical and oil. However in comparison to their synthetic counterparts, biosurfactants possess many eco-friendly features. They are characterized by [3]:

- low toxicity,
- no accumulation in organisms,
- low sensitivity to environmental factors,
- possibility of using waste materials as a substrates necessary for production of biosurfactants,
- ease of degradation in environment by microorganisms that live in water or soil.

That is why particular biosurfactants find application in technological processes of water and soil purification from petroleum substances like hydrocarbons or in metal-contaminated soil remediation [5].

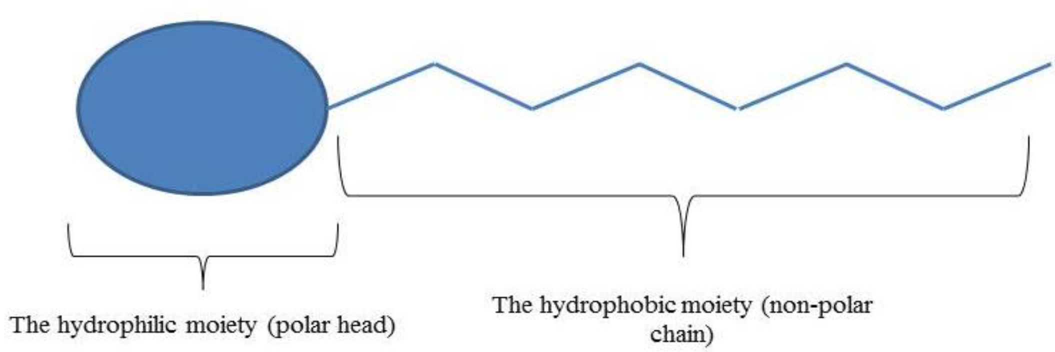

Figure 1. Structure of biosurfactant

Microbial biosurfactant can be synthesized in three ways: on the surface of the cell (e.g. on the cell wall), in the extracellular medium and inside cell (e.g. in the cell membrane). In the scientific literature five groups of microbial surface-active agents were distinguished based on their chemical structure (Table 1) [6-8]. Moreover there is a division of biosurfactants including their molecular weight [7]:

- low molecular weight compounds such as glycolipids, phospholipids and lipopeptides,
- high molecular weight compounds like polymeric biosurfactants or particulate biosurfactants (the whole cell of microorganism).

Low molecular weight biosurfactants demonstrate higher effectiveness in reducing surface and interfacial tension than high molecular weight compounds. But they possess weaker emulsifying properties compared to high molecular weight biosurfactants [2].

Table 1. Division of biosurfactants.

Class	Biosurfactant	Microorganism
Glycolipids	Rhamnolipids	*Pseudomonas* spp. *Bacillus subtilis* *Pseudomonas putida*
	Trehalose lipids	*Rhodococcus* sp. *Arthrobacter* sp.
	Sophorolipids	*Candida bombicola*
	Mannosylerythritol Lipids	*Candida antarctica*
Lipopeptide and lipoproteins,	Surfactin	*Bacillus subtilis*
	Lichenysin	*Bacillus licheniformis*
	Iturin	*Bacillus subtilis*
	Fengycin	*Bacillus subtilis*
Fatty acid, phospholipids, neutral lipids,	Fatty acid	*Corynebacteria lepus*
	Neutral lipids	*Nocardia erythropolis*
	Phopholipids	*Thiobacillus thiooxidans*
Polymeric biosurfactants	Emulsan	*Acinetobacter calcoaceticus*
	Alasan	*Acinetobacter radioresistens*
	Biodispersan	*Acinetobacter calcoaceticus*
	Liposan	*Candida lipolytica*

Particulate surfactants	Fimbria	*Acinetobacter calcoaceticus*
	PM factor	*Pseudomonas marginalis*
	The whole cells of microorganism	*Cyanobacteria* sp.

Source: [6-8].

The purpose of this article is to present various application methods of microbiological surface active agents in environmental remediation based on literature studies. Such application include inter alia: bioremediation of hydrocarbons, PAHs or binding heavy metals.

2. APPLICATION OF BIOSURFACTANTS IN THE ENVIRONMENT

Soil and water contamination caused by mixtures of petroleum hydrocarbons, polycyclic aromatic hydrocarbons and the presence of heavy metals are a considerable threat to environment. These compounds are toxic to the environment and manifest carcinogenic or mutagenic properties. Nowadays various cleaning methods are used [2]: 1) physicochemical methods and 2) biological methods, which use microorganisms.

Bioremediation is a biological process that involves the degradation of contaminants (e.g. hydrocarbons, PAHs) by the use of microorganism [9]. Surface active compounds are synthesized by microorganisms to increase the solubility of hydrocarbons, which are subsequently used by living organisms as nutrients [2]. Consequently it contributes to more intensive biodegradation process of soil and water contamination. Bioremediation is a relatively cheap and fast method. The rapidity of bioremediation process depends on the following factors [10]:

- environmental condition – humidity, temperature, pH, availability of oxygen or redox potential,
- abundance and activity of microorganisms,
- hydrocarbon toxicity to microflora,
- content of nutrients, like phosphorus or nitrogen,
- content of hydrocarbons.

Studies showed that properties enhancing the biodegradation process of hydrocarbons are possessed by specific biosurfactants e.g. rhamnolipids, sophorolipids, surfactin or trehalose lipids [2].

