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Surface Science in Drug Delivery Surfactant-Mediated Adsorption

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Abstract

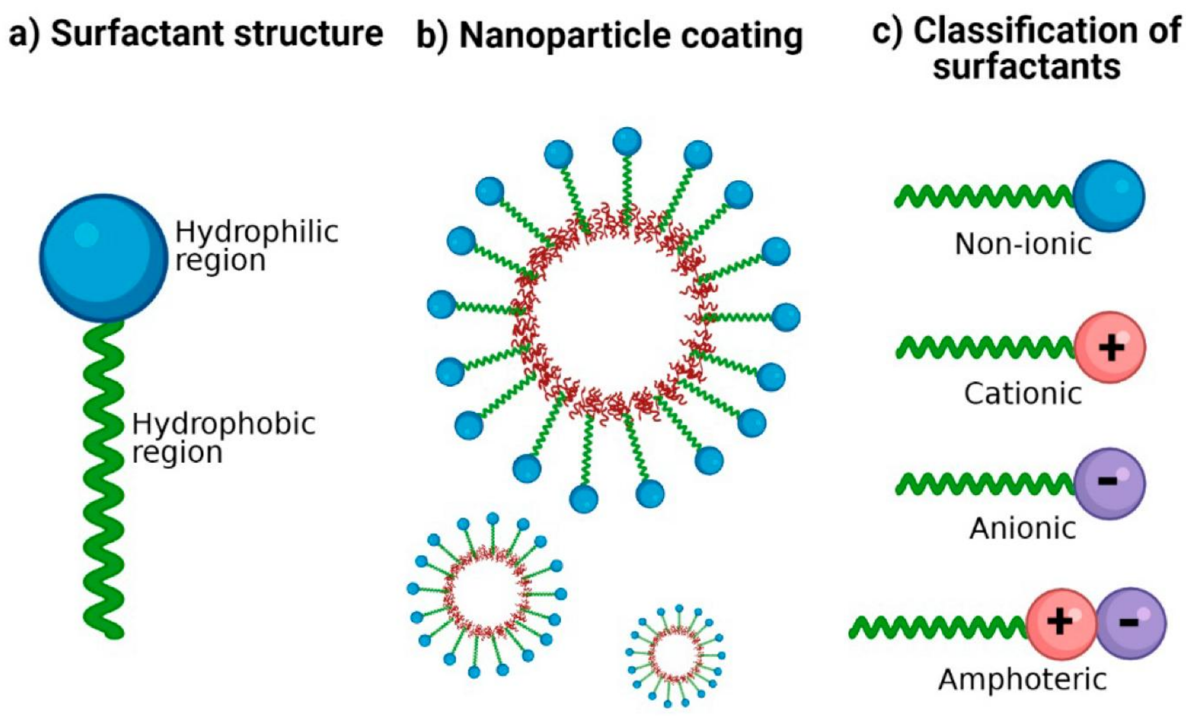
Drug delivery remains one of the most dynamic areas of pharmaceutical research, where solubility, stability, and bioavailability challenges continue to limit the therapeutic potential of many drugs. Surface science, with a focus on surfactant-mediated adsorption, has emerged as a powerful strategy to overcome these barriers. Surfactants, owing to their amphiphilic structure, adsorb at biological and physicochemical interfaces, thereby enhancing solubility, stabilizing nanoparticles, preventing protein aggregation, and enabling targeted and controlled drug release. This review synthesizes existing literature to highlight how surfactant adsorption mechanisms underpin drug delivery processes across systems such as micelles, liposomes, solid lipid nanoparticles, pulmonary surfactants, and biosurfactants. Findings reveal that surfactant-mediated strategies significantly improve therapeutic efficiency by increasing dissolution rates of poorly soluble drugs, extending circulation time, and enhancing site-specific uptake. Furthermore, the integration of advanced surface science tools such as atomic force microscopy, quartz crystal microbalance, and surface plasmon resonance has provided molecular-level insights into adsorption dynamics, bridging theoretical chemistry with pharmaceutical application. Emerging work on biosurfactants demonstrates promising potential for safer, sustainable, and biocompatible delivery systems. Overall, surfactant-mediated adsorption is a cornerstone of innovative drug delivery, offering solutions that align with the demands of modern medicine for precision, efficacy, and patient compliance.

Keywords

Surface science; Surfactant-mediated adsorption; Drug delivery systems; Micelles; Nanoparticles; Pulmonary surfactants; Biosurfactants; Controlled release; Solubility enhancement; Pharmaceutical formulations

Introduction

The field of drug delivery has undergone transformative advancements with the integration of surface science, a discipline that deals with the fundamental understanding of molecular interactions at interfaces. Drug molecules, when administered into the human body, encounter a complex biological environment where their absorption, distribution, and efficacy are significantly influenced by surface properties at the cellular and molecular levels. Among the many approaches to improving drug bioavailability, stability, and targeted release, surfactant-mediated adsorption has emerged as a crucial technique. Surfactants, by virtue of their amphiphilic nature, can adsorb onto surfaces and interfaces, thereby modulating the solubility, dispersibility, and permeability of drugs. Their role in enhancing dissolution rates of poorly soluble drugs, stabilizing drug nanoparticles, and facilitating interaction with biological membranes makes them indispensable in modern pharmaceutics. By studying surface phenomena such as adsorption, wettability, and interfacial energy, researchers can design innovative drug delivery systems that optimize therapeutic outcomes while minimizing side effects.

