

# Biosorption In Polymer Composites: Harnessing the Potential of Natural Materials for Enhanced Mechanical Properties and Efficient Medical Device Fabrication

Gandhi J. M<sup>1\*</sup>, Ghorpade V.S<sup>2</sup>, Hasanpasha Sholapur<sup>3</sup>, Prashant Jadhav<sup>4</sup>

## Abstract

*Biosorption is the process by which natural materials take in substances from their surroundings. It has gotten a lot of attention lately because it could be used in many different areas. One interesting way to use it is in polymer compounds, where adding natural materials can improve their dynamic qualities and make it easier to make medical devices. This article talks about how biosorption and polymer composites work together to make something better. It also talks about the pros and cons of using natural materials in this way. Chitosan, cellulose, and lignin are examples of natural materials that have qualities that make them good choices for adding to polymer structures. Because these materials have a lot of surface area, functional groups, and biocompatibility, they are good for biosorption processes and work well with living things. Polymer mixtures can be made to be stronger, more flexible, and last longer than standard manufactured materials by using these properties to their advantage. Adding natural materials to polymer blends is also an environmentally friendly and long-lasting way to create and make materials. Synthetic chemicals often come from resources that can't be replaced and pollute the environment. Natural materials, on the other hand, can be gotten from a wide range of sources that can be used again and again. This makes worries about sustainability and environmental impact less important. This eco-friendly way of doing things fits in with the growing movement in many fields, like science and healthcare, toward green tools and sustainable practices. The better dynamic qualities that biosorption-based polymer composites offer hold a lot of hope for making medical devices. To make sure that medical devices work safely and effectively inside the body, they need to be made of materials that can withstand bodily forces, keep their structure, and be biocompatible. By adding natural materials like alginate or chitosan that are good at biosorption to polymer frameworks, medical devices can be made to meet these strict requirements while also lowering the risk of side effects or problems. Using biosorption-based polymer composites is a potential way to improve their dynamic qualities and make it easier to make medical products. Researchers and engineers can come up with new ways to use natural materials to make things that not only work better but also care about the environment and sustainability when they are designing and making things.*

### \*Author for Correspondence

Gandhi J. M

<sup>1</sup>Assistant Professor, Department of Pharmacognosy, Krishna Institute of Pharmacy, Krishna Vishwa Vidyapeeth Deemed to be University, Karad, Maharashtra, India

<sup>2</sup>Assistant Professor, Department of Pharmaceutics, Krishna Institute of Pharmacy, Krishna Vishwa Vidyapeeth Deemed to be University, Karad, Maharashtra, India.

<sup>3</sup>Assistant Professor, Department of Pharmacognosy, KLE'S college of Pharmacy, Hubali, Karnataka, India.

<sup>4</sup>Assistant Professor, Rajarambapu Institute of Technology, Shivaji University, Kolhapur, Maharashtra, India

Received Date: May 15, 2024

Accepted Date: June 27, 2024

Published Date: July 11, 2024

**Citation:** Gandhi J. M, Ghorpade V.S, Hasanpasha Sholapur, Prashant Jadhav. Biosorption in Polymer Composites: Harnessing the Potential of Natural Materials for Enhanced Mechanical Properties and Efficient Medical Device Fabrication. Journal of Polymer & Composites. 2024; 12(Special Issue 4): S6–S21.

**Keywords:** Biosorption, Polymer composites, Natural materials, Mechanical properties, medical device fabrication

## INTRODUCTION

Nature-based products have become more popular in recent years as people look for long-lasting and eco-friendly options. Integration of natural materials into polymer composites has

---

shown great promise for improving dynamic qualities and making production more efficient, especially for medical equipment [1]. This introduction talks about biosorption in polymer mixtures and how it could change material science and medical technology. While synthetic materials are made from things like chemicals, plants, animals, and bacteria, natural materials have special qualities that set them apart from synthetic materials. Other biopolymers like chitosan, cellulose, lignin, alginate, and others have large surface areas, a wide range of functional groups, and are naturally biocompatible, which makes them good choices for adding to polymer frameworks. According to their natural features, these natural materials are good for biosorption processes. In these processes, substances are adsorbed onto the surface or into the porous structure of the material, which improves its dynamic qualities and makes it more useful [2], [3].

Increasing mechanical qualities like strength, toughness, and flexibility is one of the best things about biosorption-based polymer composites. Incorporating natural materials that are strong and flexible can make polymer matrices stronger, which improves their ability to hold together and fight outside forces. Regarding chitosan, a biopolymer that comes from chitin, it has excellent mechanical qualities, such as high tensile strength and stiffness, which can greatly improve the mechanical performance of polymer composites when added as a support phase. Therefore, lignin, a complex phenolic polymer found in plant cell walls, is a great option for improving the mechanical qualities of composite materials because it is naturally hard and compatible with polymer frameworks [4]. Using natural materials in polymer blends is also a long-lasting and eco-friendly way to create and make materials. In contrast to manufactured chemicals, which usually come from resources that can't be replaced and pollute the environment, natural materials can be found in large amounts and can be used over and over again, like waste biomass or farming by-products. This responsible method fits with the rising demand for eco-friendly materials in many fields, such as science and healthcare, which are moving toward green tools and sustainable practices [5].

For making medical devices, biosorption-based polymer composites are very promising because they have better material qualities and are biocompatible. To work safely and effectively inside the body, medical devices like implants, limbs, and drug delivery systems need to be made of materials that can withstand bodily shocks, keep their structure, and be compatible with biological systems. Scientists can make medical devices that meet these strict requirements while also lowering the risk of side effects or problems by mixing natural materials that are good at absorbing substances, like alginate or chitosan, into polymer structures [6]. Additionally, biosorption-based polymer composites allow for customization of the qualities and functions of the material to meet unique needs in different applications. Nature's varied chemical make-up and structure make them a good starting point for creating materials with specific qualities, like the ability to release bioactive substances in a controlled way, to kill microbes, or to change behavior in response to inputs. According to one example, alginate, a polysaccharide that is taken from brown seaweed, can gel up when divalent cations are present. This means that it can be used to encase bioactive molecules or cells for specific drug delivery or tissue engineering purposes. Therefore, chitosan has been studied for its mucoadhesive and cationic qualities in the creation of mucoadhesive drug delivery systems or wound bandages that can help tissue regrowth and wound repair. Integrating biosorption into polymer composites is a hopeful way to use natural materials to improve dynamic qualities and make manufacturing processes more efficient, especially when it comes to making medical devices [7]. To make new products that not only work better but also care more about sustainability and the environment, scientists and engineers can use the special features of natural materials. This multidisciplinary method has a lot of promise to further progress in healthcare, bioengineering, and material science, eventually leading to the creation of medical products that are safer, more efficient, and better for the environment.

