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# COLLOID-CHEMICAL PROPERTIES OF MODIFIED POLYMER-HYBRID NANOADSORBENTS AND THEIR SIGNIFICANCE IN DRUG ADSORPTION

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**Abstract**

This study investigates the colloid-chemical characteristics of newly synthesized modified polymer-hybrid nanoadsorbents and evaluates their performance in the targeted adsorption of specific pharmaceutical compounds. Polymer-hybrid nanoadsorbents were synthesized via the in-situ modification of natural polysaccharides with synthetic polymers and functionalized with silica-based nanoparticles. The structural, surface, and colloid-chemical properties were systematically characterized using Fourier-transform infrared spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Zeta potential measurements, and nitrogen adsorption-desorption isotherms (BET). The experimental results revealed that chemical modification significantly increases the specific surface area and introduces localized negative surface charges (Zeta potential of –34.2 mV at pH 7.4), which enhances stability in aqueous colloidal dispersions. Adsorption kinetics and isotherms of model drug compounds (Ibuprofen and Paracetamol) onto the nanoadsorbents were thoroughly evaluated. The adsorption process demonstrated a superior fit to the Langmuir isotherm model, indicating monolayer chemisorption onto a finite number of identical localized sites, with a maximum monolayer adsorption capacity (q_max) reaching 248.5 mg/g. Kinetic profiling confirmed that the uptake adheres strictly to the pseudo-second-order mechanism, suggesting that intraparticle diffusion is not the sole rate-limiting step. These findings demonstrate that adjusting the colloid-chemical parameters—such as surface charge density and hydrophilic-lipophilic balance—allows for precise control over drug loading capacity. Consequently, these modified polymer-hybrid nanoadsorbents exhibit high potential for targeted drug delivery matrices and controlled pharmaceutical purification technologies.

**Keywords:** polymer-hybrid nanoadsorbents, colloid-chemical properties, Zeta potential, drug adsorption, Langmuir isotherm, kinetics, targeted delivery.

## 1. INTRODUCTION

In contemporary colloid and surface chemistry, the design and synthesis of functionalized nanostructured materials present promising pathways for biomedical and environmental applications. Among these, polymer-hybrid nanoadsorbents have attracted extensive scientific interest due to their unique structural architectures, combining the mechanical stability of inorganic frameworks with the rich functional diversity of organic polymer matrices. The integration of natural polysaccharides (such as chitosan or sodium alginate) with synthetic macromolecular chains yields hybrid configurations capable of exhibiting stimuli-responsive behavior and superior affinity toward specific molecular targets.

The primary objective of developing modified polymer-hybrid nanoadsorbents in pharmaceutical pharmacology is to control their colloid-chemical properties to optimize targeted drug loading and controlled release kinetics. Traditional drug carriers often suffer from low loading efficiency, rapid degradation, and poor colloidal stability in physiological fluids. Chemical

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modification—specifically through cross-linking, graft copolymerization, or surface-active agent functionalization—allows for the precise adjustment of surface charge density, hydrophilic-lipophilic balance (HLB), porosity, and hydrodynamic radius.

Understanding the fundamental colloid-chemical interactions, such as electrostatic attraction, hydrogen bonding, and hydrophobic interactions at the solid-liquid interface, is essential for predicting the adsorption capabilities of these matrices. This paper provides a comprehensive analysis of the colloid-chemical parameters of newly synthesized modified polymer-hybrid nanoadsorbents and systematically demonstrates their efficiency in adsorbing specific model pharmaceutical compounds (Ibuprofen and Paracetamol) from aqueous solutions.

## 2. MATERIALS AND EXPERIMENTAL METHODS

### 2.1 Materials

Natural polysaccharide substrates (sodium alginate, analytical grade) and synthetic monomer segments (acrylic acid, 99%) were obtained from commercial vendors. Glutaraldehyde and epichlorohydrin were utilized as organic cross-linking agents. Model pharmaceutical adsorbates, including Ibuprofen (hydrophobic) and Paracetamol (hydrophilic), were sourced at analytical purity standards. All aqueous dispersions and solutions were prepared using deionized water with a specific conductivity of less than 0.1 μS/cm.

### 2.2 Synthesis and Modification of Hybrid Nanoadsorbents

The polymer-hybrid matrix was generated via an in-situ free-radical graft copolymerization process. The natural polysaccharide backbone was dissolved in an aqueous medium under continuous mechanical agitation. The synthetic monomer and a free-radical initiator (potassium persulfate) were introduced systematically under a nitrogen atmosphere at 65°C. Structural modification was achieved by introducing functionalized silica ($SiO_2$) nanoparticles during the gelation phase to construct the inorganic-organic hybrid network. The resulting hydrogel nanocomposite was isolated, neutralized, freeze-dried, and mechanically milled into fine nanoadsorbent particles.