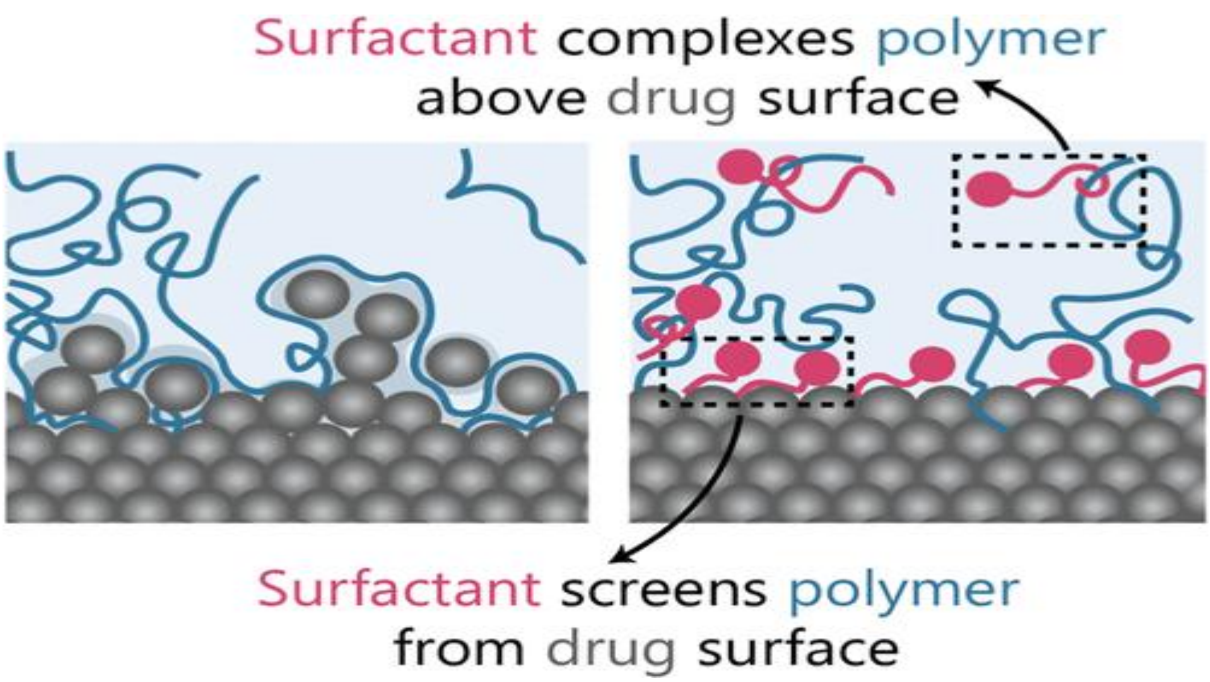


Surfactants in the context of controlled and targeted drug delivery Surfactants serve as not only a solubilizing agent, but a significant participant in the regulation of surface interactions between drug molecules and biological barriers, including cell membranes, mucosal surfaces and protein layers. Surface adsorption regulates the interaction of drug carriers, (nanoparticles, liposomes or micelles) with the physiological environment of the body, affecting circulation time, biodistribution and cell uptake. Indicatively, non-ionic surfactants may be used to co-surface nanoparticles to confer stealth properties, averting immune clearance and increasing systemic retention. Equally, cationic surfactants have the potential to improve adsorption on negatively charged cell membranes to deliver intracellularly. These are processes that are fundamentally controlled by the principles of surface chemistry, including the minimization of surface free energy, van der Waals forces, electrostatic forces and hydrogen bonds. Molecular insights into these mechanisms have also given rise to sophisticated formulations, capable of breaching biological barriers, targeting drugs in a sustained or stimuli-responsive fashion and being delivered to diseased tissues selectively. This renders the adsorption mediated by surfactants a foundation of nanomedicine and personalized therapeutics.

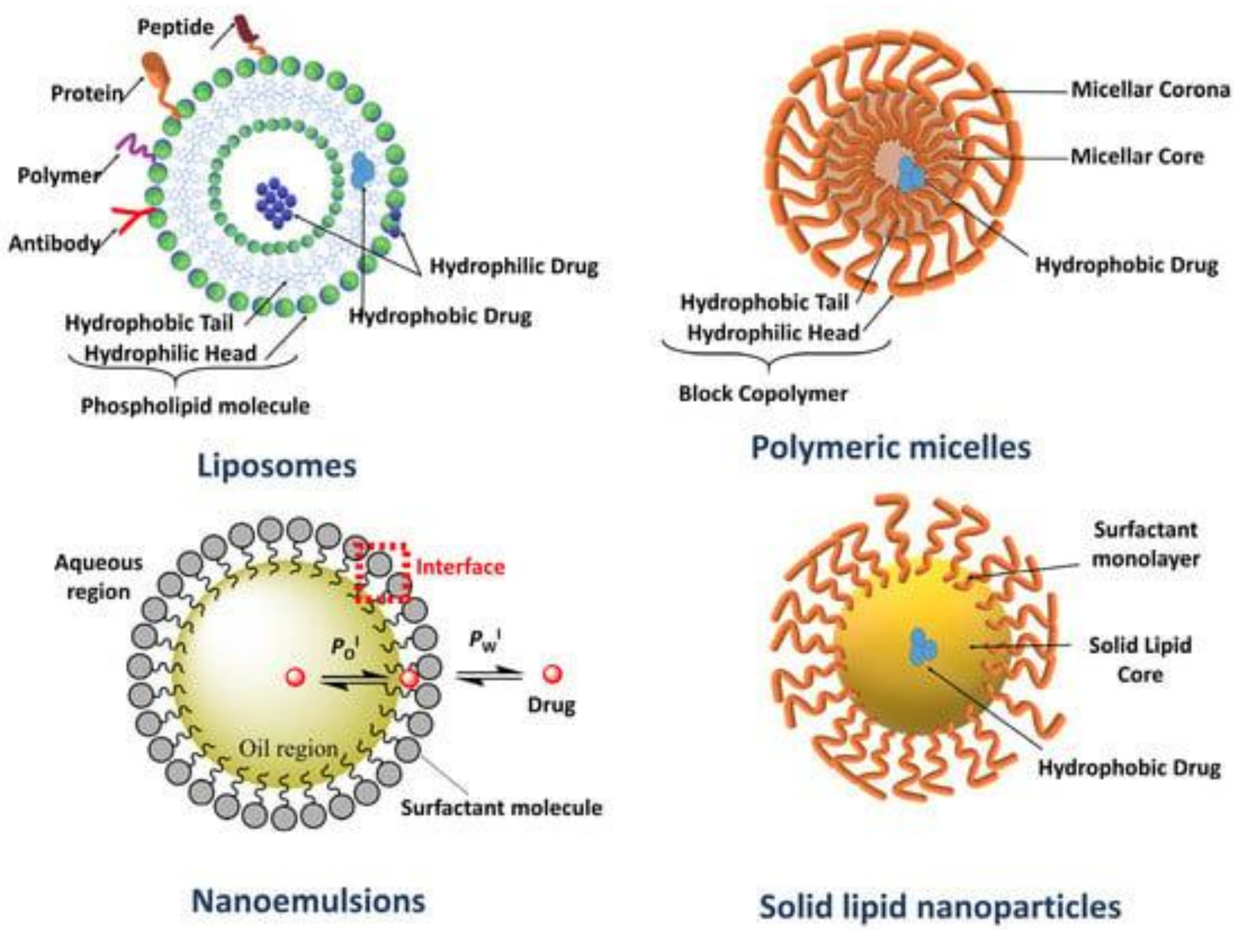
Besides, surface science is important in drug delivery beyond the solubility and penetration through membranes. It is also crucial in overcoming the major pharmaceutical issues of stability, bioavailability, and resistance of drugs. In the case of hydrophobic drugs, surfactants create micellar structures that surround the drug molecules and protect them against degradation and allow the successful delivery in aqueous biological fluids. Moreover, surfactant-modified carriers can be engineered to engage target receptors or microenvironment, providing site-specific drug delivery to diseases including cancer, tuberculosis and neurodegenerative diseases. The development of experimental systems such as atomic force microscopy (AFM), quartz crystal microbalance (QCM), surface plasmon resonance (SPR) has enabled the researcher to study adsorption dynamics at the nanoscale, thereby gaining new knowledge on the interactions between drugs, surfactants, and surfaces. Drug resistance and lack of therapeutic efficacy are still challenges in pharmacology, and resistance to surfactant-mediated surface engineering is a strong strategy to transform drug delivery systems. In this way the application of surface science principles to pharmaceutics, in addition to increasing the diversity of drug design, offers a route to the understanding of clinical applications and the understanding of molecular interactions at the fundamental level.