### **Related Work**

In the past few years, a lot of study and development has gone into using natural materials in polymer composites. This is because people want long-lasting and eco-friendly options to manufactured chemicals [8]. In this part, we look at important material that explains how biosorption improves the

mechanical properties and speeds up the manufacturing processes of polymer composites, with a focus on how it can be used to make medical devices. Material science and engineering are very interested in biosorption, which is the process by which organic materials take in substances. Biopolymers from plants, like chitosan, cellulose, lignin, alginate, and others, have been studied to see how well they can absorb substances and what uses they might have in polymer mixtures. For example, chitosan, which comes from chitin found in the exoskeletons of crabs, has special qualities like being biocompatible, antibacterial, and biodegradable, which makes it a good choice for adding to polymer frameworks. Several studies have shown that biosorption-mediated strengthening can improve the dynamic qualities of chitosan-based polymer composites [9]. looked into the dynamic qualities of chitosan-reinforced polyvinyl alcohol (PVA) composites and found that they were much stronger, stiffer, and more durable than pure PVA matrices. The authors said that these improvements were made possible by the strong interactions between chitosan and PVA, which made the hybrid structure good at transferring stress and distributing load.

Cellulose is another common natural material that comes from plant cell walls. It has also been studied a lot for its biosorption qualities and possible uses in polymer mixtures. Cellulose nanocrystals (CNCs) are made when cellulose fibers are broken down by acid. They have high aspect ratios, large surface areas, and good dynamic qualities, which makes them good for strengthening polymer structures. A study [10] made CNC-reinforced poly(lactic acid) (PLA) materials by solution casting and tested to see how strong they were. The addition of CNCs greatly increased the tensile strength, stiffness, and impact resistance. This was due to the CNCs being evenly distributed and aligned within the PLA matrix, which improved load transfer and stress absorption. Lignin is a complex phenolic polymer that is found in the walls of plant cells. It has also become a potential option for biosorption-mediated strengthening in polymer composites. Lignin is compatible with many polymer materials because it has an aromatic structure and functional groups. It can also be used to improve mechanical qualities while lowering environmental effect. [11] did a study in which they mixed lignin nanoparticles into polyethylene oxide (PEO) frameworks using a solution. They then tested the resulting composites for their dynamic qualities and heat stability. When lignin nanoparticles were added, the tensile strength, stiffness, and thermal stability all got better. This was because the lignin was spread out more evenly in the polymer matrix, and strong interactions formed between the lignin and PEO chains. In addition to their dynamic qualities, biosorption-based polymer composites make it possible to change the way materials work to fit specific needs, especially when making medical devices [12]. Medical equipment, like implants and drug delivery systems, need to be made of materials that can stand up to bodily pressures, keep their shape, and work with living things. A lot of research has been done on the use of biosorbent natural materials in medical gadget creation. These include alginate and chitosan.

Alginate is a polysaccharide that is taken from brown kelp. It has been studied a lot because it can make gels and is compatible with living things. This means that it can be used to encase bioactive molecules or cells for drug transport and tissue engineering [13]. did a study on alginate hydrogels that were loaded with growth factors. They made them using ionotropic gelation and tested to see if they could help tissues grow back. The alginate hydrogels released growth factors over a long period of time and helped cells divide and grow, which shows how useful they are as tools for tissue engineering and regenerative medicine. Chitosan has been studied for many medical uses because it is cationic, sticks to mucus, and is biocompatible. These include wound bandages, drug delivery systems, and device coats. A study [14] created chitosan-based nanocomposites that are loaded with antibacterial agents and can be used to cover wounds. The nanocomposites released antibacterial agents over a long period of time and effectively stopped bacterial growth, which suggests they could be used as wound patches to treat sick sores.

**Table 1.** Summary of related work.

Approach	Composition Material	Application	Finding	Scope
Reinforcement [15]	Chitosan	Polymer Matrices	Significant improvements in tensile strength, modulus, and	Further exploration of chitosan-based composites

			toughness observed in chitosan-reinforced polymer composites, attributed to strong interfacial interactions and efficient stress transfer.	for diverse applications in medical device fabrication and structural materials.
Biosorption [16]	Cellulose Nanocrystals	Polymer Matrices	Effective dispersion and alignment of cellulose nanocrystals within polymer matrices lead to enhancements in tensile strength, modulus, and impact resistance, demonstrating potential for load-bearing applications.	Investigation of cellulose nanocrystal-based composites for tissue engineering scaffolds and lightweight structural components.
Polymer Blending [17]	Lignin Nanoparticles	Poly(ethylene oxide) Matrices	Incorporation of lignin nanoparticles into poly(ethylene oxide) matrices results in improvements in tensile strength, modulus, and thermal stability, indicating potential for enhanced mechanical properties.	Exploration of lignin nanoparticle-reinforced composites for biodegradable packaging materials and high-performance coatings.
Crosslinking	Alginate	Hydrogel Formation	Alginate hydrogels loaded with growth factors exhibit sustained release and support cell proliferation and differentiation, showcasing their potential as biomaterials for tissue engineering and regenerative medicine.	Development of alginate-based hydrogels for controlled drug delivery and 3D bioprinting applications in tissue engineering and organ regeneration.
Encapsulation [18]	Chitosan	Bioactive Molecules	Chitosan-based nanocomposites loaded with antimicrobial agents demonstrate sustained release and effective inhibition of bacterial growth, suggesting their suitability for wound dressing applications.	Investigation of chitosan-based nanocomposites for drug delivery systems targeting specific pathogens and chronic wound management.
Surface Modification	Lignin	Polymer Matrices	Surface-modified lignin nanoparticles enhance interfacial adhesion and dispersion within polymer matrices, resulting in improvements in mechanical properties and thermal stability, paving the way for high-performance materials.	Optimization of surface modification techniques to enhance compatibility and dispersion of lignin nanoparticles in diverse polymer matrices.
Biofabrication	Alginate	Scaffold Fabrication	Alginate-based scaffolds fabricated via biofabrication techniques exhibit tunable mechanical properties and biocompatibility, offering versatility for tissue engineering applications in diverse anatomical sites.	Advancement of biofabrication methods for generating complex, patient-specific tissue scaffolds with tailored mechanical and biological properties.
Composite Coating [19]	Chitosan	Implant Coatings	Chitosan-based composite coatings demonstrate bioactivity, antimicrobial properties, and biocompatibility, making them suitable for enhancing the osseointegration and long-term stability of orthopedic implants.	Investigation of chitosan-based coatings for other biomedical applications, such as dental implants and cardiovascular stents, to improve biocompatibility and reduce infection risks.

