

Trends in Biological Processes in Industrial Wastewater Treatment

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Trends in Biological Processes in Industrial Wastewater Treatment

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Maulin P Shah is a microbial biotechnologist with diverse research interests. A group of research scholars is working under his guidance on areas ranging from applied microbiology, environmental biotechnology, bioremediation, and industrial liquid waste management to solid state fermentation. His primary interest is the environment, the quality of our living resources, and the ways that bacteria can help to manage and degrade toxic wastes and restore environmental health. Consequently, he is very interested in genetic adaptation processes in bacteria, the mechanisms by which they deal with toxic substances, how they react to pollution in general, and how we can apply microbial processes in a useful way (e.g., bacterial bioreporters). He has more than 300 research publications in highly reputed national and international journals. He directs the research program at Enviro Technology Ltd, Ankleshwar. He has guided more than 300 postgraduate students in various disciplines of the life sciences. He is also a reviewer in various journals of national and international repute, and has edited more than 175 books in wastewater microbiology, environmental microbiology, bioremediation, and hazardous waste treatment.

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Trends in Biological Processes in Industrial Wastewater Treatment

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Chapter 1

Surfactants and bioremediation

J Anandkumar, Manisha Agrawal and Biju Prava Sahariah

Detergents, soaps, personal care products, liquid detergents, toiletries, and emulsifiers are used daily in modern societies and are common surfactant products. Surfactants are surface active agents that can reduce the interfacial tension of the interface. Due to their broad physical and chemical properties, this group of chemicals has a wide range of uses in industries such as personal care products, pharmaceutical, agriculture, food processing, textile, laundry fungicides, pulp and paper processing, paint industries, softeners, antistatic agents, detergents, and metal treatment industries. There are four broad categories of surfactants, namely anionic, cationic, zwitterionic, and nonionic, which are well studied and have growing utilization. The elements present in surfactants can significantly alter the quality of aquatic bodies and the soil. They can also induce a variety of problems in wastewater.

Microbial bioremediation is a successful option for various xenobiotics when applied with efficient microbes in their optimum environment. Furthermore, metabolic activity can transform complex surfactants to simpler forms. This chapter discusses the chemistry of dominant surfactants and their fate in the environment. Some possible bioremediation techniques will then be suggested for a sustainable and healthy environment.

1.1 Introduction

Surfactants are chemicals, more precisely organic substances (e.g., the regular used detergents or soaps, with the capacity to reduce the surface tension of a liquid, and hence facilitate high spreading and wetting properties), that are used for cleaning and softening of fabrics. The presence of one or more hydrophilic and hydrophobic groups enables surfactants to form micelles. The intrusion and dispersion properties of surfactants increase their use, not only in laundry but also in textile and perfume

industries for dye penetration and perfume dispersion. Surfactants are also used as corrosion regulators, ore floaters, oil flow enhancers in porous materials, and aerosol production.

1.1.1 Chemistry of surfactants

Surface active agents that are used to decrease the surface tension of water are termed 'surfactants.' These are chemical compounds with a micelles creating property via self-assembled molecular clusters in a solution. The unique molecular structure of surfactants is responsible for their amphiphilic nature and are comprised of two parts: the first part is made by a water loving hydrophilic group that is soluble in water, such as hydroxyl, carboxyl, amino, and other polar groups; the second part is a lipophilic or hydrophobic group, such as alkyl, aryl, and other non-polar groups, which are water hating in nature and insoluble in water but soluble in lipids or oils. This property facilitates them to concentrate at the interfaces between bodies or droplets of water and hydrophobic substances such as oil or lipids, and perform as an emulsifying or foaming agent (figure 1.1).

On the basis of the nature of the hydrophilic group, surfactants are classified into four types:

- (a) **Anionic surfactants:** Anionic surfactants contain negative charges on their hydrophilic head in solution and are the most commonly used surfactants, which are used in food, pharmaceutical, cosmetic, detergent, and other industries. Anionic functional groups are mainly sulfates (SO_4^{2-}), phosphates (PO_4^{2-}), and carboxylates (RCOO^-). Some examples of anionic surfactants are sulfates, sulfonates, and gluconates, such as Sodium dodecyl sulfate (SDS) $\text{C}_{12}\text{H}_{25}\text{NaO}_4\text{S}$ and Potassium oleate $\text{C}_{18}\text{H}_{33}\text{KO}_2$. They cover 50% of overall industrial production.