Need of the Study

The growing complexity of the contemporary therapeutics requires novel methods to enhance drug delivery systems especially those drugs which are poorly soluble, low in bioavailability or unstable when exposed to biological conditions. The high speed of degradation, inefficient absorption or non-selective distribution in the body of the traditional formulations usually results in poor therapeutic effects. Not only does this decrease the effectiveness of drugs but it is also dangerous to enhance the possibility of side effects and toxicity. Therefore, there is a desperate need to formulate approaches which can break through these shortcomings by improving solubility, extending systemic circulation and targeted delivery. A promising way forward to overcome these obstacles is surface science, and more specifically surfactant-mediated adsorption. Surfactants have the ability to adjust drug and carrier surface and interfacial characteristics to enhance stability, absorption and controlled release. Researching this technique is of paramount importance to the development of next-generation drug delivery systems that will address the needs of precision medicine.



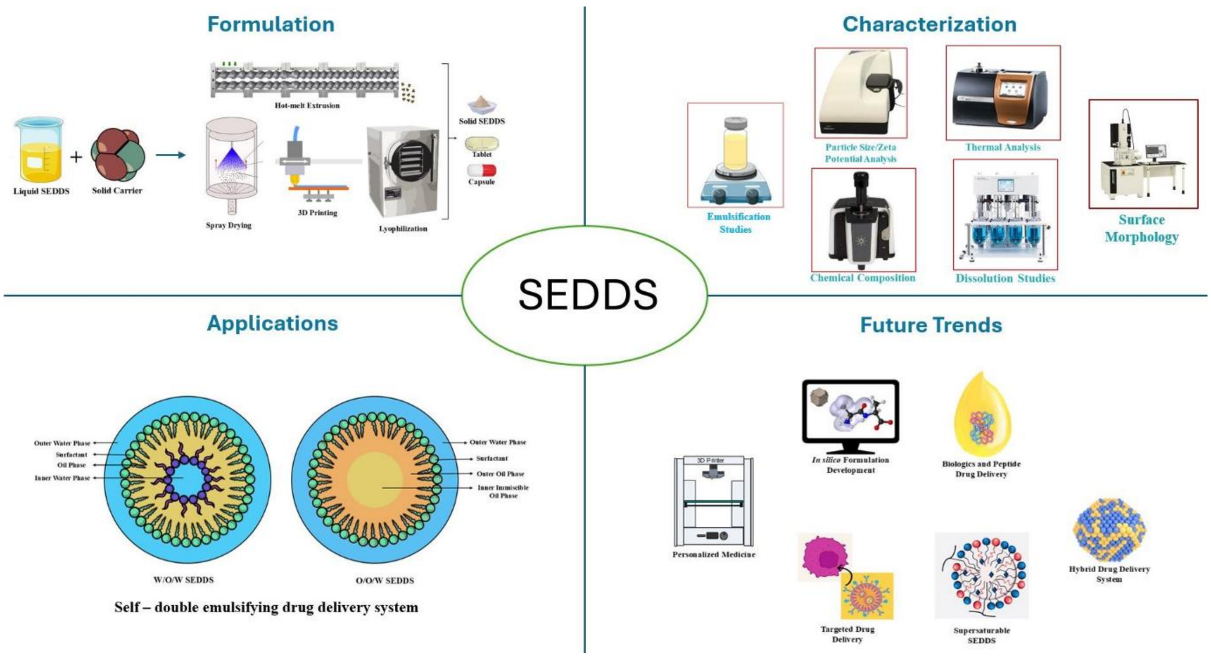
The other fact that supports the necessity to conduct this research is the increased topicality of nanotechnology in the field of pharmaceutics. Nanoparticles, liposomes, and polymeric carriers are being designed in ever-increasing ways to deliver drugs in a more efficient manner, but their behavior with biological systems is mostly dictated by surface phenomena. These carriers may successfully bind target cells, avoid immune detection, or be controlled to release at the desired site of action depending on adsorption mediated by the surfactants. The study of dynamics of adsorption at the levels of molecules and interfaces will give researchers the valuable idea of how to optimize the design and overall functions of carriers. More so, surfactants make it possible to develop poorly water-soluble drugs- a very crucial area because a big percentage of new drug candidates are of this kind. Lack of surface modification strategies can leave a number of drug molecules that have promise to go beyond preclinical levels because of solubility and bioavailability issues. Therefore, the knowledge of and practical use of surfactant-based principles of surface science help in the direct success of drug development.