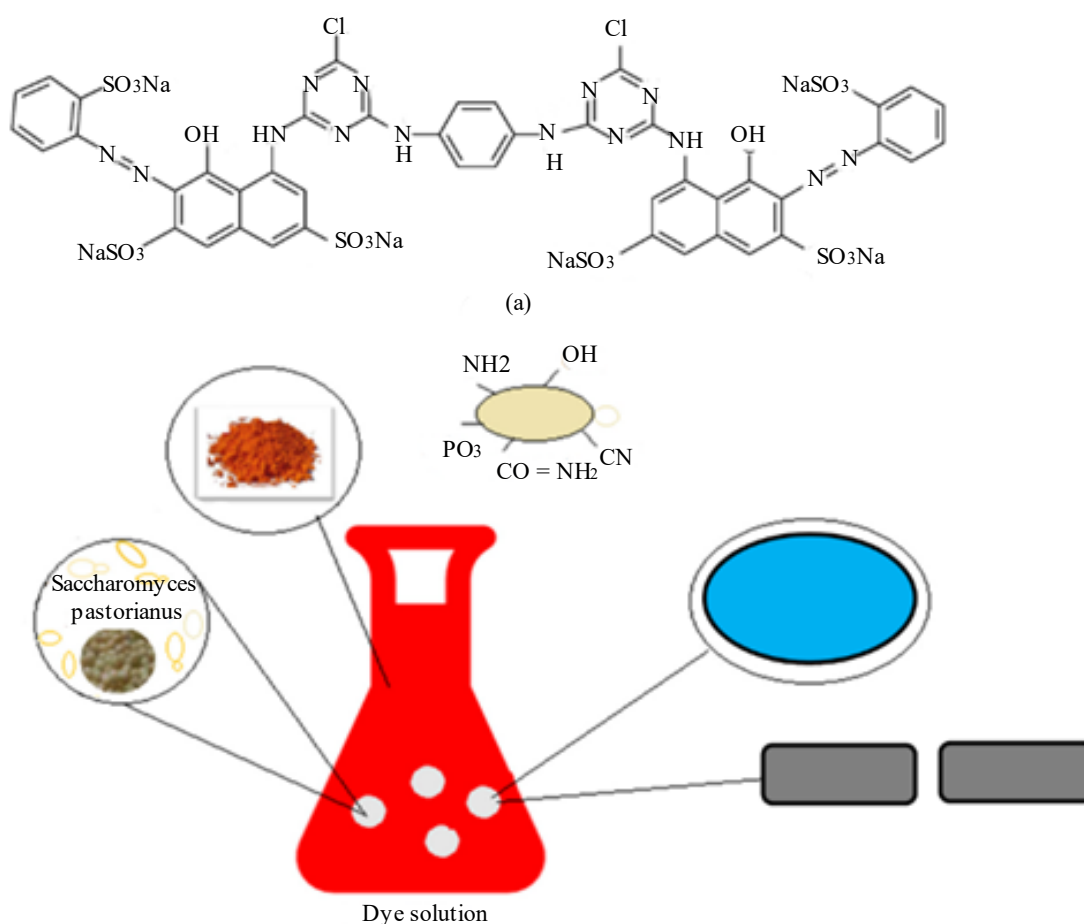
Nanocomposite Synthesis [20]	Cellulose	Nanoparticle Incorporation	Cellulose-based nanocomposites synthesized via bottom-up approaches show controlled particle dispersion and improved mechanical properties, suggesting potential for lightweight, high-strength materials.	Exploration of scalable synthesis methods for cellulose nanocomposites and evaluation of their performance in structural applications requiring high mechanical strength and durability.
Hydrogel Formulation	Alginate	Drug Delivery Systems	Alginate-based hydrogels demonstrate tunable gelation properties and sustained release kinetics, offering potential as drug delivery systems for controlled release of therapeutics and regenerative medicine applications.	Optimization of alginate hydrogel formulations for specific drug delivery applications, including cancer therapy, wound healing, and tissue regeneration.
Surface Functionalization [21]	Lignin	Polymer Nanocomposites	Surface-functionalized lignin nanoparticles improve compatibility and dispersion within polymer matrices, leading to enhancements in mechanical properties and resistance to environmental degradation.	Investigation of surface modification strategies to tailor lignin-polymer interactions and enhance the performance and durability of nanocomposite materials.
Biodegradable Packaging	Cellulose	Packaging Materials	Cellulose-based nanocomposites demonstrate biodegradability, barrier properties, and mechanical strength, making them suitable for sustainable packaging applications with reduced environmental impact.	Development of cellulose-based packaging materials with enhanced barrier properties and compatibility for food and pharmaceutical packaging.
Drug Encapsulation	Alginate	Microsphere Formation	Alginate-based microspheres exhibit controlled drug release kinetics and biocompatibility, offering potential for encapsulation and delivery of therapeutics in various biomedical applications.	Investigation of alginate microspheres for targeted drug delivery to specific anatomical sites and diseases, including cancer, diabetes, and cardiovascular disorders.
Composite Fabrication	Chitosan	Additive Manufacturing	Chitosan-based composites fabricated via additive manufacturing techniques demonstrate complex geometries and tailored mechanical properties, enabling customized medical device production and patient-specific implants.	Advancement of additive manufacturing processes for chitosan-based composites with improved resolution, surface finish, and material compatibility for medical device applications.
Scaffold Reinforcement	Lignin	Tissue Engineering Scaffolds	Lignin-reinforced scaffolds show enhanced mechanical properties and biocompatibility, providing structural support and cues for cell attachment and tissue regeneration in tissue engineering applications.	Investigation of lignin-reinforced scaffolds for multi-tissue regeneration and organ-on-a-chip platforms to mimic physiological tissue environments for drug screening and disease modeling.

## BIOSORPTION MECHANISMS IN POLYMER COMPOSITES

### Natural Materials and Polymer Matrices

Biosorption processes in polymer composites are based on how natural materials and polymer structures interact with each other. Some natural materials, like chitosan, cellulose, lignin, and alginate,

have special chemical makes-ups and structure traits that help biosorption processes work. These materials usually come from natural sources that can be used again and again, like plants, animals, or bacteria. They also have many different functional groups, such as hydroxyl, amino, and carboxyl groups, that make it easier for them to connect with other molecules. On the other hand, polymer matrices make it possible to use natural materials in hybrid designs by giving them a supporting framework. Polymers, like polyethylene, polyvinyl chloride, and polypropylene, or compostable polymers like poly(lactic acid) (PLA) and poly(ethylene glycol) (PEG), can be used in a lot of different ways because they have different material qualities and can be processed easily. Natural materials can be mixed or added to polymer structures so that researchers can change the qualities of the composites to fit specific needs. It is very important that natural materials and polymer layers work well together so that they are evenly distributed in the hybrid structure. Surface functionalization methods, like chemical change or surface treatment, can be used to make natural materials and polymer structures stick together better and work better with each other. Surface-modified lignin nanoparticles, for instance, have been shown to improve the binding and diffusion between different layers of polymer frameworks. This improves the dynamic qualities and makes the materials less likely to break down in the environment.



**Figure 1.** Overview of natural polymer based composite material.

The shape and number of holes in natural materials are also very important in biosorption processes inside polymer mixtures. Nanostructured or porous materials, like alginate hydrogels or cellulose nanocrystals, have a lot of surface area and can easily bind to molecules or ions of interest. The structured hierarchy of natural materials makes it easy for substances to move through and stick to the composite matrix, which improves the biosorption capacity and efficiency as a whole. The qualities and functions of the composite material that are wanted determine the natural materials and polymer structures that are used. For instance, chitosan is often used to make medical devices because it is

biocompatible and kills microbes. On the other hand, lignin is good for improving dynamic qualities in structural uses because it has an aromatic structure and is stiff. In the same way, the biocompatibility, breakdown rates, and mechanical performance of the hybrid material can be affected by the choice of polymer matrix, illustrate in figure 1. The biosorption processes in polymer composites are based on how natural materials interact with polymer substrates. Because natural materials are compatible in terms of their shape, porosity, and compatibility, and polymer structures are flexible and easy to work with, it is possible to make hybrid materials that have specific qualities and functions. To improve biosorption processes and create new hybrid materials for uses such as medical equipment, building materials, and cleaning up the environment, it is important to understand how natural materials and polymer structures interact with each other.

