Role of Biosurfactants in Heavy Metal Removal and Mineral Flotation

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Abstract

Surfactants are chemical compounds produced from petroleum feedstock, agro-based waste materials and microbial fermentation having wide variety of use in industries, pharmaceutical, agriculture, cosmetics, etc. These are amphiphilic moieties and chemically synthesised. These chemical compounds are toxic and are responsible for various harmful environmental problems. Recently, biosurfactants have gained lots of interest worldwide, because they are green-alternatives for surfactants. Biosurfactants are produced naturally from microorganisms like yeast, fungi and bacteria. These have both hydrophobic and hydrophilic groups which makes its unique and important in different industries. These organisms produce surface active metabolites or secondary metabolites and grow on water immiscible or oily surface. The surface active molecules help them to absorb, emulsify, wetting, solubilise and disperse the water immiscible substances. Biosurfactants are in demand and commercially promising due to their properties, i.e., low toxicity, higher biodegradability, environmental compatibility, foaming properties, shows stable activity at extreme pH, temperature and salinity, etc. Biosurfactants play very crucial role in mineral flotation. Heavy metal removal and mineral flotation is a very crucial process for industries (which commercially separates metals from ores by collecting them on the surface/froth layer—so the metals can be used commercially) and also for the environment. Biosurfactant mediated mineral floatation and heavy metal removal involves the metal ion sorption to sorbent material followed by floatation and floatation product collection. Using biosurfactants in replacement of surfactants for heavy metal removal and mineral floatation are actually effective, low cost, recyclable, reusable and environmental friendly. This chapter emphasises on removal of some metals from their respective ores using different biosurfactants. A probable mechanism of flotation by biosurfactant is also discussed.

Keywords

Surfactants · Biosurfactants · Mineral floatation · Environment · Surface active metabolites · Heavy metals

1 Introduction

The constant requirement of adequate minerals for mankind from exhaustible resources needs the use of advanced technology. The advance technology benefits in increasing mineral products and reducing waste material during the flotation of minerals ores. Froth flotation is comprehensively used worldwide by many industries for commercial preparation of minerals due to it affordability, cheap or low cost (Tolley et al., 1996).

Natural resources have been always explored and have become a source of experimentation in the science field by utilising sophisticated technologies in this global industrialisation age, resulting in development of items with high aggregate value in the global market (e.g., biosurfactants). Amphiphilic microbial compounds having hydrophobic and hydrophilic moieties that separates at liquid/liquid, liquid/solid and liquid/gas interfaces are known as biosurfactants (Santos et al., 2016).

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The properties like emulsification, foam generation, detergency and dispersion enable these particular biomolecules to play an important role and are very much desired attributes in many industrial sectors. Biosurfactant production/manufacturing is marked as one of the most important technologies for advancement of twenty-first century.

Apart from having a significant beneficial influence on the major global issues, biosurfactant manufacturing is critical to the implementation of sustainable industrial processes that involves use of renewable resources and "green" goods. Low toxicity and biodegradability of these biomolecules have led to an increase in scientific research involving wide variety of commercial uses for biosurfactants in the fields of bioremediation and others.

The froth flotation or mineral flotation used by many industries for extracting minerals/metals resulting in various toxic substances during the production process. Most of the industries contain toxic metals in their wastewater streams or their waste water treatment containers which leads to elevate the level of water pollution. These polluted waters consist of heavy metals and toxic elements as well as different mixture of hazardous substances of chemicals which is a big concern or threat for aquatic life as well as human life. This not only affects the aquatic life but it is also a threat for animal as well as humans which reaches us through food chain. Therefore, the ongoing research deals with different novel approaches or treatment technology for elimination of these toxic heavy metals from wastewater (Zamboulis et al., 2004). Similarly, for biomineral and metals processes like hydrometallurgical process and bioleaching are widely used by industries. Biomineral processing is used to remove/recover minerals from their ores by using microorganisms like fungi and bacteria. *Rhodococcus ruber* 9C strain degrades around 80% dibenzothiophene (DBT) while removing heavy sulphur content in Indian lignite, CPC and coal by 15.87%, 14.83% and 33.44%, respectively (Mishra et al., 2017). Another study shows, *Acidophilic ferroxidans*, an acidophilic chemolithotrophic bacteria used for copper recovery by using bioleaching and hydrometallurgical process (Panda et al., 2012, 2013, 2014). Similarly nickel cobalt recovery is also done by bio-reduction of chromite overburden by using DIRB (dissimilarity iron reducing bacterial Consortium) (Esther et al., 2013). These all methods show used of microorganisms as the major part. Similarly for minerals, sorptive floatation is used by industries, in which surfactants play a major role.