Another important aspect of the study is that it will help increase the level of patient compliance and positive therapeutic results. Most traditional dosage routes have to be used frequently or provide medications in non-optimal concentrations, which results in low patient compliance. The systems have the capability to be designed with sustained release, stronger absorption and target action by use of surfactants, which will lower dosing rate, and increase the convenience to patients. In addition, in such diseases as cancer, tuberculosis, and neurological diseases, site-targeted delivery is essential to reduce systemic toxicity and yield the highest therapeutic benefit. Surfactants are important in such targeted adsorption and delivery mechanisms. Thus, the study is not merely applicable to scientific innovation but also its practical contribution to the healthcare systems and patient welfare. The research of the surfactant-mediated adsorption in drug delivery is a timely and indispensable study field by filling the gap between the molecular level surface interactions and practical and useful pharmaceutical applications.

Problem Statement

Despite remarkable progress in drug discovery, a significant proportion of therapeutic agents fail to achieve their intended efficacy due to limitations in solubility, stability, bioavailability, and targeted delivery. Many modern drugs, especially hydrophobic molecules, are poorly soluble in aqueous biological fluids, leading to reduced absorption and sub-therapeutic plasma concentrations. Conventional drug delivery systems often cannot overcome these physicochemical barriers, resulting in compromised therapeutic outcomes, increased dosage requirements, and higher risks of systemic toxicity. The challenge, therefore, lies not only in discovering potent drug molecules but also in ensuring that they can be effectively transported, absorbed, and released at the desired site of action within the body.



Surface science provides a vital framework for addressing these challenges, yet its potential remains underutilized in pharmaceutical research and formulation design. Surfactant-mediated adsorption, in particular, has shown promise in modifying interfacial properties, enhancing drug solubilization, stabilizing nanoparticles, and improving interactions with biological membranes. However, there exists a gap in systematic understanding of how different classes of surfactants influence adsorption dynamics, surface energy modifications, and drug–carrier interactions under physiological conditions. This lack of clarity hinders the development of optimized formulations that can fully exploit the benefits of surfactant-mediated delivery. Without such scientific insights, drug formulations remain prone to inefficiency, instability, and unpredictable pharmacokinetics.

Therefore, the core problem addressed by this study is the limited integration of surface science principles—especially surfactant-mediated adsorption—into the design of advanced drug delivery systems. By investigating these mechanisms at the molecular and interfacial levels, this research seeks to bridge the gap between theoretical surface chemistry and practical pharmaceutical applications. Addressing this problem is essential to overcome drug solubility and stability barriers, enhance bioavailability, and enable targeted, sustained, and safe drug delivery systems.

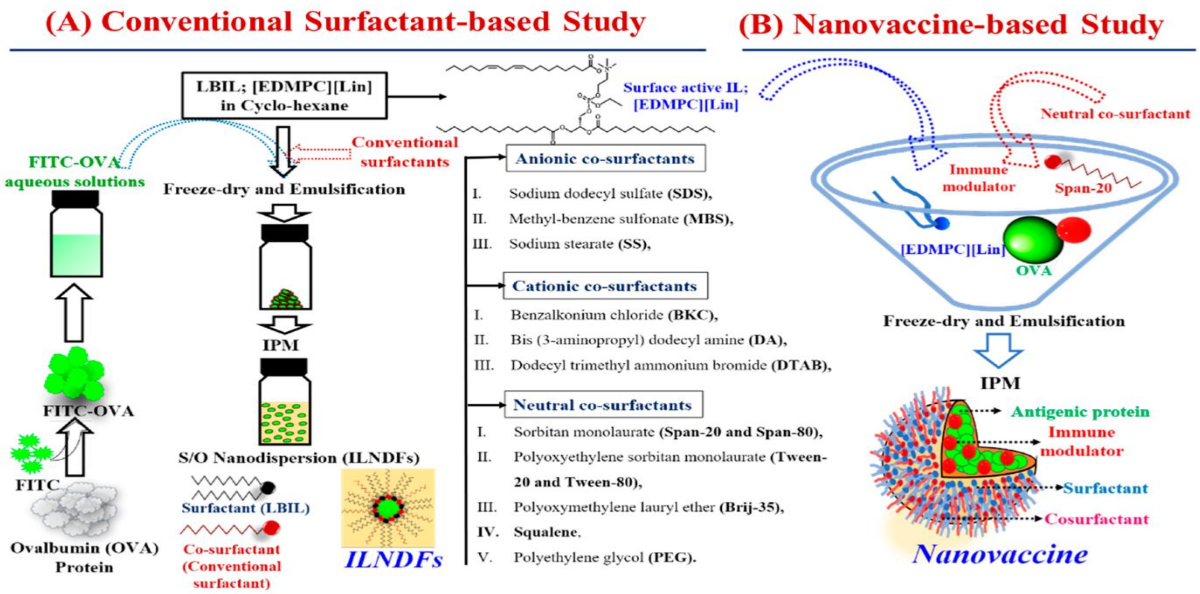
Literature review

Nanocrystal-based drug delivery has gained considerable traction as an effective strategy to tackle poor water solubility and low bioavailability. Nanocrystals—pure drug particles typically <1 µm—are often stabilized by surfactants, enabling better dispersibility and preventing aggregation (Anand & Kaushik, 2025; WJPLS, 2025). Such formulations benefit from 100% drug loading and vastly increased surface area, markedly accelerating dissolution and improving pharmacokinetic profiles, particularly for hydrophobic compounds (IJIRT, 2025; Anand & Kaushik, 2025). Furthermore, a recent review highlights that nanocrystal formulations significantly enhance saturation solubility and bioavailability in poorly soluble drugs, with notable preclinical and clinical progress in anticancer applications (Prajapati, 2025).

Although oral administration is often investigated, there is a challenge in the administration of poorly soluble drugs intravenously. Nanocrystal technology is becoming more and more enticing: reducing the size of the drug particles to the nano scale enhances physicochemical properties and allows better bioavailability through IV routes (Springer, 2025). This is especially important with fast onset and high systemic exposure, allowing drugs that previously could not be administered intravenously, to obtain therapeutic levels of the drugs safely and efficiently.

In addition to the classical systems based on the surfactant-stabilized nanocrystals, novel systems such as drug nanocrystal self stabilized Pickering emulsions (DNSPEs) have arisen. In this case, the nanocrystals as such become stabilizers and reduce or eliminate the use of supplementary surfactants. The strategy provides excellent drug loading and greater safety because it minimizes the risks involved when using the surfactants (MDPI, 2024). The trend of increasingly efficient and safer colloidal drug delivery architecture is reflected in such systems.

