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Research review of antibacterial surfactants

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Abstract:

The COVID-19 outbreak a pandemic since 11 March 2020, drastic measures to stop the spread of the pandemic have been carried out around the world. Since then, many people have paid more attention to hygiene as well as antibacterial. There are a large number of microorganisms in nature, which have great harm to people, animals, and plants, affecting people's health and even threatening life. Nowadays, there has been growing interest in antimicrobial surfactants, and many investigators have recently turned to studying antibacterial surfactants. However, medical disinfection can be irritating to human skin and have other disadvantages. In this review, I provide a summary of the current state of the research on different antibacterial surfactants.

Keywords: antibacterial; surfactants; antibacterial mechanisms; safe

1. Introduction

With the rapid advancement of technology and the comprehensive progress of society, the standard of living for individuals has been steadily increasing, as has the awareness of health. Consequently, there is a heightened demand for improved working and living environments. The environment in which humans exist is teeming with a multitude of microorganisms: minute entities visible only under a microscope, including bacteria, fungi, viruses, certain protozoa, and algae. [1]

The prevalent method of disinfection currently employed is chemical disinfection, which, however, has its inherent limitations: (1) Development of Drug Resistance: The overuse or misuse of chemical disinfectants may lead to the development of drug resistance in microorganisms, thereby reducing the effectiveness of disinfection. (2) Environmental Impact: Certain chemical disinfectants may harm the environment, potentially generating toxic by-products during the disinfection process, which can harm the ecosystem. (3) Corrosiveness: Some disinfectants may exhibit corrosive properties towards materials such as metals and plastics, thereby limiting their scope of application. (4) Residue Issues: The use of chemical disinfectants may leave residues on surfaces, which could pose potential risks to human health or the environment. (5) Limited Efficacy: Certain disinfectants may not be effective against specific types of microorganisms, for instance, some disinfectants have limited efficacy in killing bacterial spores. (6) Skin Irritation and Allergy: Some disinfectants may cause skin irritation and could even lead to allergic reactions. Therefore, the development of effective antimicrobial surfactants can significantly reduce the risk of cross-infection among family members in daily life.

2. Different Mixed Surfactant Systems

2.1 Biosurfactant-mediated Synthesis of Silver Nanoparticles

Silver nanoparticles (Ag NPs) exhibit a strong and broad-spectrum antibacterial activity and are widely used in the medical and pharmaceutical industries. There are a great many kinds of used silver states: (1) liquid, this element exists in aqueous solution; (2) non-nanomaterials, the particle size larger than 100 nm; (3) silver ions, the silver ions should be attached to or imbed in the inert carrier as silver compounds or silver salts, like graphite or cisplatin; (4) metallic silver, like colloidal silver or Nanosilver, the particles size smaller than 100 nm. Silver has a stronger pathogen-killing capability than other metals, it can kill 650 kinds of bacteria, fungi, and viruses.

The antibacterial mechanism of silver was achieved by damaging their cell membranes and respiratory functions and disrupting DNA structure. [2]

2.1.1 Antibacterial activity

Biological surfactants possess a certain level of antimicrobial activity but often require higher concentrations to be effective. In contrast, silver nanoparticles (Ag NPs) synthesized using biological surfactants exhibit good antimicrobial efficacy at lower concentrations and demonstrate inhibitory effects against Gram-positive and Gram-nega-

tive bacteria, making them a broad-spectrum antimicrobial material.

2.1.2 Antibacterial mechanisms

In general, due to their small size, nanoparticles possess a larger surface area-to-volume ratio compared to other silver salts and even silver particles. Consequently, they can interact with the cell membrane or penetrate it to enter the interior of bacterial cells, leading to leakage of intracellular contents and ultimately cell death. This is considered the fundamental mechanism of the antimicrobial action of metallic nanoparticles.

The affinity of Ag nanoparticles (Ag NPs) for bacterial cell membranes results in the loss of catalytic activity of the respiratory chain dehydrogenases. Moreover, Ag NPs can interact directly with the bacterial cell surface without the need for penetration, thereby altering the activity of membrane transport.

The bactericidal mechanism of this experiment involves adsorption onto the surface of the bacteria, interaction with the cell membrane, increasing membrane permeability, and subsequently leading to cell membrane destruction and cell death. Nanosilver particles synthesized using bio-surfactants indicate that lipopeptide-stabilized Ag NPs may have excellent potential applications in the medical field. [3]

2.2 The Dopant Nano-zinc Oxide

Nanosilver-doped inorganic antimicrobial materials, a subset of inorganic antimicrobial agents, have garnered extensive research attention. Zinc oxide nanoparticles exhibit photocatalytic antimicrobial activity only under ultraviolet irradiation, which to some extent, limits their broad application. Doping methods can be employed to endow them with effective antimicrobial properties in the visible light region.