Sorptive flotation is widely used treatment technology for mineral which includes a sorbent and a surfactant. Sorptive floatation is a two staged process, and this method first involves adsorption or co-precipitation or occlusion of toxic metal ions (carried out in situ) followed by flotation by adding a suitable surfactant. Because both the process absorption and floatation can be carried out in same treatment unit this is referred as sorptive floatation (Matis et al., 2003).

Most of the toxic substances present are water soluble due to their hydrophilic nature. In order to separate the minerals or flotation, hydrophobicity and hydrophilicity is needed.

Flotation process involves various frothing agents which helps in air dispersion and increases strength of the bubble in flotation unit. Surfactants are important agents which are surface active molecules. These are basically amphiphilic in nature, i.e., hydrophilic as well as hydrophobic moieties are present. There are several types of surfactants available (Fig. 2). This chapter basically deals with the use of biosurfactant for mineral flotation. The use of rhamnolipids in coal and mineral ion floatation, use of surfactin in ion floatation and some green/biosurfactants is briefly discussed in this chapter. It also explains about the future aspects of biosurfactant or green surfactants in mineral ion floatation as well its use for environment and the potential value it holds for the future generation (Zouboulis et al., 2003).

2 What Are Surfactants and Biosurfactants?

Surfactants are amphiphilic, surface active and surface tension reducing material. Due to amphiphilicity, these have the ability to replace bulky molecules of higher energy resulting in reduction of free energy in the system. The hydrophilic part has very less affinity towards bulky medium whereas hydrophobic part of surfactant has higher affinity to bulky medium.

They readily disperse as immersion in any liquid or water by maintaining a reducing interfacial and surface tension between gas, liquid and solid.

A hydrocarbon chain is frequently used as a polar moiety, whereas considering the polar moiety can be ionic, i.e., cationic or anionic, non-ionic or amphoteric (Mao et al., 2015; Silva et al., 2014).

Surfactants make hydrophilic molecules more soluble, lowering the interfacial tension as well as surface tension between the oil/water contact (Banat et al., 2010a; Campos et al., 2013). The majority of surfactants on the market today are produced chemically. Synthetic tensioactive substances, on the other hand, are often poisonous and tough to degrade by the action of microbes. Over the past few years, such issues have forewarned the scientific community to accept the ecological/environment friendly surfactants (Vijayakumar & Saravanan, 2015).

This popularity of surfactants is the reason why surfactants are widely famous in different industry due to their adhesive nature, works as foaming agent, flocculation property, emulsifying property, etc., leading to their high demand for use in different purpose (Khoshdast et al., 2012; Vijayakumar & Saravanan, 2015).

These are chemical-based compounds mainly produced by petroleum feedstock, and some are generated synthetically in the laboratory. Even though these have very useful for different processes like floatation, but are toxic in nature, harmful for the environment as well as for mankind. The growing concern for environment protection has led everyone to find an alternative for these chemical surfactants that is green surfactant or biosurfactant or naturally occurring surfactant which are mainly produced by microbes, fungi or plants known as green surfactant or biosurfactants (Fig. 1). Furthermore, consumer worries about the environment, as well as new recent environmental control regulations, have led to achieve development of natural surfactants as a substitute to existing goods. Biosurfactant research began in the 1960s, and its application has grown in subsequent decades (Cerqueira et al., 2011; Silva et al., 2014). The perks of biosurfactants are low toxicity, structural diversity, greater biodegradability, the ability to function in a wide range of temperature, pH and salinity, lower CMC (critical micelle concentration) as well as greater selectivity, and most importantly its production involves industrial waste/renewable sources and industrial by-products, i.e., mainly natural resources; therefore, these biosurfactants have piqued the attention of various industries (Makkar et al., 2011; Pacwa-Plociniczak et al., 2011a; Preetam et al., 2022; Rosa et al., 2015). But there are some factors which affects the biosurfactant production in industries such as environment factors (like pH, salinity and temperature), presence of carbon substrate (diesel and crude oil are good source of carbon), its activity measurement like change in stabalisation/destablisation, change in surface and interfacial tensions and hydrophilic-lipophilic balance. Devices like tensiometer are widely used for these checking purpose. At the end, produced biosurfactant is analysed on the basis of their nature like—type, solvent, bacteria, etc. These surfactant works on an interface, i.e., liquid–liquid, solid–liquid and vapour-liquid, and this happens due to the immiscible phases present in solution or sample (Mulligan, 2005).

