Chapter 7 Biosorbents and biomaterials: Application in the environment and in the health sector

Capítulo 7 Los biosorbentes y biomateriales: Aplicación en el medio ambiente y en el sector salud

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Abstract

The objective of this work is to carry out an analysis of the studies using sustainable materials with terms of biosorbents and biomaterials, the biosorbents applied in the environment are mentioned, mainly those applied in water, with the purpose of carrying out an analysis in the removal of different types of both organic and inorganic contaminants, mentioning the factors that are involved during the biosorption process, such as the effect of the pH value, type of material, temperature, pore size, to name a few, as well as its application in different studies. In the case of biomaterials, the biological, chemical, physical, among others, are described, mentioning the classification and applications of these biomaterials in different case studies, finally the conclusions are mentioned where it is highlighted that a large part of the reported studies have been carried out in a lot, so it is necessary to carry out more research focused on all the factors that worsen biosorption but on a pilot, industrial scale and considering economic processes with a focus on recovering the biosorbent and having better environmental sustainability. In biomaterials they are essential to improve human health and quality of life, but what stands out is that it is necessary to focus on the determining factors for the acceptance of new biomaterials for this type of applications is their useful life.

Biomaterials, Environmental Pollution, Sustainability, Processes

Resumen

En este trabajo tiene como objetivo realizar un análisis de los estudios utilizando materiales sustentables con términos de biosorbentes y biomateriales, se mencionan los biosorbentes aplicados en el medio ambiente principalmente los aplicados en agua, con la finalidad de realizar un análisis en la remoción de diferentes tipos de contaminantes tanto orgánicos como inorgánicos, mencionando los factores que involucran durante el proceso de la biosorción como por ejemplo el efecto del valor de pH, tipo de material, temperatura, tamaño de poro, por mencionar algunos, así mismo su aplicación en diferentes estudios. Para el caso de los biomateriales se describen las propiedades biológicas, químicas, físicas, entre otras, mencionando la clasificación y las aplicaciones de estos biomateriales en diferentes casos de estudio, finalmente se mencionan las conclusiones donde se destaca que gran parte de los estudios reportados se han llevado a cabo en lote, por lo que es necesario realizar más investigación enfocada a todos los factores que afectan a la biosorción pero en escala piloto, industrial y considerando procesos económicos con enfoque de recuperar el biosorbente y tener mejor una sustentabilidad ambiental. En los biomateriales son indispensables para mejorar la salud humana y la calidad de vida, pero lo sobresaliente es que hay que enfocarse a los factores determinantes para la aceptación de nuevos biomateriales para este tipo de aplicaciones es su tiempo de vida útil.

Biomateriales, Contaminación Ambiental, Sustentabilidad, Proceso

1 Introduction

Bisosorption is the ability of a biomass to remove organic or inorganic species in water, soil and air, through a mechanism of physicochemical sequestration (Akar *et al*., 2015). There are two types of biomass, live (fungus, algae, bacteria) and dead (agricultural, wood or wool waste). The use of dead biomass is frequently applied in this type of process, because it does not need maintenance conditions; whereas, the use of live biomass requires nutrients and biomass toxicity is likely to occur when in contact with contaminants, however, its potential in the removal of contaminants is recognized (Park *et al*., 2010). To consider an effective biosorbent, it must meet the properties of low cost, little processing, abundant naturally or as a waste product (Bulut and Tez, 2007), high efficiency, affinity (in terms of equilibrium and kinetics), stable (mechanically and chemically), with the possibility of recycling (Kleinübing *et al.*, 2011), that does not produce secondary compounds, short operating time (Morosanu *et al*., 2017), metal recovery (Das *et al*., 2014) and environmentally friendly (Nagy *et al*., 2017), it is worth mentioning that the biosorption capacity depends on the active sites of the material and the nature of the type of contaminant to be removed (Taty-Costodes *et al.,* 2003), because in the active sites, there are functional groups such as carboxyls, xylanes, hydroxyl, carbonyl, amino and phenolic compounds to mention the most important (Lodeiro *et al.*, 2006; Han *et al*., 2006; Pehlivan *et al*., 2008).