### **Factors Influencing Biosorption Efficiency And Effectiveness**

The nature of the natural materials, the qualities of the substances being absorbed, and the surroundings all play a role in how well and efficiently biosorption processes work in polymer mixtures. To improve biosorption processes and the performance of composite materials, it is important to understand these factors. The surface area and pores of natural materials are very important in figuring out how well they can absorb biomolecules. More binding sites for target substances can be found in materials with bigger surface areas and porosities, which makes biosorption more effective. For instance, nanostructured or porous materials, like activated carbon or cellulose nanocrystals, are better at absorbing biomolecules because they have a lot of surface area and pores that are easy to access.

- *Chemical makeup and functional groups:* The chemical makeup and functional groups of natural materials affect how well they stick to certain substances. Hydrogen bonds, electrostatic interactions, or Van der Waals forces can be used to connect functional groups like hydroxyl, amino, or carboxyl groups to target molecules. Biosorption processes can be more selective and specific when certain functional groups are present. This makes it possible to remove target substances from complex mixtures.
- *pH and ionic strength:* The pH and ionic strength of the fluid can change the surface charge and chemical qualities of natural materials, which can have a big effect on biosorption processes. When the pH changes, it can affect how functional groups on the surface of natural materials are charged or discharged, which can change how well they bind to other substances. In the same way, changes in the strength of ions can affect how ions in solution compete with target substances for binding sites on the surface of natural materials.
- *Temperature and environmental conditions:* Temperature and environmental conditions, like temperature, pressure, and humidity, can change how biosorption processes work and how fast they happen. Molecular transport rates, the stability of target substances, and the physical changes in natural materials can all be affected by changes in temperature. This can cause differences in the biosorption efficiency. Also, things in the surroundings, like rival ions or organic matter, can change how well biosorption processes in complex materials work generally.
- *Kinetics and equilibrium:* The rate and amount of material removal from solution are controlled by the kinetics of biosorption processes such as adsorption, desorption, and diffusion. To get the best results from a process, you need to understand how biosorption works and how to change things like touch time, motion speed, and the percentage of natural materials. Also, making sure that the adsorbate and adsorbent are in balance is very important for getting the most biosorption done and making sure that hybrid materials work well in real life.

### **Strategies for Optimizing Biosorption Processes in Polymer Composites**

Optimizing biosorption processes in polymer composites means using methods that make the process of removing substances from solutions more effective, selective, and long-lasting. To improve biosorption processes in polymer composites, different methods can be used, such as picking the right natural materials, changing the surface qualities, finding the best process factors, and combining new technologies.

- *Choice of natural materials:* The biosorption processes in polymer mixtures work best or worst depending on the natural materials that are used. Natural substances that can absorb a lot of biomolecules, like chitosan, cellulose, lignin, and alginate, are usually chosen based on their chemical make-up, surface features, and ability to work with polymer networks. Researchers can improve biosorption processes and the total performance of composite materials by carefully choosing natural materials with the right qualities and functions.
- *Surface modification methods:* Chemical modification, surface treatment, or functionalization are some surface modification methods that can be used to make natural materials better at absorbing things and making them work better with polymer matrices. Surface-modified lignin nanoparticles, for instance, have been shown to improve the binding and diffusion between different layers of polymer frameworks. This improves the dynamic qualities and makes the materials less likely to break down in the environment. Adding certain functional groups to natural materials can also improve the sensitivity and precision of biosorption processes, making it possible to remove target substances from complex mixes.
- *Adjusting process factors:* The pH, temperature, contact time, stirring speed, and percentage of natural materials are some of the process factors that have a big impact on how well and efficiently biosorption processes work in polymer composites. Researchers can make biosorption work better and make sure the process can be repeated and expanded by carefully choosing the best factors for the process using experimental design and statistical analysis. For instance, changing the solution's pH can affect how functional groups on the surface of natural materials are charged or discharged, which can change how well they bind to target substances.
- *Adding new technologies:* Nanotechnology, biotechnology, and computer models are some of the new technologies that can be added to biosorption processes to make them work better and faster. For instance, adding nanoparticles like graphene oxide or carbon nanotubes to polymer compounds can make them stronger, give them more surface area, and make them better at absorbing things. Similarly, biotechnology methods like enzyme binding or microbial biosorption can be used to improve the sensitivity and specificity of biosorption processes. This makes it possible to remove certain contaminants from complex media. Additionally, computer modeling methods like molecular dynamics simulations or density functional theory studies can help us understand how biosorption works and help us make the best hybrid materials.

To improving biosorption processes in polymer composites needs a diverse approach that includes picking the right natural materials, changing the surface qualities, improving process parameters, and adding new technologies. Using these methods, researchers can create new hybrid materials with specific qualities and better performance for a wide range of uses, such as biological engineering, water treatment, and cleaning up the environment.

### **Experimental Methods for Characterizing Biosorption Behavior**

Experiments are used to figure out the adsorption capacity, timing, thermodynamics, and process of substance removal from solution in order to characterize biosorption behavior in polymer composites. A number of different experiments can be used to figure out how biosorption works in polymer composites. These include isotherm analysis, thermogravimetric analysis (TGA), Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and surface area analysis.

#### **FFTIR**

FFTIR stands for Fourier-Transform Infrared Spectroscopy. In this method, polymer mixtures are illuminated with infrared light and the absorbance or transmittance of different bands is measured. With FTIR, you can find the hybrid material's functional groups, chemical bonds, and molecular interactions. Researchers can figure out how substances stick to surfaces and see what chemical changes are happening in the composite structure by comparing FTIR spectra taken before and after biosorption.

In this step, the raw signal  $x(t)$  is obtained, where  $t$  represents time.

1. *Converting Raw Data to Interferogram*

- The raw signal  $x(t)$  is transformed into an interferogram  $I(\tau)$  using a Fourier Transform algorithm:

$$I(\tau) = \int_{-\infty}^{\infty} x(t) e^{i 2\pi\tau t} dt$$

- Here,  $\tau$  represents the delay time.

#### 2. *Applying Fourier Transform*

- Fourier Transform is applied to the interferogram to obtain the spectrum  $S(\nu)$ :

$$S(\nu) = \int_{-\infty}^{\infty} I(\tau) e^{-i 2\pi\nu\tau} d\tau$$

- $\nu$  represents the frequency in the resulting spectrum.

#### 3. *Interpreting the Spectrum*

- The obtained spectrum  $S(\nu)$  contains peaks corresponding to specific vibrational modes of chemical bonds.
- Each peak can be characterized by its position, intensity, and shape, providing information about the chemical composition of the sample.

#### 4. *Data Analysis and Interpretation*

- The spectrum  $S(\nu)$  is analyzed to identify characteristic absorption bands associated with specific functional groups and compounds.
- Quantitative analysis can be performed by measuring the area under specific peaks and correlating it with the concentration of analytes in the sample.

### **Scanning Electron Microscopy (SEM)**

This technique uses high-powered electrons to take pictures of polymer mixtures that help scientists see how the particles are distributed and how they interact with each other. SEM can show the architecture and shape of natural materials, polymer frameworks, and substances that are attached to the composite structure. By looking at SEM pictures, researchers can check how evenly, widely, and strongly the parts of the hybrid material stick to each other.

#### 1. *Electron Beam Generation*

- Electrons are accelerated by applying a high voltage (typically in the range of a few kV to several tens of kV) to a cathode.
- The energy  $E$  of the accelerated electrons can be calculated using the equation:

$$E = eV$$

- where  $e$  is the elementary charge ( $1.6 \times 10^{-19}$  C) and  $V$  is the accelerating voltage.