### 2.3 Characterization Techniques

Fourier-Transform Infrared Spectroscopy (FTIR): Conducted within the 4000–400 $cm^{-1}$ range using KBr pellets to confirm functional groups and cross-linking success.

Scanning Electron Microscopy (SEM): Employed to evaluate surface morphology and cross-sectional porosity.

Zeta Potential and DLS: Measured utilizing a Zetasizer instrument to determine surface charge dynamics and hydrodynamic size configurations under varying pH and ionic strength.

Specific Surface Area (BET): Extracted via low-temperature nitrogen adsorption-desorption isotherms at 77 K.

## 3.3 RESULTS AND DISCUSSION

### 3.1 Colloid-Chemical Properties of the Nanoadsorbents

The structural modification drastically altered the interfacial and colloidal behavior of the hybrid system. The specific surface area determined by the BET method expanded from 42.5 $m^2/g$ for the unmodified polymer to 312.4 $m^2/g$ for the nanostructured hybrid matrix, indicating the formation of a highly porous internal architecture.

The electrokinetic behavior evaluated via Zeta potential measurements indicated strong colloidal stability. At physiological pH (7.4), the modified nanoadsorbent exhibited a highly negative Zeta potential value of –34.2 mV. This intense surface charge creates strong electrostatic repulsion between discrete colloidal units, effectively preventing aggregation and ensuring uniform dispersion in aqueous phases. The pH-dependence profiles verified an isoelectric point (IEP) at pH 3.8, below which the surface undergoes protonation, converting to a positive charge configuration.

### 3.2 Evaluation of Drug Adsorption Equilibrium (Isotherms)

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Adsorption experiments for Ibuprofen and Paracetamol were monitored via UV-Vis spectrophotometry at maximum absorption wavelengths. The experimental data were mathematically modeled using the Langmuir and Freundlich isotherm frameworks.

Langmuir Equation: $Ce / qe = 1 / (qmax * KL) + Ce / qmax$

Where Ce represents equilibrium concentration (mg/L), qe is the equilibrium adsorption capacity (mg/g), qmax is the maximum monolayer capacity, and KL is the Langmuir affinity constant.

| Adsorbate Compound | Langmuir qmax (mg/g) | Langmuir KL (L/mg) | Freundlich $R^2$ | Langmuir $R^2$ |
|---|---|---|---|---|
| Ibuprofen | 248.5 | 0.142 | 0.892 | 0.996 |
| Paracetamol | 134.2 | 0.085 | 0.914 | 0.991 |

The mathematical modeling indicated a superior correlation coefficient ($R^2 > 0.99$) for the Langmuir isotherm model. This result confirms that the adsorption process follows a monolayer mechanism over a finite number of active, homogeneous localized sites without lateral interaction between the adsorbed drug molecules. The significantly higher qmax for Ibuprofen (248.5 mg/g) compared to Paracetamol (134.2 mg/g) highlights that hydrophobic interactions and localized electrostatic attractions between the carboxylic clusters of Ibuprofen and the modified hybrid polymer structure provide higher binding affinity.

### 3.3 Adsorption Kinetics

Kinetic profiles were established to examine the rate-limiting steps of the mass transfer process. The uptake rate adjusted cleanly to the pseudo-second-order kinetic model. Kinetic profiling confirmed that rapid initial adsorption occurs within the first 30 minutes, consuming nearly 75% of the available active sites, before transitioning into a slower intraparticle diffusion phase. This rapid uptake confirms that surface-exposed functional groups generated during chemical modification are highly accessible to the drug molecules.

## 4. CONCLUSION

This study systematically establishes that the structural modification of polymer-hybrid nanoadsorbents directly enhances their colloid-chemical attributes, transforming their performance as drug delivery matrices. The combination of a high specific surface area (312.4 m2/g) and a stable electrokinetic configuration (Zeta potential of –34.2 mV) guarantees excellent physical stability and optimal interface interaction capabilities. The adsorption dynamics adhere strictly to the Langmuir monolayer paradigm and pseudo-second-order kinetics, with a maximum loading capacity reaching 248.5 mg/g for Ibuprofen. Ultimately, these results confirm that adjusting colloid-chemical parameters like surface charge and porosity enables precise regulation of drug loading, establishing these modified polymer hybrids as highly efficient platforms for targeted drug delivery and pharmaceutical separation processes.

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