On the other hand, the science of biomaterials in recent years has been developing with the incorporation of biologically active compounds, these have gone from being merely implantable devices, designed to replace the loss of a biological function, to become multifunctional and complex interfaces with a dynamic behavior in the interaction with the body and capable of activating the innate regenerative potential of living beings. Around 2700 types of medical devices considered biomaterials have been developed. At present, the science and engineering of biomaterials are multidisciplinary activities that, both in the field of research and development, as well as in industry and clinical and environmental application, occupy an increasing number of highly qualified people. Biomaterials combine medicine, biology, physics, chemistry, tissue engineering, materials science and environmental science.

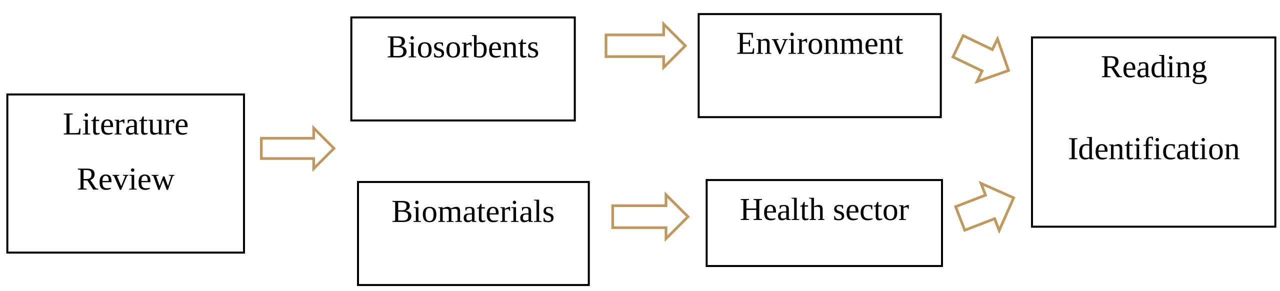
For this reason, this research mentions the study of different materials called biosorbents for the removal of organic and inorganic pollutants that in a certain way is an alternative to purify environmental pollution because they promise to be somehow profitable likewise it has been found that modifications of materials with different chemicals increase the removal of contaminants, however, such modifications can increase the cost of biosorbents (Park *et al*., 2010), taking into account the feasibility and efficiency, as well as optimal operating conditions for the removal of different contaminants that exist in the environment. In this way, the information of several studies carried out on biomaterials applied in the health sector was also considered because they are essential to improve the quality of life due to their wide spectrum of physical, mechanical and chemical properties, to mention a few, as well as today the extensive research, development and applications of different biomaterials has been promoted.

Therefore, this chapter is divided into the following sections: introduction, methodology and results in which it is divided into two sections, the first section mentions biosorbents and the second section biomaterials.

2 Methodology to be developed

A qualitative research was carried out, based on the bibliographic review of documents related to biosorbents and biomaterials at national and international level, as well as their application in the environment and in the health sector. Scientific articles from which data and information were collected were reviewed. The Science Direct and SciELO databases were consulted. Figure 2.1 shows a diagram of the general methodology.

Figure 2.1. Diagram of the methodology



Source of Consultation: Own Elaboration

3 Results

This study will mention biosorbents applied in the area of the environment and biomaterials in the health sector. We will begin to describe the biosorbents applied in the removal of organic and inorganic pollutants present in aqueous solutions (water) and in the second section what is related to biomaterials used in the health sector.

3.1 Biosorbents

Within the environment, a biomaterial helps water, air and soil not to be polluted, since thanks to the toxic and harmful pollutants that exist on the planet they cause global warming to increase and can end life on the planet. Nowadays, research is being developed to help generate biomaterials which are effective and efficient to reduce environmental pollution in water, soil and air.