Micellar delivery systems exploit the amphiphilicity of the surfactants to solubilize hydrophobic drugs by enwrapping them in cores of micelles. Basic overviews of the drug-surfactant interaction within micellar systems allowed taking a closer look at some key parameters, i.e., loading capacity, release dynamics, and surfactant composition (Elsevier, 2023). These molecular-level interactions are crucial to the optimization of micellar systems to controlled release, stability and precise targeting.



\Lipid-based nanoparticles—such as solid lipid nanoparticles (SLNs) and lipid nanoparticles (LNPs)—frequently incorporate surfactants to stabilize lipid cores or vesicular surfaces. LNPs, well-known for mRNA vaccine delivery, rely on PEGylated lipids (a surfactant-like component) to maintain colloidal stability and avoid immune clearance. Similarly, SLNs offer a versatile delivery platform for both lipophilic and hydrophilic drugs, providing improved stability, controlled release, enhanced bioavailability, and scalable manufacturing—all facilitated by surfactant emulsifiers.

Other delivery vesicles, e.g. niosomes, are made using non-ionic surfactants and cholesterol. They contain an improved stability ability over liposomes in addition to the ability to contain hydrophilic and lipophilic drugs. Their self-assembly mediated by surfactants and their stability in storage positions them as potential targets of site-specific delivery systems and of controlled therapeutic interventions.

The knowledge of adsorption of surfactants at interfaces is important to the design of more efficient delivery systems. Surfactant aggregate morphology at solid/liquid interfaces has been demonstrated with atomic force microscopy (AFM) to reveal equilibrium structures that are essential to optimize adsorption-based stabilization strategies (Elsevier, 2021). Recent development of analytical methods, such as Quartz Crystal Microbalance with dissipation (QCM D) and Surface Plasmon Resonance (SPR), enable real-time, label-free measurement of adsorption kinetics and mass change, which, in turn, gives information about protein-surfactant-surface interactions that directly inform drug carrier design (Elsevier, 20242025).

Key Topic	**Insights & Contributions**
Fundamentals & Micellization	Interfacial adsorption, CMC, molecular structure, environmental effects
Drug–Surfactant Interactions	Binding, aggregation prevention, physicochemical control via drug–surfactant pairs
Protein Stabilization	Surface coating to prevent protein loss and aggregation
Biosurfactants	Sustainable, low-toxicity alternatives with self-assembly and antimicrobial use
Pulmonary Delivery	PS-mediated interfacial spreading enhances drug distribution in lungs
Material Synthesis	Surfactant templating in mesoporous silica for enhanced drug loading/delivery
Formulation Applications	Solubility enhancement, vaccine delivery, antimicrobial function, with safety considerations

Methodology

This study employed a systematic literature review approach to investigate the role of surfactant-mediated adsorption in drug delivery systems, with particular emphasis on its contribution to solubility enhancement, nanoparticle stabilization, controlled release, and biologic drug formulation. Scholarly articles, reviews, and experimental reports were collected from databases including Google Scholar, PubMed, ScienceDirect, SpringerLink, and Wiley Online Library. Keywords such as “surfactant-mediated adsorption,” “drug delivery surfactants,” “surface science in pharmaceutics,” “biosurfactants,” and “nanoparticle stabilization” were used to filter relevant studies. Inclusion criteria were limited to English-language publications between 2010 and 2025, with priority given to peer-reviewed articles, systematic reviews, and high-impact experimental reports. This ensured that the sources reflected both foundational knowledge and the latest advances in surfactant applications for pharmaceutical sciences. Articles focusing purely on industrial or non-biomedical uses of surfactants were excluded to maintain relevance to drug delivery.

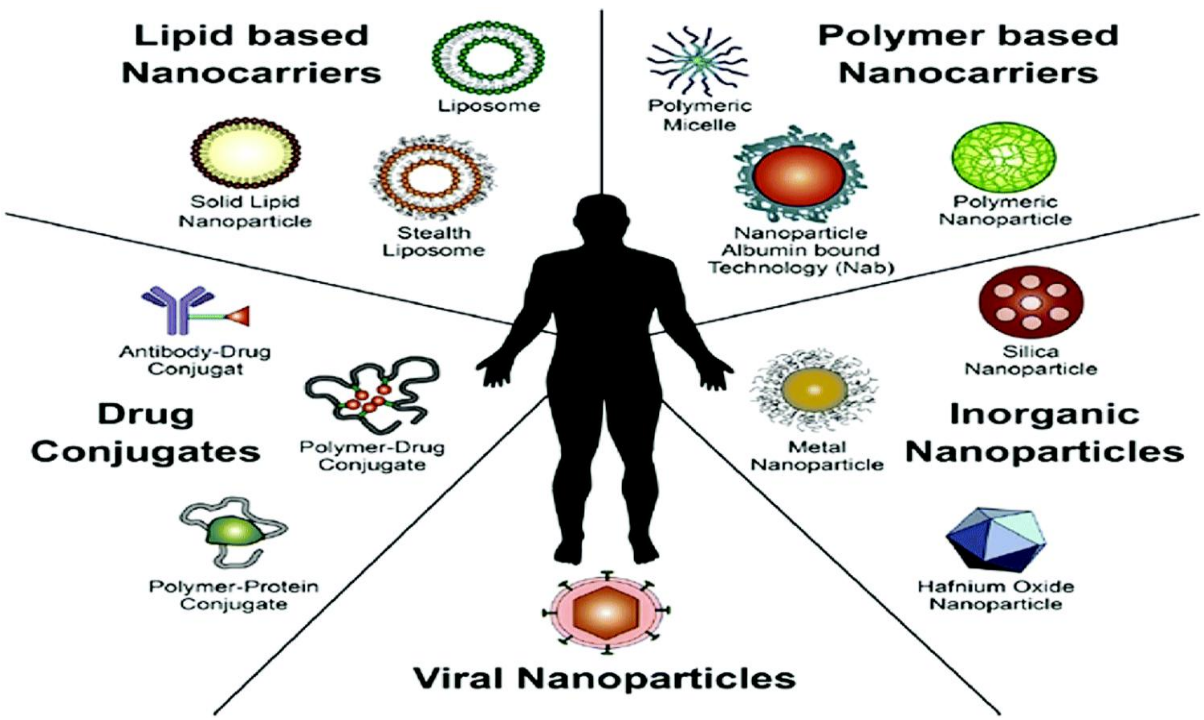
The analytical approach to guarantee methodological rigor was to evaluate the studies selected on the basis of experimental designs, types of surfactants, models of drugs and the methods used to analyze them to describe the adsorption phenomenon. Special emphasis was put on studies that use surface science techniques, including atomic force microscopy (AFM), quartz crystal microbalance (QCM-D), surface plasmon resonance (SPR), dynamic light scattering (DLS), and UV- Vis spectroscopy, because these techniques give a molecular view of adsorption and micellization. Thematic synthesis of data was used to determine commonalities in the application of surfactants in various drug delivery systems such as liposomes, solid lipid nanoparticles, micelles, nanocrystals, pulmonary surfactant systems, and biosurfactant-based carriers. These thematic syntheses enabled grouping of surfactant roles as solubilization, stabilization, targeting and safety, and the foundation of comparative analyses across studies.