The hydrophilic part always attached towards the solution, i.e., liquid–liquid interface where the hydrophobic part sticks to the surface that is air–liquid interface. This process is efficient and reduces the work load to separate a molecule and bring it to surface. While reducing the surface tension of water micelle formation takes place, micelle formation has correlation with surface tension. Hence, good and efficient surfactant have low critical micelle concentration (CMC). CMC is defined as the surfactant's concentration in bulky phase of solution, upon which the micelle forms, i.e., from surfactants molecules and foaming starts. Biosurfactants are produced naturally as co-metabolites or secondary metabolites from particular type of microorganism. Therefore, these are produced extracellularly or as a part of cell membrane from bacteria, fungi or yeast and from few plants (Mulligan et al., 1993) (Table 1).

A surfactant generally has the property like solubility enhancement, surface tension reduction and critical micelle concentration and mainly used for the application like low surface tension, foaming capacity, detergency power, increasing solubility and wetting ability.

The basic criteria for industries to choose surfactants is their energy consumption or energy cost, their solubility

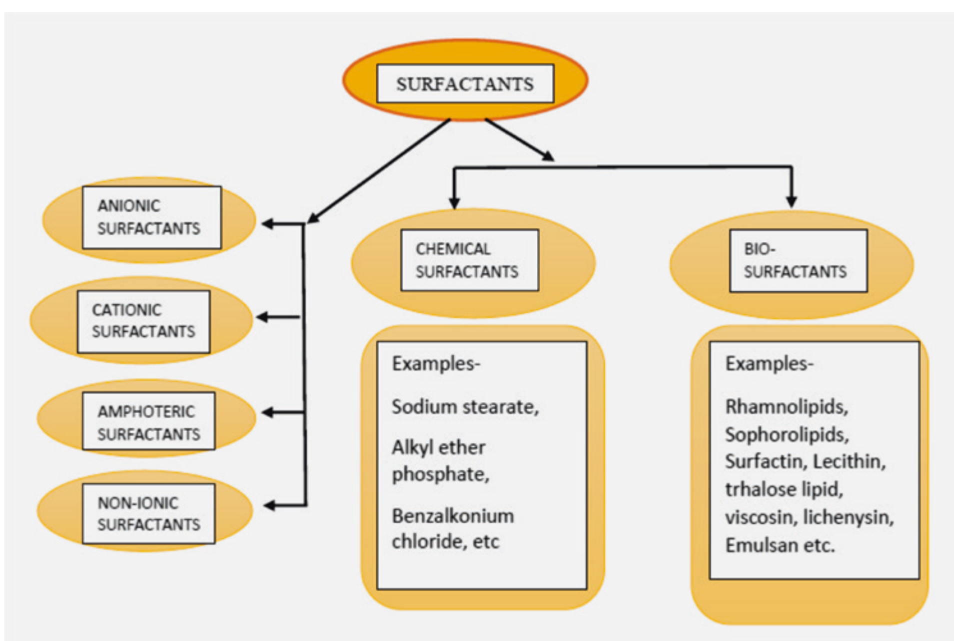

Fig. 1 Different types of surfactants

Table 1 Biosurfactants and the microorganisms they are produced from and its application