Biosorbents are natural materials available in large quantities or from certain waste products of industrial or agricultural operations, for application in the bioadsorption process, the material used as biosorbent must meet the following requirements: a) have an availability and as a type of waste, b) easy to obtain and process for a conditioning of the material, and (c) it must be economical and sustainable. Several researchers have investigated various types of materials of biological origin and have proposed bacteria, fungi, algae, plant remains and crustacean residues as biosorbents. These materials have the advantage that they are produced in large quantities, are economical and can have capabilities as adsorbents due to the presence of the active functional groups in their structures (Gallego *et al.*, 2022). In the literature it is reported that adsorbents are divided into three main categories: natural materials, industrial by-products and products of anthropogenic origin.

However, new studies have focused on the use of various materials mainly of organic origin such as sawdust. Particularly for similar materials, it has been pointed out that the bioadsorption capacity is due to the potential amount of organic compounds capable of interacting with contaminants, among which are: tannins, polysaccharides, glycoproteins, heterocyclic compounds, flavonoids etc., of which the functional groups amino, hydroxyl, carboxylate and sulfhydryl, have been associated with the adsorption of various contaminants. In the same way, some research has been reported for the removal of heavy metals and dyes using coffee residues or chitinous residues as biosorbents. These studies indicate the potential of these residues to be used as biosorbents.

On the other hand, there are factors that affect the biosorption process, since it depends on the nature of the substance to be eliminated, the characteristics of the adsorbent and the experimental conditions, which are determinants in the greater or lesser affinity of the adsorbate for the adsorbent. Table 3.1 lists the main factors affecting the biosorption process.

Table 3.1 Factors affecting the biosorption process

Factors	Description
Effect of pH	It affects the capacity of biosorption in aqueous solution, influencing the surface charge of the adsorbent and the way in which the species to be adsorbed are
Surface functional groups	They are responsible for the adsorption sites in a solid, depending on the type of ions present, the characteristics of the surface, the nature of the adsorbate and the pH of the solution.
Pore surface and structure	The biosorption capacity of the solid adsorbent is generally proportional to the specific surface. However, if it is a less porous adsorbent, which has surface functional groups, the interactions may cease to be physical, entering to dominate other mechanisms such as ion exchange and complexation.
Particle size	For a porous solid, particle size is expected to be independent of retention capacity, since most of its surface is in its internal porous structure. However, in some cases the biosorption capacity increases by reducing the particle size, as well as increasing the contact area and accessibility of small molecules.
Nature of adsorbate	Retention is influenced by solubility, molecular weight, and solute particle size. In the biosorption process there must be greater affinity for the biosorbent since it requires a certain attraction between it and the solute, in addition to a repulsion against the solvent.
Effect of temperature	The effect of temperature on biosorption depends on the thermodynamics of the process, generally when the heat of biosorption is negative the reaction is exothermic and the process is favored at low temperatures.
Equilibrium time	It is the time when the biosorbent is saturated. It has been determined that the retention mechanism occurs initially with the migration of the adsorbate from the solution to the surface of the biosorbent, followed by a diffusion process to end in the fixation at the active site.

Source: Own Elaboration

Table 3.2 lists the biosorbents applied in the bioremoval of organic and inorganic pollutants.

Table 3.2. Biosorbents applied in the removal of organic and inorganic contaminants.