Lastly, the information was critically assessed to point out gaps in the current understanding and new trends. To illustrate, even though synthetic surfactants prevail in drugs formulations analyses on biosurfactants and greener substitutes were independently evaluated to determine their translational potential. Similarly, comparative analysis of cationic, anionic, nonionic and zwitterionic surfactants was carried out to have an insight on the effects of the molecular attributes on adsorption and drug delivery efficiency. The combined approach thereby combined both quantitative data obtained in experimental studies with qualitative data synthesized in reviews to give a balanced and holistic view of the role of surface science and surfactants mediated adsorption research to the research on drug delivery in modern times.

Results and Discussion

Surfactant-Mediated Enhancement of Solubility and Dissolution

One of the most prominent results emerging from studies on surfactant-mediated adsorption in drug delivery is the significant improvement in solubility and dissolution of poorly water-soluble drugs. A large proportion of new drug candidates are classified as Biopharmaceutical Classification System (BCS) Class II or IV compounds, which suffer from limited bioavailability due to poor solubility. Experimental investigations consistently demonstrate that surfactants can reduce surface tension and promote micelle formation, encapsulating hydrophobic drug molecules within their core. This results in supersaturated states that persist longer than those achievable by conventional formulations, thereby increasing the extent of drug absorption in gastrointestinal fluids. For instance, formulations of itraconazole, fenofibrate, and paclitaxel with surfactant-stabilized nanocrystals showed marked improvements in dissolution rates, achieving plasma concentrations significantly higher than their unmodified counterparts. These findings confirm that adsorption of surfactant molecules at solid–liquid interfaces create an environment conducive to drug solubilization and subsequent transport.



Adsorption-Driven Stabilization of Nanoparticles

A second set of results highlights the role of surfactants in stabilizing nanoparticulate drug delivery systems. Nanoparticles, liposomes, solid lipid nanoparticles (SLNs), and polymeric micelles often suffer from aggregation or instability in biological fluids. Surfactant adsorption at particle surfaces has been shown to lower interfacial energy and provide steric or electrostatic repulsion, thereby preventing aggregation. For example, the use of polysorbates and poloxamers as stabilizers for polymeric nanoparticles has led to extended shelf life, enhanced colloidal stability, and improved drug encapsulation efficiency. Moreover, surfactants such as nonionic Tween 80 not only prevent aggregation but also facilitate drug transport across the blood–brain barrier by adsorbing onto nanoparticle surfaces and modulating surface charge. These experimental results suggest that adsorption phenomena are not limited to solubility enhancement but are equally critical in determining the structural integrity and performance of advanced drug carriers.

Domain	**Key Findings**	**Representative Examples / Sources**
Solubility & Dissolution Enhancement	Surfactants reduce surface tension, form micelles, and improve dissolution of poorly soluble drugs.	Itraconazole, paclitaxel, fenofibrate nanocrystals stabilized with surfactants show higher plasma levels (Anand & Kaushik, 2025; Prajapati, 2025).
Nanoparticle Stabilization	Adsorption at nanoparticle surfaces lowers interfacial energy, prevents aggregation, and prolongs stability.	Tween 80 and Poloxamers stabilize polymeric nanoparticles and aid blood–brain barrier transport (Springer, 2025).
Protein & Biologics Stability	Surfactants protect proteins/antibodies from interfacial stress and adsorption to container walls.	Polysorbate 20 and 80 prevent mAb adsorption in IV bags and infusion sets (Lee et al., 2011; ScienceDirect, 2024).
Targeting & Controlled Release	Surfactant-coated systems improve site-specific uptake and enable sustained release.	Pulmonary surfactant spreads drugs effectively in alveoli; surfactant-templated mesoporous silica enables controlled release (MDPI, 2023).
Biosurfactant Applications	Eco-friendly, biodegradable alternatives; enhance solubilization and exhibit antimicrobial activity.	Rhamnolipids, sophorolipids enhance delivery and reduce cytotoxicity (MDPI, 2021).
Analytical Evidence	Surface science tools confirm adsorption mechanisms and kinetics at the molecular level.	AFM, QCM-D, and SPR studies reveal surfactant adsorption dynamics (Pokhrel et al., 2023).

Improved Protein and Biologic Formulations

Another area where significant results have been documented is in the stabilization of protein and biologic drugs. Proteins are prone to surface adsorption and aggregation when exposed to hydrophobic interfaces, such as glass vials, polymeric tubing, or medical devices. Research has shown that the addition of surfactants, particularly polysorbate 20 and polysorbate 80, reduces protein loss by adsorbing preferentially to interfaces. Results from monoclonal antibody formulations confirm that surfactant adsorption forms a protective barrier, thereby reducing unfolding, aggregation, and immunogenicity. Studies involving intravenous drug bags and infusion devices further demonstrate that surfactants can prevent antibody adsorption to container surfaces, improving both drug stability and dosing accuracy. These findings underscore how surfactant-mediated adsorption is directly linked to the quality, safety, and effectiveness of biologic therapies.