S. No.	Origin	Biosurfactant	Common applications	References
1	*Pseudomonas aeruginosa*	Rhamnolipids	Cd, Zn, Pb	Khoshdast et al. (2012), Fazaelipoor et al. (2010)
2	*Candida bombicola*	Sophorose lipids	Cd, Cu, Zn cosmetics and deodorant industries	Mulligan (2005)
3	*Bacillus subtilis*	Surfactin	Antibiotics, Cu, Zn	AytarÇelik et al. (2021)
4	*Pseudomonas fluorescens*	Viscosin	n-hexadecane mineralisation, etc.	Mulligan (2005), Mulligan et al. (1993)
5	*Arthrobacter parafineus*	Trehalose lipid	Used as antibacterial and antiadhesive agents	Mulligan et al. (1993)
6	*Anthrobacter* spp.	Glycolipids	Cu, Zn, bioleaching	Mulligan et al. (1993)
7	*Pseudomonas* spp.	Ornithine lipids	–	Desai and Banat (1997)
8	*Lactobacillus fermentum*	Diglycosyl diglycerides	Food additives/Food products	Mulligan et al. (2001a)
9	*Serratia marcescens*	Serrawettin	–	Okoliegbe and Agarry (2012), Zhang et al. (2009)
10	*Acinetobacter* spp.	Polymeric surfactant	Cosmetics, inks, drystuffs, paper coatings, agrochemicals, etc.	Nakar and Gutnick (2003), Sarma et al. (2019)

nature, charge type, adsorptive nature and physiochemical nature.

For metal removal along with surfactants some acids, bases and organic solvents are also used. Hence, the chemical surfactants are toxic as compared to biosurfactants which are fully biodegradable (Mulligan et al., 1999).

The biosurfactants are basically glycolipids, alkane, oil, sugars, lipopeptide, phospholipids, fatty acid, polymer, etc. The hydrophilic part of the surfactant attaches with amino acids, carbohydrates, cyclic peptide, phosphates, carboxylic acid or alcohol whereas the hydrophobic part attaches with long chain of fatty acid or Alpha alkyl beta hydroxy fatty acid.

Advantages of biosurfactants over chemical surfactants or synthetic surfactants are high specificity, biodegradability, environment compatibility less toxic or negligible toxic and have many environmental applications. The major industries using biosurfactants are soil washing of flushing, petroleum industries for oil removal application, mineral flotation in pharma industries, bioremediation of the contaminated landslides, etc. (Mulligan et al., 2001a) (Fig. 2).

3 Removal of Heavy Metals by Biosurfactants

Biosurfactants are widely used for heavy metal recovery, decontamination of organic substances and also for different scientific studies and processes. The organic substance decontamination or pollutants removal of hydrocarbons is carried out by the method of emulsification and pseudo-solubilisation (during cleaning process) for improving their bioavailability. Whereas for recovery of inorganic compounds, chelating agents are used during ion removal/cleaning aided with chemical interactions between metal ions and the amphipathic molecules (Banat et al., 2010b; Bodek et al., 1998; Pacwa-Plociniczak et al., 2011b).

In the restoration of heavy metal-contaminated soil, there are two primary techniques. The first method is used ex situ, which involves excavating contaminated soil, placing it in a glass column and washing it with a biotensioactive solution. The second method includes washing the soil at the original site, which involves the use of trenches and drainage tubes for collecting the biosurfactant solution (Mulligan et al., 2001b). Even a small amount of polluted soil can be treated with biosurfactants.

The biosurfactant metal complex is extracted from the soil in a massive cement mixer. After that, the soil is returned to its original site, and the biosurfactant metal complex undergoes treatment process so that the biosurfactant separates and precipitates while separating the metal behind (Sarubbo et al., 2015). In this way, the recovery is completed and metals are recovered. A probable mechanism for removal of heavy metal from contaminated soil with the help of biosurfactant is given in Fig. 3.