2. 1. Bioremediation of hydrocarbons and polycyclic aromatic hydrocarbons (PAHs)

In order for microorganisms to use hydrocarbons derived from petroleum, the first step is to simplify the access to these compounds. Studies recognized two basic mechanism of facilitating the access of hydrocarbons [11, p. 66]:

- direct interaction between microbes and hydrocarbons (cell-associated biosurfactants),
- the process of pseudosolubilization (extracellularly biosurfactants).

Biodegradation of hydrocarbon using microbes is the basic method of soil purification [5]. The results of the previous research prove that the addition of biosurfactant, in this case sophorolipids, accelerate the biodegradation of hydrocarbons mixture (tetradecane, pentadecane, pristane and phenyldecane) [13]. It has been shown that the addition of sophorolipids contributed to the degradation of 90% hydrocarbon mixture within 79 hours. In contrast, in the absence of biosurfactants, the hydrocarbons were degraded up to 81% within 114 hours [13]. The addition of biosurfactant obtained from *Pseudomonas* sp. to contaminated soil increases biodegradation of heksadecane, tetradecan and pristane [20]. Moreover rhamnolipids and surfactin showed the ability to remove total petroleum hydrocarbons (TPH) at high level from soil [15]. It has also been noted that increased concentration of biosurfactant results in intensification of the biodegradation process [15]. The effectiveness of tested biosurfactants proved to be higher than their synthetic counterparts (Triton X-100 and Tween 80) [15]. Also one of the processes of soil purification is the one of soil washing using rhamnolipids to remove oil from coastal sand [12].

Authors [16] suggest that the synthesis of biosurfactants derived from *C. antarctica* on different carbon sources affect the bioremediation processes in a variety of ways. It means that if the contaminants possess similar chemical structure to the carbon source used to produce a particular biosurfactants, the biodegradation process is more effective [16].

Previous studies [17] indicated that the addition of biosurfactant obtained from *Pseudomonas* sp. – rhamnolipid together with poultry litter and coir pitch improved the remediation of gasoline contaminated soil. Also further research [18] carried out on Petri dishes, showed that microbial surfactants synthesized by *Pseudomonas marginalis* demonstrate the ability to increase the solubility of polycyclic aromatic hydrocarbons (PAHs) like phenanthrene. In the previous studies performed by Franzetta et al. [14] the applied biosurfactant stimulated the biodegradation of compounds derived from the pitch tar – phenanthrene and anthracene, respectively at 74% and 45%.

Beside biosurfactants can find application in oil storage tank cleaning, where they can facilitate the recovery of heavy oils and also in microbial enhanced oil recovery (MEOR) [5]. For example biosurfactants such as rhamnolipids, sophorolipids, trehalose-6,6' dimycolate and cellobiose lipid recovered the oil respectively in 94%, 97%, 93% and 99% [19].

2. 2. Bindings of heavy metals

Heavy metals such as zinc, cadmium, lead or mercury are serious issue for the aquatic and soil environment. Because, as opposed to hydrocarbon contaminants, they do not degrade. However microorganisms can be employed to bind them. Different microbial processes for uptake and sequestration of heavy metals are distinguished [25-27]:

- direct involvement, e.g. binding into the cell as an essential nutrients or accumulation by surface binding to the extracellular elements or to the microbes' cell wall,
- indirect involvement, e. g. production of hydrogen sulfide by sulfate reducing bacteria.

Consequently microbes can reduce their toxicity and ability to migration [5]. Biosurfactants create ionic bonds with heavy metals cations. Such complex can be easily washed out with water from soil [5]. The most commonly used biosurfactants for this type of bioremedation are rhamnolipids and sophorolipids [5]. Rhamnolipids are characterized by a high affinity for many trace elements.

In laboratory conditions, where artificially contaminated soil was used, cadmium and lead were removed from 80% to 100%. Nevertheless, in the case of samples obtained from the environment, the ability to reduce cadmium and lead was between 20% and 80% [21]. Juwarkar et al., [22] proved that biosurfactants have the ability to remove several heavy metals at the same time. Their research showed that using the rhamnolipids can remove 92% of cadmium and 88% of lead from contaminated soil within 36 hours [22]. It has also been proven that biosurfactants – surfactin and sophorolipids have the capability to bind heavy metals, such as copper, zinc or manganese [23]. Microbial surface active agents are applicable in the removal of heavy metals ions from water [24]. Surfactin allows the effective elimination of cadmium, zinc and copper from contaminated water [24].

Researchers [25] examined the possibility of application sophorolipids, rhamnolipids and surfactin to remove heavy metals (Cu and Zn) from sediments [25]. The use of 4% of sophorolipids resulted in the removal of 60% of the Zn and 25% of the Cu and using 0,5% of rhamnolipids eliminated 18% of the Zn and 65% of the Cu. While surfactin removed only 6% of zinc and 15% of the copper [25].

3. CONCLUSIONS

Previous scientific evidence indicates numerous possibilities for the microbiological surfactants to be applied in soil and water bioremediation processes. It should be mentioned that microbial surfactants manifest many positive features. They are easily biodegradable, nontoxic and they do not accumulate in living organisms. They are able to enhance the degradation of polycyclic aromatic hydrocarbons and petroleum compounds such as tetradecane, heksadecane or pristane. Moreover biosurfactants possess the ability to uptake heavy metals, for example: zinc, copper, cadmium or lead. Due to the versatile properties, rhamnolipids are the most common biosurfactants used in the bioremediation processes. Furthermore biosurfactants can be used in many industries such as: petroleum, textile, pharmaceutical or cosmetic.

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