Biosorbent	Conditions	% Removal
Activated carbon (Burciaga, 2020)	It is a function of several factors, including pH, temperature and contaminant concentration, where the properties of the adsorbent determine the removal mechanism.	Pb(II): 70.32 mg/g Cr(VI): 169.5 mg/g Hg (II): 25.88 mg/g
Zeolite	Grain size: 2mm PV= 1.0 g/cm^3 Bulk density 2.0 g/cm^3 CIC=138.7 meq/100 g zeolite pH=7.4	Pb (II): 510 mg/g Cu (CI): 170 mg/g Hg (II): 25.88 mg/g SiO_2 63 % Al_2O_3: 11,57 % FeO_3: 1.87 % Na_2O: 2.39 % H_2O: 3.44 % TiO_2: 0.45 %
Double network hydrogels	They can be degraded quickly for the elimination of adsorbed species by modifying the pH of the medium.	Cd (II): approx. 180 mg/L. 1 g/L of the biosorbent was quickly reached equilibrium, achieving complete removal of the contaminant.
Chitasan hydrogels coupled with clay minerals.	It exhibited extraordinary mechanical, optical and swelling properties.	Cr(VI): 96 mg/g Cu(II): 172.4 mg/g
Hydrogel reinforced with nanocomposites (assembly of attapulgite on a polyacrylamide matrix).	Acidification Copolymerization Polymerization in suspension.	Recovery of Pb (II) and Cu (II) in aqueous solutions. Cu(II): 69.75 mg/g
Compound hydrogel (Collagen/ chitosan/ cellulose)	Generation of interpenetrated networks by pH modification and cooling and drying cycles.	Cu(II): 145 mg/g
Rice straw (Diaz, 2021)	Particle size: 2mm Density: 1.56 g/cm^3 Bulk density: 0.017 g/cm^3 pH=7.0.	Ca:1.1-5.8 % P: 0.3-4.3% Na: 0.1-2.5 % Mg: 1.0-3.6%
Sugarcane bagasse	Grain size: 1.5-2mm Bulk density 0.052 g/cm^3 pH=7.88	Lignin (20%) Cellulose (42%) Hemicellulose (25%)
Activated sludge	Grain size: 1.6mm Density 0.55 g/cm^3	Ca: 12 % Yes: 1.5 Mg: 0.8 % Na: 0.15 % P: 1 %
Eggshell (Escobar *et al*., 2014)	10 kg of eggshell were collected. Constituted by 2.00; 4.00 and 6.00 g of pre-treated shell (F_1, F_2 and F_3, respectively). Placed in constant stirring for 7 h with 500 mL of a Chromium (VI) solution of initial concentration 3.00 ppm	The absorbance in the aliquots was measured, determining the final concentrations of Chromium (VI), obtaining a removal percentage of 5.24% for F_1, 34.36% for F_2 and 24.43% for F_3.
Bagasse and rice straw	Higher adsorption capacity at 20 min of contact. Under packaging conditions values of this parameter for COD 67 and 70 mg/g	Removals greater than 95% for sulphides, fats and oils with all materials.
Rice husk	Discontinuous study with 20 min of contact time and 20 g of material biosorption capacities were obtained for Pb, Cu, Ni and Fe of 1.3; 6.6; 8.2 and 40 mg/g,	With an elimination of 22%, 24, 95 and 68%, respectively
Argomena	Grain size: 1.6mm PV=0.98 g/cm^3 Density 2.1 g/cm^3 pH=7.01 Cation exchange capacity (CEC)=40-70 meq/100 g	Zeolite 42 % Phosphate rock 36 % Peat 16 % Urea 2.6 % $(NH_4)_2HPO_4$ 1.2 % KCl 2%
Natural cane bagasse	Biosorption capacity less than 7.57 mg/g that was improved up to 86.5% from bagasse modified with H_3PO_4.	Cu^{2+} removal of 18.3%
Coffee grounds (Duany, Timosthe, 2022)	Dose of 30 g of coffee grounds, coffee grounds washed with deionized water applying 30 g / L of water.	The removal of cadmium and dissolved lead was 96.54 % and 94.05 % respectively.
Banana peel	Insoluble polymers, it has a high molecular weight, which results from the union of several acids and phenylpropyl alcohols, pulverized in it.	The highest clearance percentage is 80%
Moringa	High efficiency in turbidity reduction	It eliminated up to 85-94% and improved dissolved oxygen (DO). It was observed after treatment as Fe, Cu and Cd, were eliminated up to 98% and Pb 78.1%.
Orange peel	The maximum removal capacity was presented 40 minutes after contact with contaminated water and the maximum biosorption capacity was obtained with a pH of 4.8. Orange peel has an adsorption power for Pb of 99.5% and for Cu (II) has a yield of 36.23 mg / g.	100% removal
Potato pulp (Burciaga *et al*., 2020)	1 kg raw pastusa potato A solution containing 1 L of ascorbic acid (1 % w/v, pH 5.0) Stored at - 20 °C for 12 h	Being the contribution by biosorption 35% of total pollutant removal