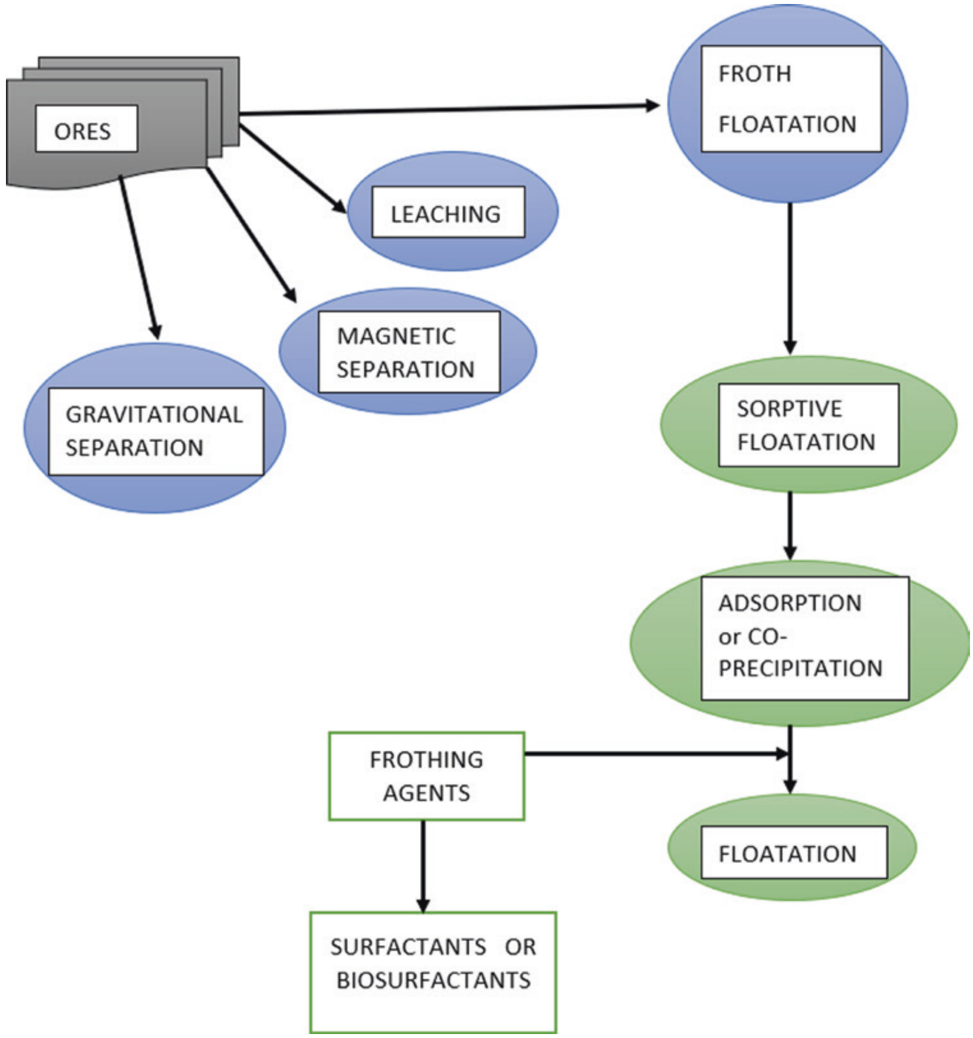

Fig. 2 Brief process of floatation and application of biosurfactant. Adapted from Refs. Matis et al. (2003), Zouboulis et al. (2003)

3.1 Heavy Metal Binding Mechanisms of Biosurfactants

The major interactions involved in biosurfactants and heavy metal binding are ionic interaction, electrostatic interactions, precipitation–dissolution and counter ion binding. Biosurfactants can directly bind to the sorbed metals and then collection of metals is done at solid–liquid interface having low interfacial tension. In the sorptive floatation process, metal–surfactant combination is seen while co-precipitating the toxic complexes. Anionic surfactants promote the interaction of metal with surfaces while the cationic surfactants reduce metal association by competing for certain but not all negatively charged surfaces. The concentrations and different kinds of biosurfactants have a different impact on heavy metal removal (Christofi & Ivshina, 2002; Frazer, 2000; Singh & Cameotra, 2004).

The most popular example is rhamnolipid which forms different micelle of ≫5 nm in diameter, vesicular structures of less than 50 nm diameter depending on pH of solution and at concentration above CMC. Increase in pH above 6.8 leads to spontaneously aggregate the surfactant molecules into complex structures called micelles. Ionic bond formation is seen when rhamnolipid, i.e., anionic biosurfactant carrying negative charge interacts with cationic metal (e.g., Cd(II) or Zn(II)) carrying positive charge (Açıkel, 2011; Zhang & Miller, 1992).

Micelles consists of polar head groups which binds to metal and makes them soluble in water.