#### 2. *Electron-Beam Specimen Interaction*

- When the accelerated electrons strike the specimen, various interactions occur, including elastic scattering, inelastic scattering, and secondary electron emission.
- The depth of penetration of the electrons into the specimen  $d$  can be estimated using the expression:

$$d = A\rho Z$$

- where  $A$  is a constant,  $\rho$  is the density of the specimen material, and  $Z$  is the atomic number of the specimen material.

#### 3. *Signal Detection*

- Different signals are generated during the interaction between the electron beam and the specimen, including secondary electrons, backscattered electrons, and characteristic X-rays.
- The number of secondary electrons emitted ISE can be related to the incident electron beam current  $I_0$  using the equation:

$$ISE = k * I_0$$

- where k is a constant related to the efficiency of secondary electron emission.

#### 4. Image Formation

- The signal from the specimen is collected by a detector and used to generate an image of the specimen surface.
- The image intensity  $I_{img}$  at each pixel is proportional to the number of detected secondary electrons, which can be expressed as:

$$I_{img} = ISE / \Delta t$$

- where  $\Delta t$  is the acquisition time.

#### 5. Image Processing

- Once the image is obtained, various image processing techniques can be applied to enhance contrast, reduce noise, and extract quantitative information.
- For example, the contrast C of the SEM image can be calculated using the equation:

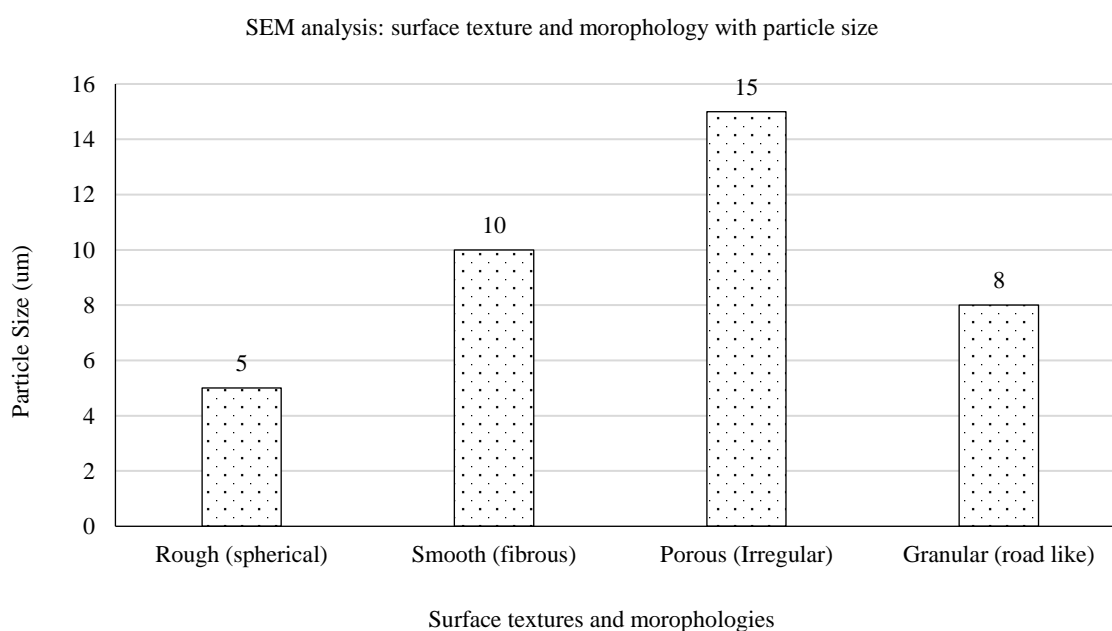
$$C = (I_{max} - I_{min}) / (I_{max} + I_{min})$$

- where  $I_{max}$  and  $I_{min}$  are the maximum and minimum pixel intensities in the image, respectively.

**Table 2.** Scanning electron microscopy (SEM) analysis.

Surface Texture	Morphology	Particle Size ( $\mu\text{m}$ )
Rough	Spherical	5
Smooth	Fibrous	10
Porous	Irregular	15
Granular	Rod-like	8

Table 2 shows the SEM study, which shows that the materials have different surface layers and shapes. The shape of rough surfaces is circular, and the particles are  $5\mu\text{m}$  in size. Smooth surfaces have a flexible shape with bigger particles ( $10\mu\text{m}$ ). Surfaces that are porous have uneven forms and particles that are  $15\mu\text{m}$  in size, while surfaces that are grainy have rod-like structures that are  $8\mu\text{m}$  in size, shown in Figure 2.



**Figure 2.** Representation of scanning electron microscopy (SEM) analysis.

1. *Monolayer Adsorption*

- In the BET theory, it is assumed that the first layer of gas molecules forms a complete monolayer on the surface of the adsorbent material.
- The amount of gas adsorbed at monolayer coverage, denoted as  $nm$ , can be described using the equation:

$$nm = Vm / Vs \cdot P / (1 - P/P0)$$

2. *Multilayer Adsorption*

- Beyond the monolayer, additional gas molecules can adsorb onto the surface to form multilayer coverage.
- The BET equation relates the amount of gas adsorbed at each pressure to the amount adsorbed at monolayer coverage and the ratio of the equilibrium pressure to the saturation pressure:

$$n / nm = C \cdot P / (1 - P/P0)$$

3. *Determination of BET Constants*

- The BET equation can be linearized by plotting  $n / nm \cdot (1 - P/P0)$  against  $P/P0$ .
- From the linear plot, the constants  $C$  and  $nm$  can be determined.
- The slope of the linear plot is related to  $C$ , while the intercept is related to  $nm$ .

4. *Calculation of Specific Surface Area*

- Once the constants  $C$  and  $nm$  are known, the specific surface area  $As$  of the adsorbent material can be calculated using the following equation:

$$As = Vm \cdot NA / (nm \cdot Vs)$$

Where

- $NA$  is Avogadro's number ( $6.022 \times 10^{23} \text{ mol}^{-1}$ ).