Uses

Textile industry: Oiling agents, dyeing auxiliaries, bleaching agents, and soft processing agent.

Pesticides: Spraying agents, emulsifying agents, and dispersants.

Highway: Asphalt emulsifier.

Civil engineering: Water reducing agent for cement.

Petroleum industry: Emulsifiers and fuel additives.

Polymer industry: Emulsifiers and antistatic agents, metal cleaning agents, mining flotation agents, and water treatment agents.

- (b) **Cationic surfactants:** Cationic surfactants contain negative charges on their hydrophilic end. Alkyl ammonium chlorides and Quaternary Ammonium salt (N^+R_4) are common examples of cationic surfactants. Cationic surfactants dissociate to positively charged ions in solution, and are used as fungicides, softeners, and antistatic agents. In general, the dosage of the cationic surfactant is less than that of the anionic surfactants. The hydrophobic group of cationic surfactants is composed of an alkyl group and a functional group containing nitrogen, phosphorus, sulfur, and so on. At present, most industrial cationic surfactants are composed of nitrogenous

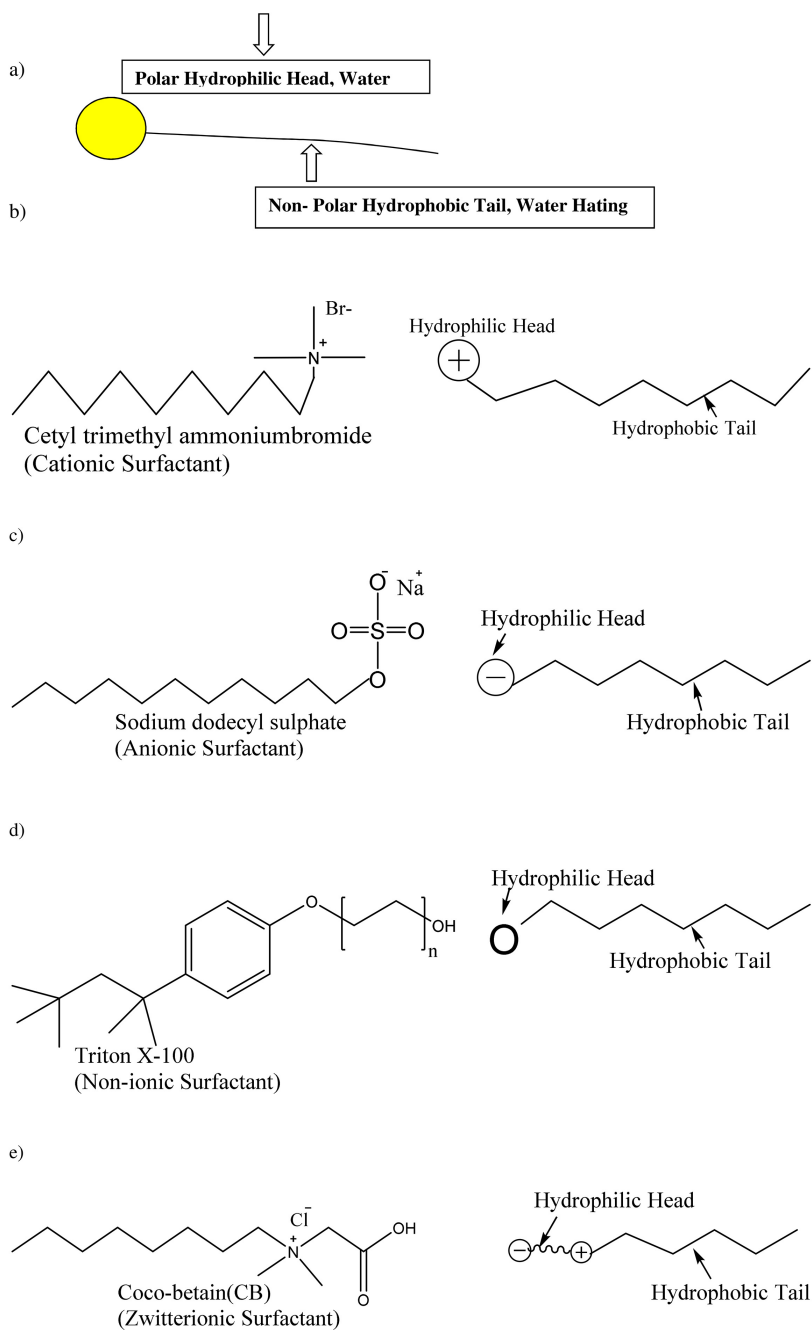


Figure 1.1. (a)–(e) Some examples of the structure of surfactants.