Source: Own Elaboration

In Table 3.3, biomaterials for the removal of different types of contaminants are mentioned.

Table 3.3 Biomaterials for the removal of contaminants

Biomaterial	Conditions	% Removal
Potato pulp for removal of industrial contaminants (Morales, 2022)	Orange II: PM= 350.32g/mol Solubility= 116g/L at 30°C Total volume of mixture= 6.6 mL t= 0.5 and 1 h The absorbance at 420 nm increased as a function of time to a certain final value, which became stable over the time studied. The maximum absorption peak at 485 nm did not change as a function of pH	pKa=pK_1=1.0; pK_2=11.4 At the pH studied (5 – 9), the dye was in its undissociated state The molar extinction coefficient at 485 nm was 4.2 ± 0.2 a. u/c m/mM
Biomaterial for high-performance water-based adhesives (Presti, 2021)	Dopamine hydrochloride (Sigma-Aldrich, >99.9%), anhydrous ferric chloride $FeCl_3$ (Sigma-Aldrich, ≥99.99% trace metal base), hydrochloric acid, HCl (Sigma-Aldrich, reactive grade, ≥37%) and sodium carbonate (Na_2CO_3)	The silk fibroin solution (7.3%) was modified with the addition of dopamine hydrochloride at a final concentration of 2×10^{-3}, 20×10^{-3} and 200×10^{-3} m
Agromena (Agrom) (CIP14-184, 2015) (Rodriguez, 2021)	Grain size: 1.6 mm, PV=0.98 g/cm3density 2.1 g/cm^3; pH=7.01; cation exchange capacity (CEC)=40-70 meq/100 g	Zeolite 42 %; phosphate rock 36 %; peat 16 %; urea 2,6 %; $(NH_4)_2HPO_4$ 1,2 %; KCl_2%
Product Improver (PM)	Grain size: 1.5-2 mm, pH=7.88	Rice straw, bagasse, activated sludge and urea; N_1 %; P_1,34 %
Compound hydrogels; 1) Polyacrylamide 2) Carboxymethyl cellulose 3) Chitosan 4) Sodium Alginate/ Vinyl	1)Acidification and polymerization in suspension It has great adsorbent capacity, and is simple to reactivate 2) Generation of hydrogels by modification of pH and temperature. High adsorbent capacity and biodegradability 3) Dispersion of the inorganic phase by sonication modifying the pH Simple and efficient functionalization and absorbance	1) Cu (II): 69.75 mg/g 2) Cr (VI): 21.7 mg/g Cd (II): 25.7 mg/g 3) Cu (II): 172.4 mg/g 4) Pb (II): 432.28 mg/g

Source: Own Elaboration

The atmospheric applications within the field of study of biomaterials is broad, since to produce any type of biomaterial a proposal analysis has to be done to verify that the synthesis or creation of this does not affect the environment anymore. This type of analysis serves to avoid less atmospheric emissions in order to try to reduce the damage that occurs from the beginning.

Currently, innovation efforts are focused on improving their properties and reducing their cost, work is being done to overcome the sustainability of these biomaterials, for example; Biopolymers so that they are not only commonly used in packaging, but also become the new star material of contemporary society. On the other hand, 0.4% of world production corresponds to biopolymers, however, its high cost can not fight against the economic, some strategies that are being evaluated to reduce the cost of biopolymers is the use of by-products of the industry as raw material, the design of bioreactors or improvements in processes.