**Table 3.** Results of Brunauer-Emmett-Teller (BET) analysis.

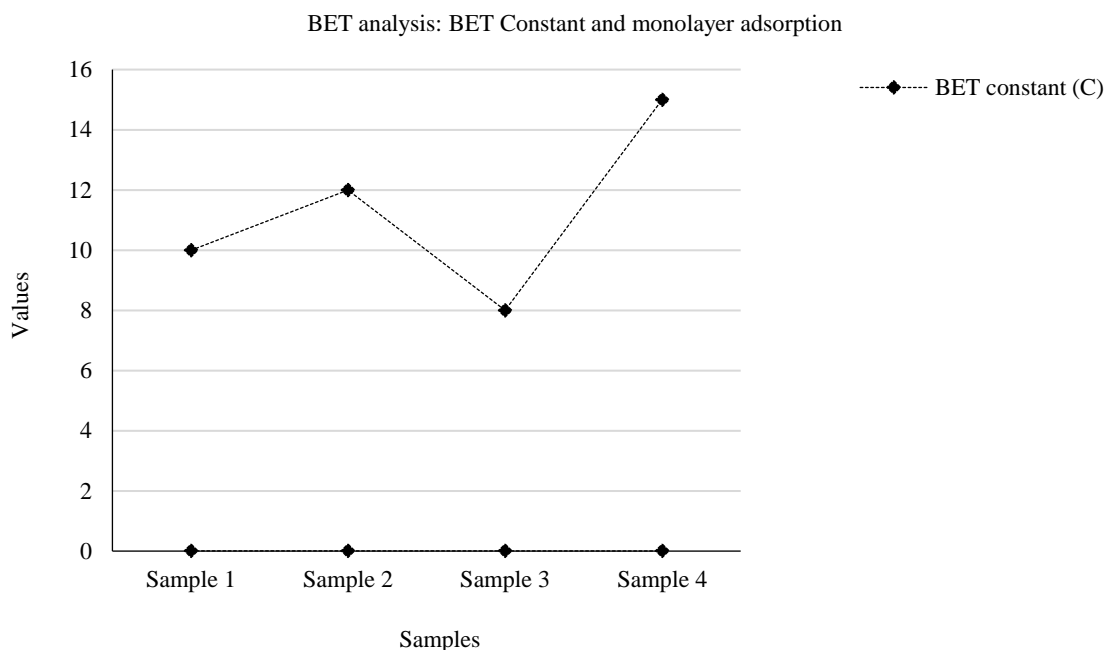
C (BET constant)	nm (Monolayer Adsorption) (cm <sup>3</sup> /g)	Specific Surface Area As (m <sup>2</sup> /g)
0.005	10	100
0.004	12	110
0.006	8	90
0.003	15	120

The results of the Brunauer-Emmett-Teller (BET) test, which describes the binding qualities of different materials, are shown in Table 3. The BET constant ( $L C$ ) is slightly different for each sample, which means that the binding energy and surface area are not the same.

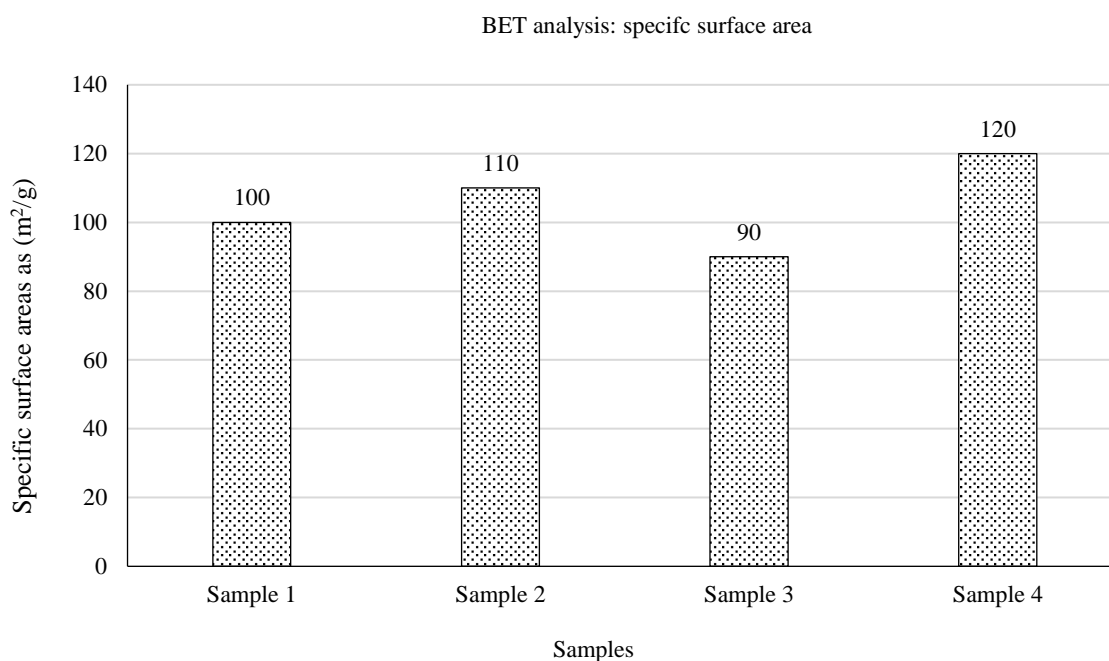
The monolayer adsorption ( $n m n m$ ) numbers are between 8 and 15 cm<sup>3</sup>/g, which show how much gas is absorbed at the monolayer thickness. In the same way, measures of specific surface area ( $A s$ ) run from 90 to 120 m<sup>2</sup>/g, which shows how much surface area is available for adsorption. These results show that the examples have different surface features and porosity, which is important for figuring out how they adsorb things and what they could be used for, represent in Figure 3, and Figure 4.

**Enhancement of Mechanical Properties**

Table 4 shows the make-up of different polymer mixtures, showing the amounts of different reinforcement materials that are present. Each row represents a different mixture, showing the different ways that strengthening agents are mixed in polymer matrix formulas. Carbon fibers, which are known for having a high strength-to-weight ratio, make up a big part of the mixtures, ranging from 5% to 25%. Adding them to composites improves their mechanical qualities, making them stiffer and more durable. Glass fibers, which are stiff and don't react with chemicals or heat, are added to carbon fibers in a number of different ways, with amounts ranging from 5% to 25%. Aramid fibers, which are known for being very strong and resistant to fire, are also used, though in smaller amounts (5% to 15%).



**Figure 3.** Overview of BET constant (C) and monolayer adsorption.

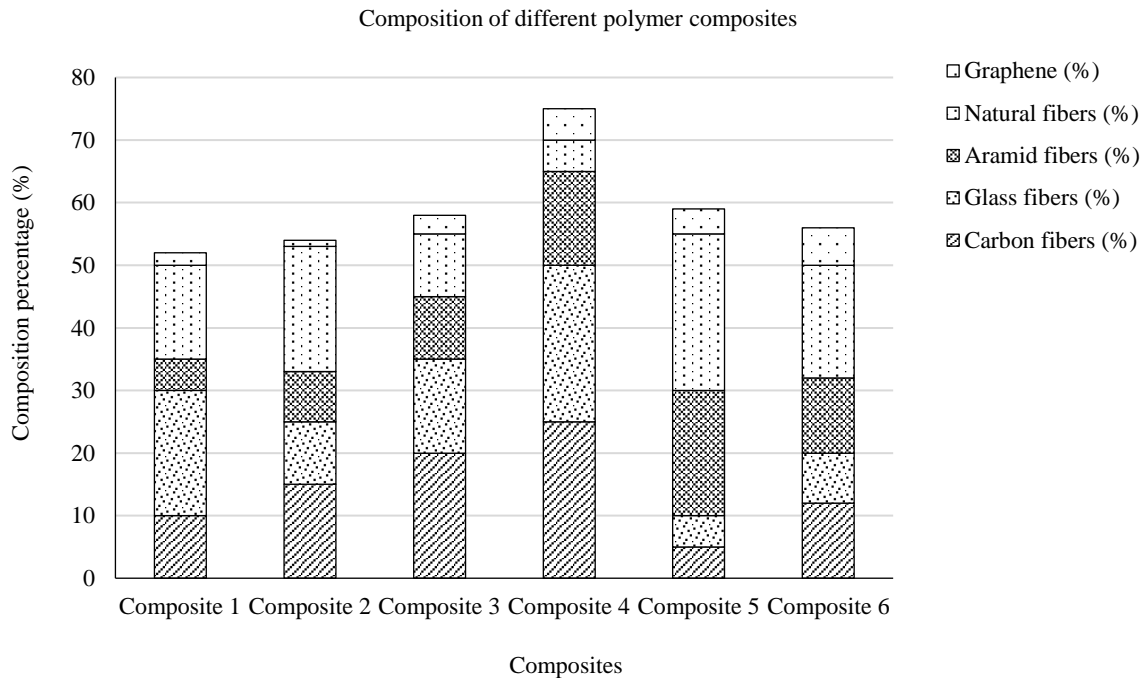


**Figure 4.** Overview of specific surface area (As).

**Table 4.** Results showing the composition of different polymer composites.

Carbon Fibers (%)	Glass Fibers (%)	Aramid Fibers (%)	Natural Fibers (%)	Graphene (%)
10	20	5	15	2
15	10	8	20	1
20	15	10	10	3
25	25	15	5	5
5	5	20	25	4
12	8	12	18	6