Adsorbed metals are also dissolved by surfactant monomers, which create dissolved complexes. On the other hand, certain metals may bind to the anionic exterior of rhamnolipid micelles. Metal ions are coupled with oppositely charged ions, or they can be replaced with the same charged ions or they can form chelates on the micelle surface by complexing with agents. Hence, various binding mechanisms are seen between different biosurfactant and heavy metals. This method of using surfactant and micelle

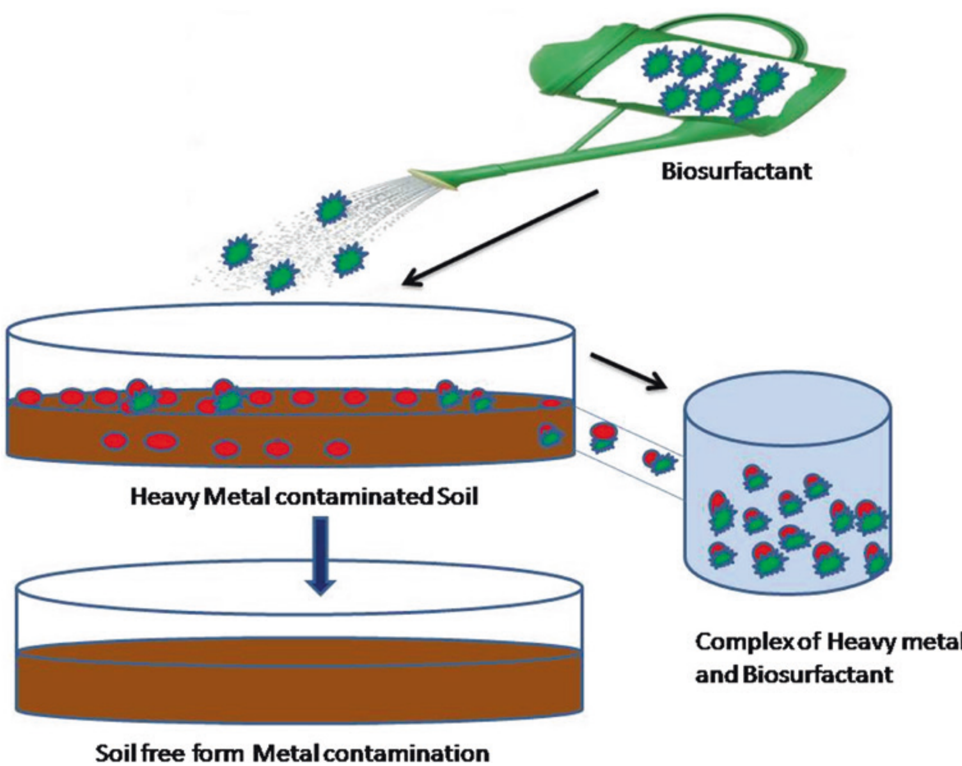

Fig. 3 Removal of heavy metal from contaminated soil by biosurfactant

formation not only helps making the process simpler and also user friendly (Açıkel, 2011; Zhang & Miller, 1992).

4 Biosurfactant in Mineral Floatation

4.1 Rhamnolipids in Mineral Ion Floatation

Rhamnolipids biosurfactants are the most popular, extensively studying or exploited by the biosurfactant among other biosurfactants. These are produced from bacteria *Pseudomonas aeruginosa*. About seven different types of homologues of these rhamnolipids are also found (Abalos et al., 2001). Two types of rhamnolipid are seen whose structure involves two rhamnose linked with beta hydroxy decanoic acid and one rhamnose attached to similar or identical fatty acid. *P. aeruginosa* takes up C12 and C11—glycerol, Glucose, fructose, mannitol, pyruvate, succinate, citrate, alkanes, etc., as raw materials to produce and form C8–C12. Some of them are also unsaturated with double and triple bonds (Robert et al., 1989). This *P. aeruginosa* are ubiquitous environmental bacterium which are isolated from water or soil and plants. Rhamnolipids are the most cultivated biosurfactants in the laboratory in large scale for different substrates and their applications.

Two major kinds of rhamnolipids, having molecular mass of 504 g mol^{-1} and 650 g mol^{-1}, respectively are RLL (R1) and RRLL (R2). RLL (R1), i.e., ($C_{26}H_{48}O_9$) is l-rhamnosyl-ß-hydroxydecanoyl-ß-hydroxydecanoate. RRLL (R2), i.e., ($C_{32}H_{58}O_{13}$) isl-rhamnosyl-ß-l-rhamnosyl-ß-hydroxydecanoyl-ß-hydroxydecanoate. The mixture of RLL, RRLL and mono- and di-rhamnolipid forms are specifically needed for removal of hydrocarbons and heavy metals from soil (Açıkel, 2011; Haba et al., 2003; Hamme et al., 2006).