compounds, which are classified into amine, quaternary ammonium, heterocyclic, and rhodium salts. Quaternary ammonium salts (QACs) are widely used in cationic surfactants because of their solubility in both acids and bases. There are four functional groups that attach with a covalent bond to the positively charged central nitrogen atom in QACs. QACs are basically organic compounds. A long hydrophobic alkyl chain is present in functional groups, along with other short chains such as methyl or benzyl groups. The ingredients of ester cationic surfactants include (for example) diethyl ester dimethyl ammonium chloride (DEEDMAC). The QACs are mostly used in pharmaceuticals (antiseptic agents), softeners (fabric softeners), fungicides, preservatives, etc.

- (c) **Nonionic surfactants:** Nonionic surfactants, as the term suggests, are neutral in nature and cannot dissociate in solution to produce ions, they have high stability, and they are the most commonly used type after anionic surfactants. They do not contain any charges on their hydrophilic end. The hydrophilic part possesses covalently bonded oxygen-containing groups such as hydroxyl and ether bonds, which are bonded to hydrophobic parent structures. Nonionic surfactants are less sensitive to water hardness than anionic surfactants. There is no or insignificant effect of acid and alkali on nonionic surfactants, which make them highly suitable for applications in washing, dispersion, foaming, solubilization, and in industries such as food, medicines, textiles, and paints. Examples of nonionic surfactants are ethoxylates, alkoxylates, alkylphenol polyoxyethylene ether (APEO), high carbon aliphatic alcohol polyoxyethylene ether (AEO), fatty acid polyoxyethylene ester (AE), and cocamide. They comprise 45% of overall industrial production, where they are used as wetting agents in coatings, food ingredients, cell staining, DNA extraction, and pharmaceutical experiments. The major ingredients of alkylphenol polyoxyethylene ether (APEO) are octylphenol polyoxyethylene ether and nonylphenol polyoxyethylene ether, composed of a polyoxyethylene chain and an alkyl chain attached to a benzene ring. They are widely used as insecticides, emulsifiers, and solvent enhancers. Other examples are Triton X-100 ($C_{14}H_{22}O(C_2H_4O)_n$ ($n=9-10$)) and Tergitol ($C_{12-14}H_{25-29}O[CH_2CH_2O]_xH$).

Uses:

Textile industry: Cationic surfactants are widely used as fabric softeners, as well as the antistatic agents for chemical fiber oils.

Metal industry: Cationic surfactants are used as metal corrosion inhibitors thanks to their high efficiency, low toxicity, easy production, low price, and the waste liquid can be used as a metal oil cleaning agent and rust remover after cleaning.

Paper industry: Cationic surfactants can improve the strength of paper, and the retention rate of the filler and fine fibers.

Coating industry: Cationic surfactants are mainly to evenly distribute and disperse pigment particles.

Oil industry: Cationic surfactants are used for oil viscosity reduction, oil well fixation, oil pipeline protection and sterilization.

Water purification industry: Cationic surfactants are used to treat domestic sewage and industrial wastewater.

- (d) **Amphoteric surfactants:** These surfactants are also known as zwitterionic surfactants, whose amphoteric properties are independent of pH over a wide pH range. They have both positive and negative charges on their hydrophilic end with a net charge of zero. Betaines and amino oxides are common examples of this type of surfactant. Amphoteric surfactants include amphoteric surfactants (amphoterics) and amphoteric ionic surfactants (zwitterionics). The amphoteric surfactants are comparatively mild surfactants and are used in daily necessities and cosmetics. Nevertheless, the high cost and complex synthesis limits the production of amphoteric surfactants. There are three general types of amphoteric surfactants, namely amino acid amphoteric surfactants, betaine type amphoteric surfactants, and imidazoline surfactants. The cationic part of betaine type amphoteric surfactants is composed of quaternary ammonium salt, which can be divided into carboxylate betaine, sulfobetaine, and phosphate betaine according to different anions. The structure of the betaine type surfactants is based on the substitution of methyl or carboxyl groups of trimethylglycine with different substituents, such as betaines ($C_5H_{11}NO_2$) and amphoacetates ($RC(O)NH(CH_2)_2N(CH_2CH_2OH)CH_2COONa$).