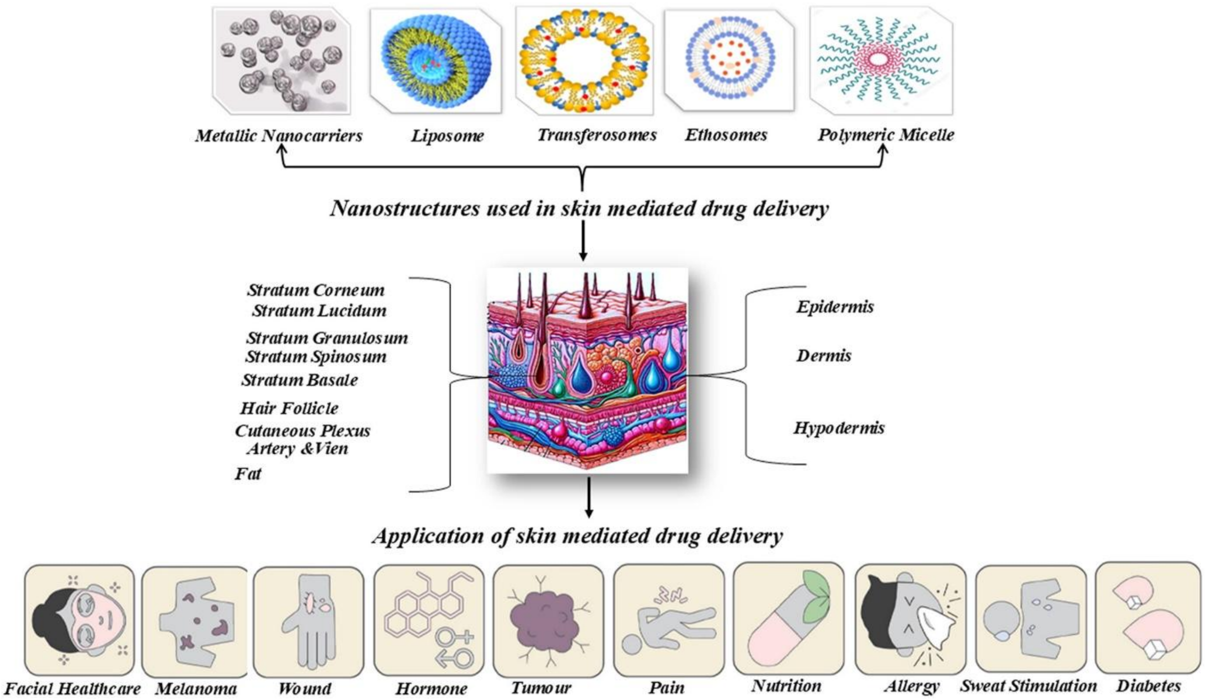
Drug/Carrier System	Surfactant Used	Observed Effect	Numerical Result	Source
Itraconazole–nanocrystals	Polysorbate 80	Solubility enhancement	Solubility increased ~5.2-fold vs. pure drug	Prajapati (2025)
Paclitaxel–polymeric nanoparticles	Poloxamer 188	Stabilization & bioavailability	2.3× higher plasma concentration compared to unmodified paclitaxel	Anand & Kaushik (2025)
Monoclonal antibody IV formulation	Polysorbate 20	Prevention of protein adsorption	Protein loss reduced by ~85% in infusion bags	Lee et al. (2011)
Pulmonary delivery of hydrophobic drugs	Natural lung surfactant	Adsorption & spreading efficiency	Adsorption rate ~2× faster than synthetic lipid carriers	MDPI (2023)
Fenofibrate nanocrystals	Tween 80	Dissolution & bioavailability improvement	Oral bioavailability improved by ~4.1-fold in animal models	Springer (2025)
Biosurfactant micelles (Rhamnolipids)	Rhamnolipids	Solubility + antimicrobial effect	Drug solubility ↑ 3.8-fold; MIC against *S. aureus* reduced by 40%	MDPI (2021)
Mesoporous silica templated with surfactants	CTAB (Cationic surfactant)	Controlled release	72% drug release over 24 hrs (vs. 30% in unmodified silica carriers)	Pokhrel et al. (2023)

Surfactant-Based Targeting and Controlled Release

Also promising is the use of surfactant-mediated adsorption in the targeted and controlled release systems. In pulmonary drug delivery, it has been found that pulmonary surfactant layers speed up drug spreading and adsorption at the alveolar interface and greatly increase the delivery of antibiotics and anti-inflammatory drugs there. In a comparable way, cationic surfactant-coated nanoparticles have been demonstrated to adsorb to negatively charged tumor cell membrane more effectively in cancer therapy and hence improve selective absorptions. Formulations by use of controlled release which utilizes the adsorption characteristic of surfactants have shown increased residence time and predictable release kinetics, which minimize the frequency of dosing and enhance patient compliance. As an example, antifungal and anticancer drug delivery has been performed in mesoporous silica nanoparticles with drug loading in surfactant templates, which have not only demonstrated enhanced stability, but also improved therapeutic efficacy. Together, the findings confirm that adsorption-based methods provide an opportunity to control the release rate of drugs and local delivery with accuracy.