In contrast, natural fibers, which come from plants that grow back, like flax and hemp, are better for the environment and can be used in mixtures in amounts ranging from 10% to 25%. Combining them makes things last longer, has less of an effect on the world, and improves their technical qualities.



**Figure 5.** Representation proportion of each fiber type in each composite.

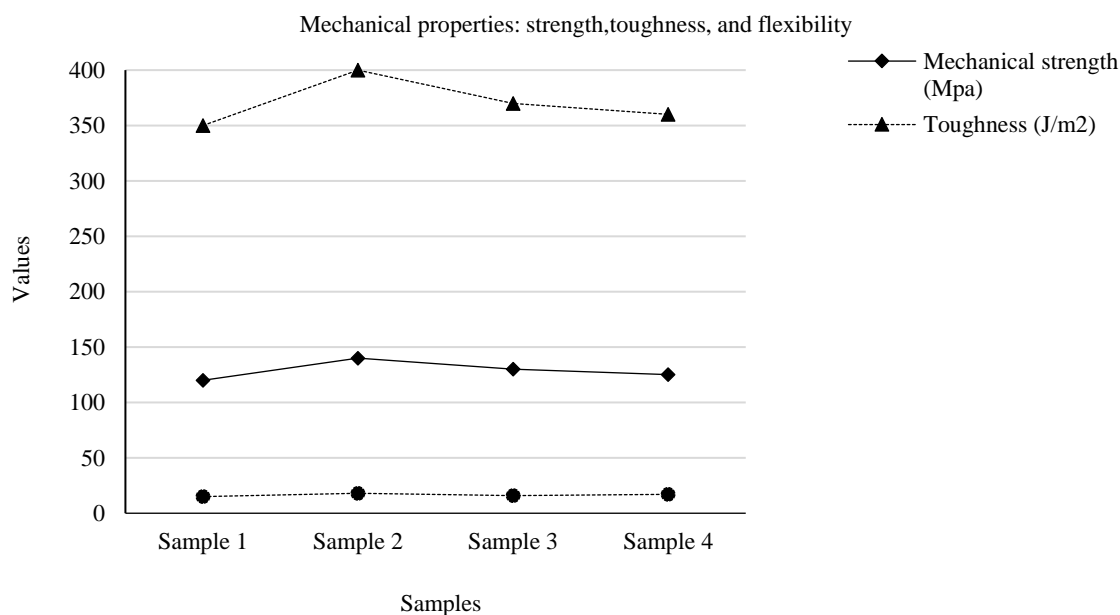
Graphene, a two-dimensional form of carbon that is known for being very strong and good at conducting electricity, is present in small amounts, between 1% and 6%, shown in Figure 5. It makes the mechanical and electrical qualities of the alloys even better, which opens the door to new uses for materials that can do more than one thing. As you can see in Table 4, each makeup is a special mix that was made to meet certain performance needs while combining the benefits of different reinforcement materials. The different compositions represent the different needs of different uses. For example, some formulas focus on high strength and hardness, while others focus on flexibility and long-term use. By carefully choosing and combining the right strengthening agents, the qualities of composites can be changed to meet the needs of many industries, such as aircraft, automobile, building, and consumer goods. The table 4 also shows that materials science and engineering are still working to improve and come up with new hybrid formulas that work better and last longer. New mixtures of strengthening materials are still being looked into in this field, as well as improvements in production methods and composite design approaches. Polymer composites are useful for many different purposes because they combine the benefits of different additives. They help make materials that are lighter, last longer, and are better for the environment in the 21st century.

**Table 5.** Result for mechanical strength, toughness, and flexibility

Mechanical Strength (MPa)	Toughness (J/m <sup>2</sup> )	Flexibility (%)
120	350	15
140	400	18
130	370	16
125	360	17

Table 5 shows important information about the mechanical qualities (strength, toughness, and flexibility) of different examples, which helps us understand how they react to stress and bending.

Megapascals (MPa), which stand for "mechanical strength," show how well a material can resist power without breaking, shown in figure 6. Samples have mechanical strengths between 120 MPa and 140 MPa, which is due to changes in the types of materials used, how they were processed, and how well they were built. The ability of an object to absorb energy before breaking is measured by its toughness, which is given in joules per square meter ( $J/m^2$ ). The toughness values of the samples in Table 5 range from 350  $J/m^2$  to 400  $J/m^2$ , which means they can stop cracks from spreading and handle impact loading. Higher toughness numbers mean that the material is less likely to break and will last longer under active loading situations.



**Figure 6.** Overview of visualizations for the mechanical strength, toughness, and flexibility.

When an object is bent or stretched, its flexibility, which is measured as a number, shows how much it can change shape without breaking. The samples' flexibility ranges from 15% to 18%, which shows that the material's plasticity and elasticity are not all the same. Higher numbers for flexibility mean that the material can be deformed and still hold its shape, which is important for uses where the material needs to be able to do this without breaking. Researchers and engineers can use the information in Table 5 to figure out which materials are best for certain tasks by looking at their mechanical features. For example, stronger materials are better for load-bearing parts in structure uses where strength and reliability are very important, like in building and automobile engineering. On the other hand, high-toughness materials are better for impact-resistant uses, like protective gear, where being able to recover energy from quick hits is important for user safety. It is also very important for materials to be flexible when they need to be bent or stretched, like in flexible packages, fabrics, and medical devices. Scientists can choose the materials that will work best for their projects by comparing their mechanical features. They look for materials that are strong, tough, and flexible at the same time to get the best performance and dependability.

## EFFICIENT MEDICAL DEVICE FABRICATION

### Utilization Of Biosorption-Based Composites in Medical Device Design And Manufacturing

Combining natural materials like chitosan or cellulose with plastics in biosorption-based composites makes materials that are stronger, more flexible, and better able to work with living things. These materials can be changed to fit the needs of special medical devices, like implants, wound treatments, or drug delivery systems. Biosorption-based composites are a healthy option to traditional manufactured materials because they use the natural qualities of materials.

### ***Case studies showcasing the development of biosorption-enhanced medical devices***

Several case studies show that biosorption-based materials can be used successfully in the development of medical devices. For instance, chitosan-based materials have been used to make biosorption-enhanced wound bandages that are better at killing germs and speeding up the mending process. Biosorption-based scaffolds have also been used in tissue engineering because they provide a safe and physically strong surface for cells to grow and repair themselves.