Uses:

These are expensive surfactants and are generally used in cosmetics, shampoos, shower gel, hair conditioners, and toothpaste because of their mildness, safety, and lack of irritating effects on skin and eyes.

The surfactant market is largely dominated by the nonionic surfactants, followed by the anionic surfactants. The cationic surfactants are generally expensive, and hence have a small share of the market. The demands for surfactants are increasing day by day, due to their wide range of domestic and industrial applications in many facets of daily life. Global market data about manufacturing of surfactants shows that surfactant market size was USD 42.1 billion in 2020 and is predicted to will reach to USD 52.4 billion by 2025 because of growing population and awareness about the importance of cleanliness. It is noticeable here that surfactants are an important ingredient in sanitizers and soaps. Frequent use of hand wash and soaps due to COVID-19 led to a nearly ten times increase in demand and production of surfactants and detergents. The brand site EVALED suggests that the formation of 800ppm detergent leads to 20ppm discharge of surfactants into wastewater. Generally, surfactants are present in detergent industry effluents and other industrial effluents. In addition, the residues of surfactants are discharged into the environment, which creates many problems, e.g., they hinder the transfer of oxygen from the atmosphere to the water in the process of aeration and they are accumulated in the body, which can lead to long term problems such as carcinogenicity and loss of fertility.

1.1.2 Toxicity of surfactants

The unique properties and diversified functions of surfactants have led to their widespread use in industries such as textiles, fibers, paints, polymers, plant protection, cosmetics, mining, oil recovery, pulp and paper, agriculture, pharmaceuticals, food, and daily chemicals. Their extensive use is directly related to the increased release of surfactants to the environment at levels that are sufficient to cause detrimental effects to the soil and aquatic ecosystems. A buildup of surfactant compounds in the soil can severely interfere with the structure and functioning of soil microbes, resulting in several harmful effects, e.g., on photosynthesis and damage to the root system of plants. In the case of aquatic organisms, the accumulation of surfactant compounds in the gills and viscera of fishes result in asphyxiation leading to death. Meanwhile, exposure to surfactants in the environment can lead to human diseases such as dermatitis, bronchopulmonary dysplasia, gingivitis and periodontitis, and oral ulcers. In addition, chemical species of surfactants can interact with bodily fluids through the food chain. The metabolites nonionic surfactants APEO are identified as environmental endocrine disruptors that can interfere with normal hormonal function and health status in animals, and are responsible for a decrease in sperm count in males, breast cancer, testicular cancer, and so on. Many surfactants have been shown in experiments to evade the interaction with the protein units involved in immune system, and are hence detrimental to health.

1.2 Treatment of surfactants

In view of the steady accumulation and negative impact of surfactants on the environment and population health, the removal of residual surfactants from the environment or conversion to non-toxic elemental compounds are important tasks. Eliminating surfactants during production or removing residual surfactants are required to maintain the environment and reduce potential health hazards.

The treatment process generally focuses on altering or breaking the structure of harmful compounds in the surfactant with the help of physical–chemical–biological forces into less harmful, elemental, and environmental-friendly compounds. Successful processes for the removal of surfactants from the environment include adsorption, oxidation, electrolysis, electrochemical oxidation, photolysis, sonication, and biodegradation (Berna *et al* 2007, Christopher *et al* 2021).

1.2.1 Physical–chemical process

The small pores in adsorbent materials such as activated carbon, alumina, and silica gels provide effective room for the adsorption and removal of surfactant molecules. The parent material of the activated carbon, and the electrostatic potential of the interface of the adsorbate and adsorbent influence the adsorption efficiency of pollutants (Adak *et al* 2005, Koner *et al* 2012, Siyal *et al* 2020). Strong oxides such as ozone, hydrogen peroxide, and ferric salt are capable of oxidizing surfactant molecules through oxidation reduction reactions dissociating them into non-toxic