4.2 Use of Rhamnolipid in Coal and Mineral Floatation

The experiment for coal and mineral floatation was initially carried out by fazaelipoor et al. They studied the rhamnolipid as frother as well as isolated, cultivated them in large scale. Here, they used diesel oil as solvents and heavy metal residues were seen after solvent dispersion. Upon adding rhamnolipid they did not see much frothability but the product recovery rate was high about 72–80%, with about 10–15% of ash content (Fazaelipoor et al., 2010; Khoshdast & Sam, 2012).

Khoshdast et al. briefly explain Rhamnolipid use, for which they isolated strains, cultivated them, produced them which followed up by measuring there, surface tension, pH, solubility and structural analysis as well as physical characterisation. Through this analysis, they concluded that the Rhamnolipid of 97.5% can reduce water from 72 to 30 mN $m^{-1}$with critical micelle concentration of 10 mg l^{-1} (Fazaelipoor et al., 2010; Khoshdast et al., 2011).

Another paper of Fazaelipoor et al. explains very beautifully the process of coal flotation test by desirable by surfactant (in this case Rhamnolipid). In this they added rhamnolipids as frother. Then surfactant concentration, particle size, oil concentration and solid present in concentration, where observed at intervals. The raw material of the solution was placed in 1 L capacity container along with the water of PH 7 and rotated in the speed of 1000 RPM in the impeller. The reaction was given about 3.2 L min^{-1}, and temperature was set to 25–26 °C. Initially, the raw materials or the collectors were added to the container and incubated for 2–3 min and then biosurfactant were added and incubated for 1 min more. The rotation continues for 6 min and the sample collection happens in the interval of 30, 60, 90, 150, 210 and 360 s to measure the kinetics of the floatation (Fazaelipoor et al., 2010).

Finally, the samples were filtered, dried, weighted and analysed, and ash content was determined. Software's like MINTLAB 14.1 were used for analysis of the floatation result and then statistical analysis was done. Because these are non-ionic molecules they also act as frother and their polar part links with the hydrogen bond of the water where is the non-polar and links with the surface or their air water interface. By changing the surface tension, we can also measure the surface activity. Rhamnolipid shows higher surface activity and biodegradability than the chemical surfactant (Fazaelipoor et al., 2010).

Having good ability and biodegradability make biosurfactant a promising frother and environmental friendly in protection of our nature. The result of these experiments was amazing and showing successful application of coal flotation. About 72 to 80% of solid combustible matter a recovery was done and about 10–15% ash content and 55–57% of efficient separation. This shows that rhamnolipids or biosurfactants can easily be used in mineral surfactants which are far better and more friendly than chemical or synthetic surfactants.

5 Surfactin in Ion Floatation

Bacillus subtilis, *Bacillus pumilus* and *Bacillus licheniformis* generate surfactin that is a cyclic peptide antibiotic composed of 7 amino acids bound to carboxyl and hydroxyl groups of a 14-carbon acid. Surfactin is made up of aspartic and glutamic amino acids. The glutamate residues have shown its binding affinity to metals that include Ca, Mg, Mn, Li, Ba and Rubidium. Because of the two charges on the surfactin molecule, the theoretical metal-surfactin ratio is 1 mol metal:1 mol surfactin (Açıkel, 2011). Surfactin has a potential benefit of having two charges owing to the aspartic and glutamic amino acids in its peptide structure, which makes it particularly potent and successful for ion flotation. Another method is precipitate floatation of metal ions for metal separation because as we know surfactants generates thick foam even at low concentrations. A low-flow foam fractionation technique is used that includes metal precipitation in aqueous solution involving constant binding of precipitates and its clusters to the rising bubbling foam. The metal content and solution's pH are two most important factors that influence metal removal through foam separation (Gurjar & Sengupta, 2015).

6 Other Biosurfactants in the Removal of Heavy Metals

LPS or Lipopolysaccharides are a form of biosurfactant that is made up of hydrophobic phospholipids and hydrophilic polysaccharide moiety. Langley and Beveridge were the first to test them for heavy metal extraction, demonstrating that lipopolysaccharides improve the outer cell walls hydrophilicity and allowing bacterial cells to absorb metallic cations. Kim and Vipulanandan investigated the elimination of lead from polluted soil and water (kaolinite) (Kim & Vipulanandan, 2006; Langley & Beveridge, 1999). *Flavobacterium* sp. grew on used vegetable oil to create the biotensioactive substance which is used for removal of lead from polluted water, hence, is quite effective.