2.2.1 Antibacterial activity

Under the condition of identical bacterial strains selected in the experiment, the minimum inhibitory concentrations (MICs) of Ag-Ce-ZnO and Ag-ZnO samples treated with the surfactant PAAS are both less than those treated with the surfactant SDBS. Under the same surfactant treatment, the relationship between the inhibitory concentrations of single-doped and double-doped samples is: Ag-Ce-ZnO < Ag-ZnO. It can be deduced that the photocatalytic antibacterial ability of the samples is as follows: double-doped samples are stronger than single-doped samples, and PAAS dispersion is superior to SDBS dispersion. [4]

The double-doped nano zinc oxide exhibits stronger photocatalytic performance and antibacterial properties. After dispersion treatment with PAAS, its excellent performance is further enhanced, offering broad prospects for its applications in various fields. The spectrophotometric method for detecting free radicals in the system is highly sensitive and easy to operate, providing new avenues for the clinical and laboratory detection of free radicals.

2.2.2 Antibacterial mechanisms

Photocatalytic Antimicrobial Mechanism: Under illumination, nanoscale zinc oxide generates electrons and holes. The holes capture hydroxyl electrons from the environment to form hydroxyl radicals. These radicals possess strong oxidizing properties, capable of degrading organic matter within microorganisms and disrupting the reproductive capacity of bacterial cells. Contact Antimicrobial Mechanism: Upon contact with bacterial cells, nanoparticles can disrupt the structure of the bacterial cell membrane, leading to a loss of cellular vitality. Release of Zinc Ions: Nanoscale zinc oxide dissolves in water to release zinc ions. These ions exhibit redox properties and can interact with bacterial cell membranes, achieving antimicrobial effects.

2.3 Gemini Surfactants

Gemini surfactants are a novel class of surfactants characterized by the presence of two hydrophilic groups, two hydrophobic chains, and a linking group. Compared to traditional surfactants, Gemini surfactants exhibit a lower critical micelle concentration (CMC), enhanced surface activity, and an efficient reduction in the surface tension of water as well as the interfacial tension between oil and water, coupled with good aqueous solubility. The application of Gemini surfactants is extensive, ranging from antimicrobial and sterilization processes to food production, defoaming and foam control, controlled release of pharmaceuticals, and industrial cleaning. They play a significantly positive role in advancing societal, economic, and industrial progress. [5]

2.3.1 Antibacterial activity

The antimicrobial activity of Gemini surfactants can be categorized into the following four types.

Anionic Gemini Surfactants: The bactericidal mechanism of anionic surfactants is fundamentally different from that of cationic surfactants. The antimicrobial effect of anionic surfactants is related to their solution system and the bacteriostatic groups. Therefore, this type of surfactant is subject to limitations. These surfactants must reach a sufficient concentration to ensure their presence in every part of the system to exert an effective microbicidal action. Moreover, the bactericidal action of this type of surfactant lacks specificity and targeting, leading not only to unnecessary waste but also to the development of drug resistance with prolonged use.

Cationic Gemini Surfactants: The primary type of cationic

gemini surfactants developed is the quaternary ammonium type. Quaternary ammonium gemini surfactants possess strong bactericidal properties due to the presence of two hydrophobic long alkyl chains in their molecules, which form hydrophobic adsorption with the cell wall (peptidoglycan). Additionally, they contain two positively charged nitrogen ions, facilitating the adsorption of surfactant molecules onto the negatively charged bacterial surface. Through permeation and diffusion, their hydrophobic chains penetrate the lipid layer of the bacterial cell membrane, altering its permeability and leading to cell rupture. Furthermore, the hydrophilic groups penetrate proteins, causing enzymes to lose activity and proteins to denature. The combined effect of these actions endows the disinfectant with a potent bactericidal capability. [7]

Nonionic Gemini Surfactants: There are currently two types of nonionic gemini surfactants, one being the derivatives of sugars and the other being alcohol ethers and phenol ethers. The antimicrobial mechanism of sugar-derived gemini surfactants relies on molecular affinity; they can bind to the cell membrane, which contains a large amount of phospholipids. When the concentration of sugar-derived surfactants reaches a certain level, they alter the membrane permeability, forming pores and ion channels that affect the transport of nutrients and gas exchange, leading to the outflow of contents and ultimately causing cell death.