and harmless substances. In the Fenton oxidation process, hydrogen peroxide (H_2O_2) and ferrous sulfate (FeSO_4) are employed to form a strong oxidizing agent (hydroxyl radicals), which has high oxidation potential (2.8 V) compared to ozone (2.07 V). Photolysis of UV-excited hydrogen peroxide for oxidation of surfactant, the application of non-toxic and efficient semiconductor TiO_2 , the ultrasonic degradation of surfactant in the presence of high sound pressure, and high temperature and pressure oxidation are used for surfactant removal. Electrolysis treatment is renowned for the efficient mineralization and removal of surfactants due to the application of strong oxidizing substances produced on the surface of the electrodes, such as PbO_2 and boron-doped diamond (BDD). For example, galvanostatic electrolysis using a Ti–Ru–Sn ternary oxide and a BDD anode for sodium dodecyl benzene sulfonate and car wash wastewater; and porous graphite as anode and cathode, with the effective $\text{CuO-Co}_2\text{O}_3\text{-PO}_4^{3-}$ modified kaolin catalyst in a single undivided cell provided efficient anionic surfactant removal.

Though effective treatment results are achieved, oxidation, photocatalytic, and electrochemical treatment are relatively costly methods and either require secondary waste handling or consume more energy, and some of the processes with no secondary waste are associated with low treatment rate.

1.2.2 Bioremediation

Bioremediation involves mechanisms such as biosorption, biodegradation, bioaccumulation, and bioleaching for pollutant removal. Bioremediation includes phytoremediation (rhizodegradation, phytoextraction, phytovolatilization, phytodegradation, rhizofiltration, and rhizostabilization), mycoremediation, microbial remediation (bacteria, fungi, and microalgae), and phyco-remediation.

In biosorption, and bioaccumulation, pollutants are immobilized inside or outside a microbial cell equipped with extracellular polysaccharide substances (EPS) and through the secretion of various organic acids. Similarly, bioleaching involves numerous organic acids and enzyme secretions for pollutant extraction and processing according to the properties of the pollutants and the microbes. The biodegradation of surfactants biodegradation agents that derive their required life sustaining energy and nutrients from dissociating the chemical bonds in the surfactants while converting the latter to non-toxic elements. Biodegradation is highly prominent in the case of microbial, algae, and a few plant species (phytoremediation). Biotic and abiotic factors of the environment play a key role in the bioremediation technique. Biotic factors incorporate genetic and enzymatic molecules and properties that govern the physical and functional interactions of organisms and surfactants. Cell wall component orientation and secretion of specific enzymes, organic acids, EPS, and formation of biofilm are principal features that influence the performance efficiency of biotic factors. The abiotic factors mainly include temperature, pH, moisture, and bioavailability of surfactants together with nutrients ratios. Electron acceptors, mostly oxygen in aerobic biodegradation and nitrate/sulfate in anoxic conditions, significantly influence treatment efficiency.

In this chapter, the microbial process is emphasized for surfactant biodegradation. A number of microbes, which are tiny unicellular organisms associated with biodegradation, form a heterogeneous colony or mixed culture of different species in nature. In complete treatment, the mineralization of surfactants to carbon dioxide and water occurs via microbial metabolism, which is a factor of species involved in the biodegradation, environmental conditions, and property of the surfactants to be removed. A few frequently noted microbial species for surfactant biodegradation are *Acinetobacter*, *Aeromonas*, *Comamonas*, *Dechloromonas*, *Desulfovibrio*, *Geobacter*, *Holophaga*, *Parvibaculum*, *Pseudomonas*, *Sporomusa*, *Stenotrophomonas*, *Variovorax*, and *Zoogloea*.

Owing to the complex chemical structure of surfactants, degradation may follow a series of phases where the initial or parent surfactant compound is changed while losing its original structure, and hence surface activation properties. These intermediates are then processed by another group of microbes for rapid and complete mineralization, resulting in water, CO₂, mineral salt, and other inorganic substances, while avoiding secondary pollution.

The dissociation property of polar group defines the classification of surfactants as cationic, nonionic, and amphoteric, while the hydrophobic group determines the biodegradability to a great extent. It is also common to note that different surfactants have utterly different biodegradability.

1.3 Biodegradation mechanism of surfactants

The prominent ways to degrade surfactants with microorganisms are ω -oxidation, β -oxidation, α -oxidation, and benzene ring oxidation under the catalysis reactions of various enzymes. The microbes consider the pollutants (here surfactants) as a carbon source for their survival. In ω -oxidation, terminal alcohol is generated from alkyl chains via ω -oxidation in the presence of alkane monooxygenase. This is followed by sequential production of terminal aldehyde and the carboxylic acid in the presence of two kinds of dehydrogenases enzymes.