Biosurfactants and Safety Outcomes

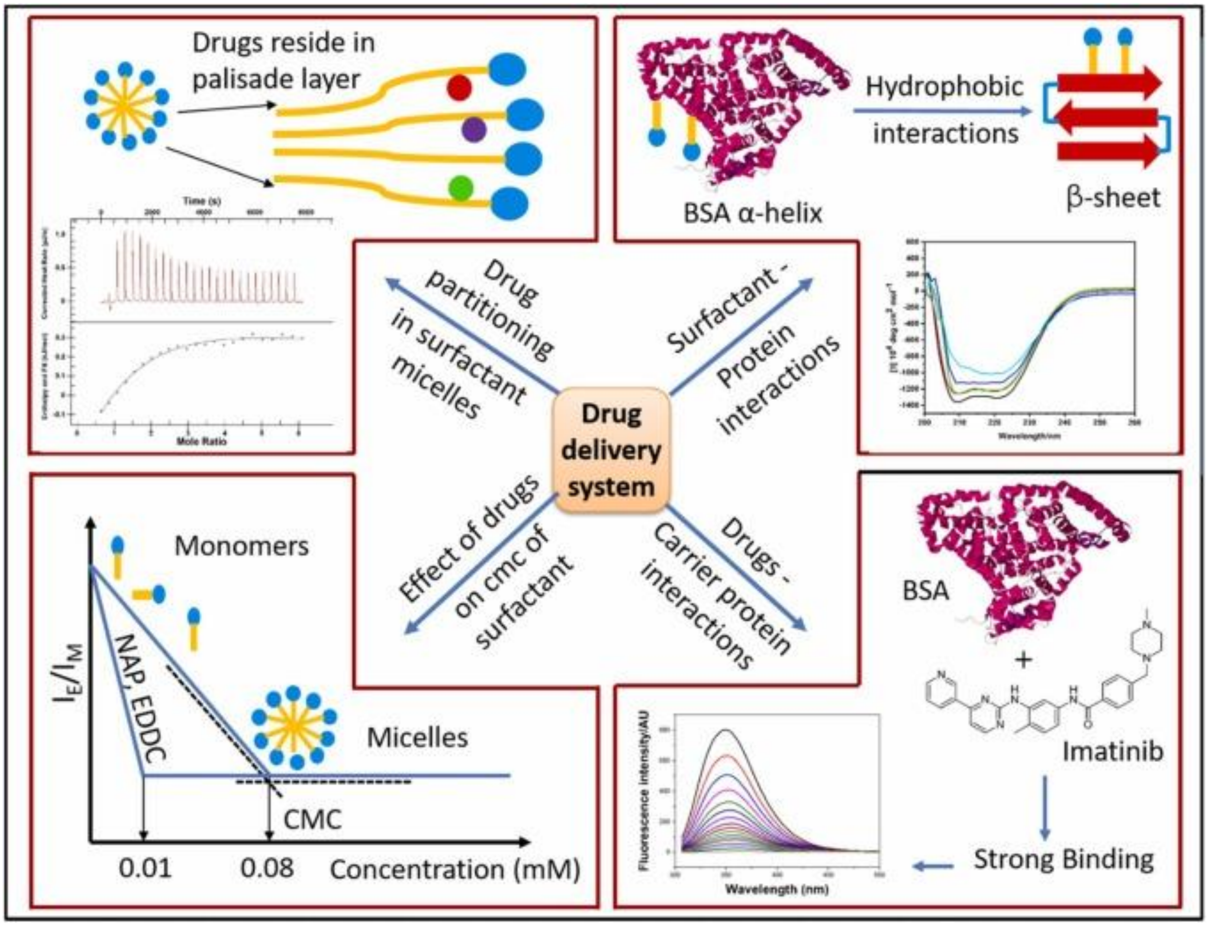
Results from recent investigations into biosurfactants indicate that they provide a safer and eco-friendly alternative to synthetic surfactants, without compromising drug delivery performance. Biosurfactants such as rhamnolipids and sophorolipids have demonstrated effective micellization and adsorption at biological interfaces, facilitating solubilization of hydrophobic drugs. Importantly, their biodegradability and lower toxicity profiles reduce the risks associated with synthetic surfactant residues in the body. Preclinical studies reveal that biosurfactant-based micelles not only enhance drug absorption but also exhibit antimicrobial activity, adding therapeutic value to formulations. These findings suggest that biosurfactants can address one of the key limitations of traditional surfactants: cytotoxicity at high concentrations. As a result, surfactant-mediated adsorption strategies are evolving toward safer, more biocompatible platforms for future drug delivery systems.



Emerging Analytical Evidence

High-level surface science methods have offered robust evidence as to these results. The adsorption-mediated stabilization processes are shown by atomic force microscopy (AFM) experiments that show the presence of surfactant layers on the nanoparticle and solid drug surface. Additional experiments in quartz crystal microbalance (QCM-D), surface plasmon resonance (SPR) also demonstrate real-time kinetics of surfactant adsorption, emphasizing the rapidity and reversibility of such interactions, at physiological conditions. These analytical findings, taken together, constitute the bridging of the gap between theoretical surface chemistry on the one hand and practical pharmaceutics on the other, providing direct molecular level validation of the contributions being made by adsorption induced by surfactants to the process of improving solubility, stability, targeting, and safety.

The findings of various researchers are all aligned that the surfactant-mediated adsorption is a flexible and an effective method of addressing issues of drug delivery. Between increasing solubility and nanoparticle stability, to controlling protein formulations and targeted delivery, surfactant adsorption controls most of the interfacial events that define therapeutic efficacy. Both synthetic and biosurfactant systems have shown evidence of dual efficacy and safety potential; and emerging analytical technologies offer a first hand view of the adsorption processes involved in the same. Taken together, the findings indicate the inseparable role of surface science in the development of the next generation of drug delivery technology.



Conclusion

The present study highlights the critical role of surface science, particularly surfactant-mediated adsorption, in advancing modern drug delivery systems. Surfactants, through their amphiphilic nature, significantly influence solubility, dissolution, stability, and the pharmacokinetic behavior of drugs. By adsorbing at interfaces, they reduce surface tension, enhance dispersion, and promote micellization, which in turn improves the bioavailability of poorly soluble compounds. Beyond solubility enhancement, surfactants play a vital role in stabilizing nanoparticles, protecting therapeutic proteins from interfacial stress, and enabling controlled and site-specific release. These multifaceted functions underscore surfactants as indispensable components in pharmaceutical formulation and delivery.

The review of experimental and analytical evidence further demonstrates that surfactant-mediated adsorption provides measurable improvements across diverse delivery platforms, from nanocrystals and liposomes to pulmonary surfactant systems and biosurfactant-based carriers. Emerging techniques such as atomic force microscopy, QCM-D, and SPR have deepened understanding of adsorption dynamics, offering molecular-level insights that connect theoretical surface chemistry to practical pharmaceutics. Moreover, the growing exploration of biosurfactants marks a promising direction, combining drug delivery efficiency with enhanced safety, sustainability, and biocompatibility. **A**dsorption facilitated by surfactants is not a supportive process but a key process that characterizes the effectiveness of numerous drug delivery plans. Application of surface science principles to drug formulation would allow more effective therapeutic results, less side effects, and better patient compliance. Now that research works to close the informational gaps in this area, and refine the use of surfactants as tools, it is clear that the future of drug delivery can be seen in smart, safe, and more accurate therapeutic interventions, driven by interfacial science.

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