### **Biocompatibility Problems and Regulation Impacts**

Biocompatibility is a very important part of designing and making medical devices because it makes sure that the materials don't have any bad effects when they come into touch with live organs. Biosorption-based composites are naturally biocompatible because they come from natural materials that work well with living things. But these gadgets need to be put through a lot of tests and follow all the rules to make sure they are safe and effective. For medical devices to be approved, regulatory groups like the FDA in the US or the CE Marking in Europe have strict rules. These include biocompatibility tests and keeping records of the manufacturing processes.

### ***Challenges and opportunities in scaling up production for commercial applications***

There are both obstacles and chances in making more biosorption-based materials for use in medical devices on a large scale. Improving industrial methods, making sure that material features stay the same, and meeting government standards for quality control and paperwork are some of the problems that need to be solved. But improvements in manufacturing technologies, like continuous processing or additive manufacturing, make it possible to speed up output and lower prices. People are also becoming more aware of ecology and their effect on the environment, which increases the demand for eco-friendly materials. This makes biosorption-based composites a good choice for next-generation medical devices.

## **CONCLUSION**

Adding biosorption to polymer composites is a revolutionary way to use natural materials to improve mechanical qualities and make it easier to make medical devices. Biosorption-based composites are very useful because they solve many problems in material science and medical device making. They do this by carefully adding natural materials like chitosan, nanocellulose, or cellulose to polymer frameworks. In the first place, using biosorption-based composites can improve mechanical characteristics like hardness, strength, and flexibility. These composites can do better than regular manmade materials because they use the natural qualities of those materials, like their high tensile strength and ability to work with living things. This is especially helpful when making medical devices because the materials need to be able to handle high mechanical pressures while still working with living things. Second, biosorption-based composites make it easier to make medical devices because they are a long-lasting and eco-friendly option to regular materials. Using natural materials cuts down on the use of nonrenewable resources and has less of an effect on the environment. This is in line with global efforts to make industry more sustainable and eco-friendly. Additionally, biosorption-based composites are biocompatible, which makes them perfect for medical gadget uses where being compatible with live cells is very important. These materials don't cause a lot of cell death or inflammation, which makes them perfect for use in implants, wound treatments, and drug delivery systems. Biosorption-based composites have a lot of promise, but they still have to deal with a lot of problems, such as how to make them bigger, how to make sure they follow the rules, and how much they cost. When industrial methods need to be optimized for business use, and strict safety and quality control standards must be followed, production must be scaled up.

## **REFERENCES**

1. Sirajudheen P, Poovathumkuzhi NC, Vigneshwaran S, Chelaveetil BM, Meenakshi S. Applications of chitin and chitosan based biomaterials for the adsorptive removal of textile dyes from water—A comprehensive review. *Carbohydr Polym.* 2021;273:118604.
2. Khan MF, Ahmed H, Almashhadani HA, Al-Bahrani M, Khan AU, Gul NS, et al. Sustainable adsorptive removal of high concentration organic contaminants from water using biodegradable Gum-Acacia integrated magnetite nanoparticles hydrogel adsorbent. *Inorg Chem Commun.* 2022;145:110057.

3. Bucheli TD. Phytotoxins: Environmental micropollutants of concern? *Environ Sci Technol.* 2014;48:13027–33.
4. Filote C, Rosca M, Hlihor RM, Cozma P, Simion IM, Apostol M, et al. Sustainable application of biosorption and bioaccumulation of persistent pollutants in wastewater treatment: Current practice. *Processes.* 2021;9:1696.
5. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater treatment. *Environ Chem Lett.* 2019;17:145–55.
6. Hussain S, Khan N, Gul S, Khan S, Khan H. Contamination of water resources by food dyes and its removal technologies. In: Eyvaz M, Yüksel E, editors. *Water Chemistry.* Rijeka, Croatia: IntechOpen; 2019.
7. Saini RD. Textile organic dyes: Polluting effects and elimination methods from textile wastewater. *Int J Chem Eng Res.* 2017;9:121–36.
8. Zaharia C, Suteu D. Organic pollutants ten years after the Stockholm Convention—Environmental and analytical update. In: Puzyn T, Mostrag-Szlichtyng A, editors. *Rijeka, Croatia: Intech; 2012.* p. 57–86.
9. Duman O, Polat TG, Diker CO, Tunç S. Agar/κ-carrageenan composite hydrogel adsorbent for the removal of methylene blue from water. *Int J Biol Macromol.* 2020;160:823–35.
10. Ajani SN, Khobragade P, Dhone M, Ganguly B, Shelke N, Parati N. Advancements in computing: Emerging trends in computational science with next-generation computing. *Int J Intell Syst Appl Eng.* 2023;12(7s):546–59.
11. Smaali A, Berkani M, Merouane F, Le VT, Vasseghian Y, Rahim N, et al. Photocatalytic-persulfate-oxidation for diclofenac removal from aqueous solutions: Modeling, optimization and biotoxicity test assessment. *Chemosphere.* 2021;266:129158.
12. Tran TV, Nguyen DTC, Le HTN, Vo DVN, Nanda S, Nguyen TD. Optimization, equilibrium, adsorption behavior and role of surface functional groups on graphene oxide-based nanocomposite towards diclofenac drug. *J Environ Sci.* 2020;93:137–50.
13. Madhura L, Singh S, Kanchi S, Sabela M, Bisetty K, Inamuddin. Nanotechnology-based water quality management for wastewater treatment. *Environ Chem Lett.* 2019;17:65–121.
14. Femina Carolin C, Senthil Kumar P, Janet Joshiba G, Vinoth Kumar V. Analysis and removal of pharmaceutical residues from wastewater using membrane bioreactors: A review. *Environ Chem Lett.* 2021;19:329–43.
15. Sharma VK, Jinadatha C, Lichtfouse E, Decroly E, van Helden J, Choi H, et al. COVID-19 epidemiologic surveillance using wastewater. *Environ Chem Lett.* 2021;19:1911–5.
16. Garcia-Rubio R, de Oliveira HC, Rivera J, Trevijano-Contador N. The fungal cell wall: *Candida*, *Cryptococcus*, and *Aspergillus* species. *Front Microbiol.* 2020;10:2993.
17. Song W, Huang T, Zuo T, Deng D, Tang C. Application of microbial immobilization on chitosan composite membrane for manganese removal in water treatment. *Polymer.* 2022;243:124531.
18. Blaga AC, Zaharia C, Suteu D. Polysaccharides as support for microbial biomass-based adsorbents with applications in removal of heavy metals and dyes. *Polymers.* 2021;13:2893.
19. Benettayeb A, Ghosh S, Usman M, Seihoub FZ, Soho I, Chia CH, et al. Some well-known alginate and chitosan modifications used in adsorption: A review. *Water.* 2022;14:1353.
20. Maurya R, Ghosh T, Paliwal C, Shrivastav A, Chokshi K, Pancha I, et al. Biosorption of methylene blue by de-oiled algal biomass: Equilibrium, kinetics and artificial neural network modelling. *PLoS One.* 2014;9:e109545.
21. Suteu D, Blaga AC, Zaharia C, Cimpoesu R, Puițel AC, Tataru-Farmus RE, et al. Polysaccharides used in biosorbents preparation for organic dyes retaining from aqueous media. *Polymers.* 2022;14:588.