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Role of amino acids/nanoparticles on properties of surfactant: A review

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Abstract

Surfactants reduce surface tension due to their amphiphilic structure and play a vital role in chemical, biological, and industrial applications. Their interactions with amino acids depend on factors such as pH, temperature, cosolvents, and chain length, influencing micellization and thermodynamic behavior. Furthermore, surfactant–nanoparticle interactions modify surface activity through electrostatic and hydrophobic adsorption, altering interfacial properties and stability for applications in nanofluids, foams, and enhanced oil recovery.

Keywords: Surfactant; Amino acid; Nanoparticles; Interaction

1. Introduction

1.1. Surfactant

A surfactant, also known as a surface-active agent, is a substance similar to a detergent that, when dissolved in a liquid, reduces surface tension and enhances the liquid's ability to spread and wet surfaces [1-6]. Surfactant molecules consist of two or more chemically distinct regions: one that is compatible with the surrounding solvent and another that is incompatible. Consequently, surfactants possess at least two functional groups with differing affinities within the same molecular structure. Typically, surfactant molecules contain one or more alkyl chains comprising approximately 8–22 carbon atoms.

Due to their amphiphilic nature, surfactants preferentially adsorb at interfaces, where they achieve a thermodynamically favorable state. For example, at the air–water interface, surfactant molecules orient themselves such that the hydrophilic head groups remain in the aqueous phase, while the hydrophobic hydrocarbon chains extend toward the gaseous phase. This dual affinity enables surfactants to act as mediators between immiscible phases, thereby significantly reducing interfacial tension [7-16].

The physicochemical properties of surfactants undergo abrupt changes beyond a characteristic concentration, distinguishing them from electrolytes and non-amphipathic molecules. Above this threshold, surfactant molecules aggregate to form micelles; this concentration is referred to as the critical micelle concentration (CMC).

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Table 1 Types of surfactant

Type of Surfactant	Charge on Head Group	Key Characteristics	One Example
Anionic	Negative (–)	Good detergency and foaming; commonly used in soaps and laundry detergents	Sodium dodecyl sulfate (SDS)
Cationic	Positive (+)	Antimicrobial and fabric-softening properties; low detergency	Cetyltrimethylammonium bromide (CTAB)
Nonionic	No charge	Mild, stable over wide pH and temperature ranges; good wetting ability	Alcohol ethoxylate
Zwitterionic (Amphoteric)	Both + and –	Very mild; good compatibility with skin and other surfactants	Cocamidopropyl betaine

2. Amino Acids

In aqueous solutions at approximately pH 7, amino acids predominantly exist as dipolar ions (zwitterions), exhibiting distinctive hydration behavior that is closely associated with essential biological processes [17-25]. Consequently, investigations of amino acids, peptides, and proteins are considered crucial for elucidating the role of dipolar ions in living systems. Although previous studies have examined the effects of temperature and pressure on the hydration of dipolar ions, such investigations remain relatively limited and warrant further exploration to achieve a more comprehensive understanding. In aqueous media, amino acids can also behave as acids or bases depending on the pH of the solution; therefore, knowledge of their acid–base properties is fundamental to understanding many protein characteristics. Moreover, thermodynamic and viscometric studies of these model compounds in aqueous solutions provide valuable insights into solute–solvent and solute–solute interactions, which in turn contribute to a better understanding of biochemical phenomena such as protein hydration, denaturation, and aggregation.

3. Nanoparticles

Nanotechnology has been an established field of scientific research since the latter half of the twentieth century. The concept was first introduced by Nobel laureate Richard P. Feynman in his seminal 1959 lecture, *"There's Plenty of Room at the Bottom,"* which laid the foundation for future advancements in nanoscale science and engineering. Since then, nanotechnology has led to numerous revolutionary developments, particularly in the synthesis and application of materials at the nanoscale. Nanomaterials encompass a wide range of substances, among which nanoparticles (NPs) represent a prominent class. Nanoparticles are particulate materials that possess at least one dimension smaller than 100 nm [26-30]. Based on their structural geometry, these materials can be classified as zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), or three-dimensional (3D). The significance of nanoparticles became evident when researchers discovered that reducing material size to the nanoscale can markedly alter physicochemical properties, such as optical, electrical, and catalytic behavior. Owing to their exceptionally high surface area-to-volume ratio, nanoparticles exhibit properties distinct from their bulk counterparts, enabling diverse applications in fields including medicine (e.g., drug delivery and biomedical imaging), electronics, environmental remediation, and catalysis. As such, nanoparticles serve as a critical link between bulk materials and atomic or molecular structures.

4. Interaction of amino acid with surfactant

Amino acid–surfactant interactions have attracted considerable research interest due to their enhanced effectiveness in chemical, biological, household, and industrial applications. These interactions have been extensively studied by researchers in both past and recent decades because of their broad applicability and significant relevance. Several studies have examined the influence of factors such as cosolvents, temperature, pH, and surfactant chain length on critical micelle concentration (CMC), molecular structure, binding behavior, and associated thermodynamic parameters [31,32]. Amino acids, dipeptides, and surfactants interact primarily through ionic–ionic and ionic–hydrophilic forces, while hydrophobic–hydrophobic interactions occur between the nonpolar tail of the surfactant and hydrophobic regions of amino acids. With increasing surfactant concentration, hydrophobic interactions become more dominant. At low pH, amino acids exist predominantly in a cationic form, whereas at higher pH values they generally behave as zwitterions. When the solution pH is below the isoelectric point, amino acids carry a net positive charge and exhibit strong binding with oppositely charged surfactants. Overall, amino acid–surfactant interactions are mainly hydrophobic

when both species possess the same charge, but involve both hydrophobic and electrostatic contributions when they carry opposite charges.

5. Nanoparticle surfactant interaction

Interactions between surfactants and nanoparticles can significantly influence the surface activity of surfactants. Strong attractions between the molecules can lead to the formation of multiple surfactant-nanoparticle layers. These interactions typically involve the adsorption of surfactants onto nanoparticle surfaces through electrostatic or hydrophobic forces, which in turn affect their stability, assembly, and interfacial properties, such as interfacial tension. Factors like concentration ratios, pH, and temperature govern these interactions, resulting in effects such as nanoparticle coating, multilayer complex formation, or synergistic behavior in systems including nanofluids, foams, and enhanced oil recovery, thereby altering their functional performance in various applications [33, 34,35].

6. Conclusion

In conclusion, surfactants, due to their amphiphilic structure, play a crucial role in reducing surface tension and enhancing wetting, with broad applications across chemical, biological, household, and industrial fields. Their interactions with amino acids are governed by factors such as pH, temperature, cosolvents, and chain length, influencing micellization, binding, and thermodynamic behavior. Similarly, surfactant–nanoparticle interactions significantly alter surface activity, stability, and interfacial properties through electrostatic and hydrophobic forces, leading to multilayer formation and synergistic effects. Understanding these interactions is essential for optimizing systems such as nanofluids, foams, and enhanced oil recovery, highlighting their importance in advanced material and process design.

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