Surfactants in corrosion cleaning products

Površinski aktivne materije u sredstvima za uklanjanje korozije

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Abstract

Surfactants are indispensable components in modern cleaning and corrosion control formulations. Their amphiphilic molecular structures allow them to interact simultaneously with hydrophobic contaminants and metal surfaces, providing cleaning, wetting, emulsifying, and corrosion-inhibiting functions. The selection of surfactant type, concentration, and synergistic additives determines both the cleaning efficiency and the degree of surface protection. This paper reviews the fundamental mechanisms of surfactant action in corrosion and cleaning products, discusses structure–property relationships, and summarizes current trends in environmentally friendly and multifunctional surfactant systems.
Keywords: *surfactants; corrosion; cleaning products; acid cleaners*

Izvod

Površinski aktivne materije (surfaktanti) predstavljaju neizostavne komponente savremenih formulacija za čišćenje i kontrolu korozije. Njihova amfifilna molekulska struktura omogućava istovremenu interakciju sa hidrofobnim nečistoćama i metalnim površinama, čime obezbeđuju efekte čišćenja, kvašenja, emulgovanja i inhibicije korozije. Izbor tipa surfaktanta, njegove koncentracije i prisustvo sinergističkih aditiva određuju i efikasnost čišćenja i stepen zaštite površine. U ovom radu analiziraju se osnovni mehanizmi delovanja surfaktanata u proizvodima namenjenim čišćenju i zaštiti od korozije, razmatraju se relacije između strukture i svojstava, kao i savremeni trendovi u razvoju ekološki prihvatljivih i multifunkcionalnih sistema površinski aktivnih materija.
Ključne reči: *surfaktanti; korozija; proizvodi za čišćenje; kisela sredstva za čišćenje*

Introduction

Corrosion and surface contamination represent major challenges in industrial maintenance, transportation, and household cleaning. The global market for industrial and institutional cleaners exceeds 50 billion USD annually, with surfactants comprising up to 30% of the total formulation cost. In addition to their cleaning role, surfactants influence corrosion by altering interfacial properties, forming protective films, and mediating the adsorption of inhibitors on metallic substrates.

Surfactants are amphiphilic molecules consisting of a hydrophilic head group (ionic or nonionic) and a hydrophobic tail (alkyl or aryl chain). This dual nature enables them to adsorb at solid–liquid interfaces, lower surface tension, and promote emulsification of soils and oils. Depending on their charge, surfactants are classified as anionic, cationic, nonionic, or amphoteric. Each class exhibits specific behavior toward metal surfaces and corrosion mechanisms.

Mechanism of Action in Cleaning Formulations

The cleaning process involves several concurrent phenomena: wetting of the solid surface, penetration of the contaminant layer, emulsification or solubilization of oily soils, and suspension of particles to prevent redeposition.

Anionic surfactants, such as linear alkylbenzene sulfonates (LAS) or alkyl sulfates, are widely used for their strong detergency and foaming properties. They provide excellent removal of organic soils but may increase corrosion rates on aluminum and mild steel if used without inhibitors.
Nonionic surfactants—such as alcohol ethoxylates, amine oxides, and alkylpolyglucosides (APG)—exhibit lower critical micelle concentrations (CMC) and are less sensitive to water hardness. Their mildness and compatibility with corrosion inhibitors make them preferred for neutral or mildly alkaline cleaning formulations.
Amphoteric surfactants, e.g., cocamidopropyl betaine, adjust their charge with pH and can improve both cleaning and anticorrosion properties through synergistic adsorption on metal surfaces.

Surfactants and Corrosion Mechanisms

Corrosion is an electrochemical process involving oxidation of metals and reduction of oxidizing species such as oxygen, hydrogen ions, or water. Surfactants can significantly modify these reactions by forming adsorbed films on metallic surfaces, altering surface charge, and changing the local environment at the metal/electrolyte interface.
The adsorption of surfactant molecules follows classical Langmuir or Temkin isotherms, depending on molecular orientation and surface coverage. The hydrophilic head group interacts with the metal surface through electrostatic attraction or chemisorption, while the hydrophobic tail extends into the solution, forming a compact barrier that limits the diffusion of corrosive agents such as Cl^-, SO_4^{2-}, or dissolved oxygen.
Cationic surfactants, particularly those based on quaternary ammonium or imidazolinium structures, are among the most effective corrosion inhibitors in acidic and neutral environments. They tend to adsorb strongly on negatively charged steel or copper surfaces, forming densely packed monolayers that suppress both anodic dissolution and cathodic hydrogen evolution. Experimental results have shown that certain alkyltrimethylammonium bromides reduce corrosion current density by more than 90 % in 1 M HCl solution.
Anionic surfactants, although primarily used for cleaning, can also act as inhibitors in alkaline media by forming insoluble complexes with metal cations. For example, alkyl sulfonates and carboxylates may precipitate as protective salts on steel, depending on the pH and ionic strength of the solution.
Nonionic surfactants influence corrosion more indirectly. By reducing surface tension and improving wettability, they ensure uniform distribution of inhibitors and removal of microbubbles or residues that may initiate localized pitting. Additionally, their ability to form mixed micelles with corrosion inhibitors enhances dispersion stability and prolongs protective film lifetime.
Synergistic systems combining surfactants with inorganic inhibitors (e.g., sodium molybdate, zinc phosphate, silicates) or organic compounds (e.g., benzotriazole, fatty amines) are widely applied in industrial cleaning and cooling-water treatment. The surfactant molecules facilitate adsorption of inhibitors on micro-defects of the metal surface, thus increasing the protective efficiency even at lower inhibitor concentrations.
Molecular modeling and quantum chemical calculations (DFT) have recently been employed to predict surfactant–metal interactions, allowing the design of tailor-made molecules with optimal charge density, dipole moment, and adsorption energy. Such computational approaches accelerate the development of next-generation corrosion inhibitors compatible with sustainable "green chemistry" principles.

Environmental and Green Chemistry Considerations

The environmental impact of surfactants has become a key driver of innovation. Biodegradability, aquatic toxicity, and low foaming are essential criteria in modern formulations. Biosurfactants—including rhamnolipids, sophorolipids, and surfactin—show promise as renewable and biodegradable alternatives with intrinsic anticorrosion properties.

Recent studies demonstrate that certain biosurfactants form dense monolayers on steel surfaces, reducing corrosion current density by more than 70%. Additionally, surfactants derived from fatty acids, amino acids, or sugar-based head groups can replace traditional petroleum-based agents.

Industrial Applications

Surfactants are present in virtually all corrosion-related cleaning processes: metal degreasing and pretreatment, pipeline cleaning, automotive cleaning, and household detergents for metallic surfaces. The integration of surfactants with nanoparticle additives (e.g., silica, ZnO, TiO2) is a recent trend to create self-healing or photocatalytically active protective films.

Conclusion

Surfactants play a dual role in cleaning and corrosion protection: they are essential for removing contaminants but can either promote or inhibit corrosion depending on their structure and formulation environment. Understanding the adsorption mechanisms, micellar behavior, and synergistic effects with inhibitors enables the design of multifunctional and environmentally compatible cleaning products. The future of surfactant technology lies in bio-based, low-toxicity, and smart self-assembling systems tailored for specific industrial needs.

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