Amphoteric Gemini Surfactants: Amphoteric gemini surfactants can dissociate into anionic and cationic groups in aqueous solutions. They overcome the shortcomings of a single hydrophilic group by introducing two different hydrophilic groups into one surfactant. They possess extremely low critical micelle concentrations (CMC), good solubility, antimicrobial properties, excellent calcium soap dispersibility, and minimal irritancy. However, their synthesis is complex and challenging, and they are primarily applied in the fields of medicine and cosmetics.[8]

2.3.2 Antibacterial mechanisms

As a type of organic antimicrobial agent, the antimicrobial mechanism of Gemini surfactants primarily involves their combination with anionic sites on the surface of microbial cell membranes or their reaction with thiol groups, disrupting the synthesis of proteins and cell membranes, thereby damaging microbial tissues to inhibit or kill microorganisms. In addition, there are the following antimicrobial mechanisms: (1) Electrostatic Adsorption: The cationic head groups of Gemini surfactants adsorb onto the negatively charged surface of the microorganisms through electrostatic interactions. (2) Hydrophobic Adsorption: The hydrophobic chains interact with the hydrophobic regions of the cell wall or cell membrane, leading to the disruption of the cell membrane. (3) Cell Membrane Disruption: After penetrating the cell, the hydrophobic chains of Gemini surfactants can intercalate into the cell membrane, altering its permeability, causing leakage of cellular contents, and ultimately leading to the death of the microorganism. (4) Protein Denaturation: The hydrophilic groups may penetrate the proteins within the cell, causing enzyme inactivation and protein denaturation.

2.4 Chitosan And Its Combinations With Surfactants

Chitosan is a binary linear polymer connected by β-(1→4) glycosidic bonds between 2-acetamido-2-deoxy-D-glucose and 2-amino-2-deoxy-D-glucose. Due to its functions such as antimicrobial activity, anti-tumor properties, and immune enhancement, as well as its non-toxic, degradable, and renewable characteristics, it has attracted considerable attention as an antimicrobial agent. Chitosan and its derivatives can inhibit the growth of a variety of bacteria and fungi. Research results indicate that chitosan has a certain degree of inhibitory effect on the 15 tested plant pathogenic fungi. Chitosan exhibits varying degrees of inhibitory effects on Escherichia coli, Staphylococcus aureus, Bacillus subtilis, Streptococcus, and actinomycetes, among others.

2.4.1 Antibacterial activity

Antimicrobial Activity Determination Method: The antimicrobial activity of chitosan and its derivatives against a variety of bacteria and fungi is assessed using solid plate and liquid culture methods. The determination includes the measurement of the minimum inhibitory concentration (MIC), the duration of inhibition, the rate of inhibition, and the short-term bactericidal effect. Antimicrobial Results: Chitosan and its complexes exhibit significant antimicrobial activity against Gram-positive bacteria (such as Staphylococcus aureus, epidermis Staphylococcus) and Gram-negative bacteria (such as Escherichia coli, Pseudomonas aeruginosa). Chitosan-surfactant complexes are capable of inhibiting Candida albicans, which chitosan alone cannot, thus broadening the antimicrobial spectrum.

2.4.2 Antibacterial mechanisms

For S. aureus, there are two mechanisms: first, for cells in the division phase or newly formed tender cells, chitosan may inhibit the formation of new cell walls and damage the cell membrane at the division site, causing it to rupture, with the contents flowing out, leading to cell death. Second, for mature cells not in the division phase, chitosan only accumulates on the surface; these cells are difficult to kill in a short time and maybe inhibited in their growth and reproduction by suppressing the absorption of nutrients, eventually leading to apoptosis.

Mechanism of Antimicrobial Action of Chitosan-Surfactant Complexes: Chitosan and surfactant complexes form dynamic conjugates through electrostatic and hydrogen bonding interactions, with chitosan molecular chains tending to extend, increasing the contact area with the cell membrane. The long-chain alkyl groups of the surfactant tend to penetrate the hydrophobic interior of the cell membrane, pulling chitosan towards the phosphate groups of phospholipids, enhancing the interaction between chitosan and phospholipids and destroying the integrity of the cell membrane. The antimicrobial activity of this dynamic conjugate is enhanced, making the cell membrane more susceptible to destruction, leading to bacterial death. The interaction between chitosan and surfactants has a significant impact on the antimicrobial activity of their dynamic conjugates. If the interaction is too weak, it cannot effectively pull chitosan molecules to the surface of the cell membrane; if it is too strong, chitosan cannot "shed" the surfactant in time to interact effectively with the cell membrane phospholipids, thereby destroying the cell membrane.

3. Summary

This article summarizes the synthetic methods for the combination of some antimicrobial substances with surfactants, which mainly involves mixing the antimicrobial substances with surfactants by stirring. In addition, the characterization of the resulting mixed system, as well as its antimicrobial activity and mechanism, are also discussed. The prepared mixed system that possesses both washing and sterilizing functions can be used to kill bacteria and viruses in daily life. In the future development of antimicrobial surfactants, people can continuously attempt to combine more antimicrobial substances with surfactants to develop safer and more effective antimicrobial surfactants.

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