In the case of β -oxidation, the carboxyl groups generated by ω -oxidation of the alkyl chain influence β -oxidation in continuation of degradation of the alkyl chain. The significant enzymes are coenzyme A, dehydrogenase, and hydrolytic enzyme.

Benzene ring oxidation, especially the links, is considered as the speed control step of surfactants containing benzene rings. The most influential enzyme is oxygenase. The intermediates are catechol, hexadiene diacid, acetic acid, succinic acid, 2-hydroxyhexadiene semialdehyde acid, and finally formic acid, acetaldehyde, and pyruvic acid.

1.3.1 Bioremediation of anionic surfactants

The common anionic surfactants are linear alkylbenzene sulfonate (LAS), alkyl sulfonate (AS), and alcohol ether sulfate. LAS is a widely used surfactant, comprised of 20 or more homologues isomers and accounts for more than quarter share among the synthetic surfactants. The toxicity of LAS is generally mild and shows no accumulation in organisms. The biodegradation of LAS is highly efficient at all of the basic environment of anaerobic/aerobic or facultative conditions and relevant to

its molecular structure for biodegradation. In anaerobic and aerobic conditions, LAS follows a degradation pathway with aromatic ring cleavage, desulfonation, beoxidation reactions, and ueoxidation reactions. The existing distance of the benzene ring with the central carbon atom determines the stability of the structure, i.e., when the distance is larger, there is more instability in the structure, which comprises the feasibility of degradation. The degradation of LAS by microorganisms is initiated by the breakdown of alkyl chain, which results in the generation of carboxylic acid by ω -oxidation of the terminal methyl group. This is followed by formation of acetyl-coenzyme A through β -oxidation, and hence enters the tricarboxylic acid cycle releasing CO_2 and mineral salts, which are the final products of the benzene rings. Owing to the complexity of the degradation of the benzene ring, it is regarded as the rate limiting element of LAS biodegradation. The literature recognizes more than 47 genera of microbes that are capable of LAS degradation, with almost 30 genera that are capable of aromatic ring cleavage, often denoted as aromatic compounds degraders. Desulfonation reactions are achieved by the species of seven genera, namely *Achromobacter*, *Acinetobacter*, *Aeromonas*, *Comamonas*, *Desulfovibrio*, *Hydrogenophaga* and *Pseudomonas*, and species of five prominent genera, namely *Geobacter*, *Magnetospirillum*, *Parvibaculum*, *Pseudomonas* and *Synergistes*, which are recognized for beoxidation reactions. *Parvibaculum* and *Pseudomonas* genera includes a few species that are capable of ueoxidation reactions. Several microbes from *Acinetobacter*, *Aeromonas*, *Comamonas*, *Dechloromonas*, *Desulfovibrio*, *Geobacter*, *Holophaga*, *Pseudomonas*, *Sporomusa*, *Stenotrophomonas*, *Variovorax* and *Zoogloea* genera are recognized for LAS degradation (Okada *et al* 2014). Aerobic treatment systems include a supply of molecular oxygen. The activated sludge process can provide more than 90% or even complete removal of LAS. Similarly, anaerobic processes (absence of oxygen) in the upflow anaerobic sludge blanket also exhibit very efficient treatment efficiency for LAS. A few significant strains that are capable of degrading LAS are *Pseudomonas nitroreducens*, *Pseudomonas aeruginosa*, *Pantoea agglomerans*, and *Serratia odorifera* 2. Each strain has specific preferences for degradation conditions, and hence exhibit different degradation times and rates. Therefore, achieving successful treatment depends on the selection of efficient species and the provision of their favorable conditions.

A few more of the commonly utilized anionic surfactants, namely AS and SDS, are also swiftly biodegradable. The biodegradation of AS is accomplished by devulcanization of sulfate esterase and β -oxidation of aliphatic alcohols. *Pseudomonas putida* R1, *Acinetobacter calcoaceticus*, and *Pantoea agglomerans* can completely degrade SDS into water and carbon dioxide by microorganisms.