Other forms of biosurfactants (mainly sophorolipids in nature) generated by *Candida* species have also been effectively used in heavy metal flotation. These can remove up to 90% of cations in the column and air-dissolved floatation process. Soil barrier is a unique method for separating heavy metals and petroleum by a biosurfactant produced from *Candida lipolytica*, i.e., a yeast. Biosurfactants also helps in removing Zn, Cu, Pb and Cd in groundwater by reducing soil permeability (Sarubbo et al., 2015). Sophorolipids are more effective than chemical surfactants at removing heavy metals from polluted environments. Heavy metals such as Cu and Zn have been shown to be removed from metal-polluted sediments using soil washing with sophorolipids. Water soluble anionic sophorolipids are negatively charged having COO– as head groups which makes strong ionic bonds with cationic elements hence proving that anionic sophorolipids are more efficient in metal removal than the non-ionic sophorolipids (Mishra et al., 2021).

Lipids derived from mannosylerythritol (MELs). Mannosylerythritol are glycolipid biosurfactants produced from microbial cells that are highly effective. Due to their outstanding biocompatibility, surface activity and healing capabilities, they have been widely employed in environmental sectors. Mannosylerythritol (MEL-AuNP) from the Ustilago maydis strain CGMCC5.203 is used for the synthesis of gold nanoparticles. These can also be used as reducing stabilising agents in the biosynthesis of nanoparticles (Mishra et al., 2021).

Plant-derived biosurfactants are also discovered and been used for the removal of heavy metals. Saponin is plant-based biosurfactant was investigates in Japan which removes heavy metal from soil from lakes construction sites (Mulligan et al., 2007). The soil contained zinc, copper, nickel and petroleum hydrocarbons in a bulky amount and the successive extraction revealed that the biosurfactant significantly decreased the zinc oxide, copper and organic fractions (Sarubbo et al., 2015).

Flotation is the only processing procedure that involves three phases of air, liquid and solid at the same time. The reagents involved in floatation are pH regulators, frothers and modifiers than can easily alter the chemical and physical properties of solid, liquid and air phases. These frothers are defined as surface active heteropolar molecules having hydrocarbon tail and polar head group. Hence, some biosurfactants can replace frothers as well playing their role very well. A biosurfactant produces from A *P. aeruginosa* act as frother in coal floatation giving around 72–79% of combustible matter recovery and having very little ash content, i.e., 10–15% with overall separating efficiency of 55–57%. Hence, these biosurfactants are very much efficient over chemical surfactants (Inès & Dhouha, 2015).

7 Conclusion and Future Aspects

This chapter shows that with the help of microorganisms like bacteria, fungi, yeast and plants we can cultivate biosurfactant in mineral medium along with gas oil. With the foam separation technique, it can be separated from fermentation medium, dried and used as per the requirement. This briefly explains about removal of heavy metal from soil in both the ex situ and in situ process, as well as their proper mechanism with some proved experimental methods, from literature. This indicates its benefit and is much less harmful because of the use of biological surfactants. Apart from the heavy metal recovery, mineral floatation is also focused, the use of rhamnolipid is very popular cause of its nature. Rahmnolipids are the most used biosurfactants in coal floatation and are still very user friendly, effective and environment friendly process.

But there are many different biosurfactants which are still needed to be study extensively to know their property and there use in different industries. These biosurfactant shows good profitability, good-frothability, good froth height as well as the froth stability, most importantly these are biodegradable, environmentally friendly, easily producible and less energy consuming. Rhamnolipids and surfactin can also be further investigated for its potential in different areas. This chapter also explain about the biosurfactants having low critical micelle concentration and high sorptive nature have strong potential. Therefore, these biomaterials not only used in mineral flotation but also in oil washing, biodegradation, in medicine industry, in petroleum industries and many more.

The future aspect of biosurfactant basically revolves around finding, determining, observing and analysing of different biosurfactants produced by different organisms. Placing them in an order or rank or criteria with the higher efficiency to their lower efficiency. This will help in finding many different kinds of biosurfactant and their quality as well as their ability in different fields. Therefore, these bio substances/biomaterials are much more efficient than the chemical ones.

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