1.3.2 Cationic surfactants

In the biodegradation of cationic surfactants, QACs are governed by the molecular structure of the same, the concentration of the surfactants, and the resistance of microorganisms to the surfactants. During QAC degradation, microbes generally follow three distinct pathways depending on the strain and surfactant, initiated with

the hydroxylation of the alkyl chain, and then goes through ω -oxidation and β -oxidation, which results in acetyl coenzyme A for the tricarboxylic acid cycle. In the second pathway, there is partial hydroxylation of alkyl chain, which is trailed with partial cleavage of the C-N bond under the action of the enzyme, and finally the degradation is completed by β -oxidation. In the third pathway of cationic surfactant degradation, hydroxylation long chain alkyl is accompanied with demethylation of methyl carbon. A few QAC degradation efficient strains are *Pseudomonas* sp., *Xanthomonas* sp., *Thalassospira* sp., and *Aeromonas* sp. The strong germicidal effect and soothing absorbance of QACs in the sediment, minerals, or organic matter with positive charge in wastewater makes biodegradation more challenging.

1.3.3 Nonionic surfactants

The length and complexity of the alkyl chain, and the number of elements in the benzene ring and polyoxyethylene chain mostly influence the biodegradation of APEO, which is an ideal nonionic surfactant. The branched chain structure and higher units in polyoxyethylene chain add to the difficulties of biodegradation. Microorganisms break the long chains to short polyoxyethylene chains, octylphenol, and nonylphenol. The higher toxicity of the intermediates/metabolites, such as octylphenol and nonylphenol, than the parent compound APEO demand complete biodegradation. A few strains efficient in degradation of APEO are *Pseudomonas* sp., *Moraxella osloensis*, *Cupriavidus* sp., and *Brevibacterium* sp. TX4. Oxidation of terminal hydroxyl group, a single unit of polyoxyethylene chain, to carboxylic acid is followed by its removal, which is the initiation of APEO biodegradation.

Alkylphenols are highly resistant to microbial degradation. Two different mechanisms are recognized by different microorganisms to degrade it. The first mechanism includes hydroxylation under the action of microbial enzymes, resulting in cleavage of alkyl chains and phenols, followed by subsequent degradation by microorganisms. The second mechanism includes formation of alkyl catechol through phenol hydroxylase, followed by the cleavage of an aromatic ring by the action of dioxygenase, which is readily biodegradable.

The higher toxicity of the intermediates generated from APEO result in a gradual decrease or banning and increasing demand of aliphatic alcohol polyoxyethylene ether (AEO). AEO consists of numerous congeners, containing an alkyl chain of 12–18 carbon atoms connected to a polyoxyethylene chain of different unit count, which is widely used in decontamination, cleaning, care, and other industries. Strains such as *Pseudomonas aeruginosa*, *Pseudomonas stutzeri*, and *Flavobacterium* sp. are able to degrade AEO, where initially the ether bonds between the alkyl chain and the polyoxyethylene chain are broken to generate fatty acids and polyethylene glycols, and a few other metabolites for degradation.

1.3.4 Amphoteric surfactants

Betaine type surfactants are relatively easy to biodegrade and their primary biodegradation rate can reach 100%. Strains capable of degrading betaine surfactants include *Desulfobacterium*, *Eubacterium limosum*, and *Sporomusa ovata*.

1.4 Factors affecting the biodegradation of surfactants

The length and branching degree of alkyl chains, the chemical structures of surfactants, along with the number of units of polymers, benzene rings, and their location specifically govern the biodegradability of a surfactant. In addition, the type and population strength, as well as diversity highly influence biodegradation. High adaptability, mixed culture, or high diversity are favored for high degradation of surfactants in favorable environmental conditions.

1.5 Conclusions

Surfactants have many uses, such as domestic cleaners and soap, and in the pharmaceutical, agricultural, food, medicine, and other industries. Despite their use for hygiene and as detergents, the complex structure of surfactants can cause them to become toxic in the environment when they buildup. Fortunately, there are efficient treatment processes to handle waste surfactants. Bioremediation can overcome the drawbacks of these processes, such as generation of secondary waste generation, in physical-chemical processes and is facilitated by numerous microorganisms equipped with different types of cellular molecules and enzymes that are specifically required for breaking the chemical bonds in surfactants. Microbes follow different pathways for biodegradation for different surfactants, as well as type of microbes. Nature has many microbes whose potential is yet to be recognized, and many pollutants and chemicals are released everyday whose removal and degradation is yet to be understood. Therefore, analysis by biologists, bioinformaticians, and chemists will help to develop solutions for these environmental hazards.

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Chapter 15

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