Although water-soluble plastics have been developed or that degrade under the action of light (they contain substances that weaken the bonds of their molecules when receiving light), the degradation is not total.

Another important fact is that they can be produced from renewable resources, their fermentative production uses products derived from agriculture as a source of carbon, because of their origin from renewable sources and because they are biodegradable, they are called "doubly green polymers", however it is important to mention that biopolymers are already used in other sectors, such as automotive and electronics, and are beginning to be used as co-formulants in the chemical industry and as citizens better understand the advantages that biopolymers represent in terms of saving energy resources and reducing pollution, the demand for this type of materials also increases in other sectors.

3.2 Biomaterials

A biomaterial is defined as that natural or synthetic material used to be in contact with a living being, so it must have specific properties to perform its function properly, so it must be biocompatible. They are materials, natural or artificial (man-made), used in the manufacture of devices that interact with biological systems and that are applied in various specialties of medicine either to increase or replace a tissue, organ or a function of the organism. They are systemically and pharmacologically inert, which means that they should not provoke a response in the body and that they do not adversely affect its tissues. They are designed to be incorporated or implanted in a living being, they are able to be in contact with living tissues (muscle, bone, blood, body fluids, etc.) without affecting their properties (depending on what they were designed for). They are used to replace parts of the human body; Example: Unsaturated fatty acids, to treat different diseases and wounds (sutures, catheters, needles, plates, etc.), are also used with diagnostic and storage applications. Depending on the type of biomaterial, they are used for varying periods of time. They can be metallic, ceramic, polymeric or combined (composite).

Properties of biomaterials

To succeed in the application of these biomaterials, properties such as; mechanics, toxicity, surface modification, degradation rate, biocompatibility and corrosion rate and structural design. Table 3.4 mentions the main properties of biomaterials.

Table 3.4 Properties of biomaterials

Property	Description	Example
Biological (Elices, 2020)	It is the result or reaction of a hard or soft tissue against a material.	Cozy and intelligent scaffolding for implants and spare organs.
Chemical (Saenz 2004)	They are the reactions that the material undergoes against pH changes, ionic changes or against electrical stimuli.	Ceramics: Aluminium oxides, Calcium aluminates, titanium oxides, calcium phosphates, carbon. Application in Orthopedics, Dentistry and Veterinary.
Physical	They include the properties of handling, adhesion, dimensional variations (thermal or electrical), etc.	Evaluate external actions such as light, heat, electricity or the application of forces. Type of viscosity of a biomaterial
Mechanical or biomechanical	They are physical properties that appear when a force is exerted on the material (ductility, hardness, elasticity, tensile strength, fatigue resistance). In this type of properties, it will depend on the type of device to be manufactured.	A hip replacement must be strong and rigid; Material to replace a tendon should be strong and flexible; Heart valve should be flexible and hard; Dialysis membrane should be strong and flexible; Joint cartilage replacement should be soft and elastic. These materials have high elasticity and can be deformed long before they break, for example, an elastic band.
Thermoplastic	They can be melted and molded repeatedly when heated and then cooled and solidified while maintaining their basic chemical properties. Their ability to be reused and recycled makes them very versatile and easy to process.	Applications such as packaging, pipes, toys, car parts, textiles, among others.
Toxicity	It consists of the identification and quantification of adverse effects associated with exposure to physical agents, chemical substances and other situations.	Effects that occur in tissues by contact with released biomaterials and can occur independently or associated, for example, the adverse effect resulting from contact with a xenobiotic (Laygre, 1995). Adverse reactions may be allergic or non-allergic.
Biocompatibility	It is the description and characterization of a reproducible response by biological tissue or relative to the materials used. From the development of biomaterials according to the response of the organism there are 4 types: Inert. Implantable materials that generate little or no response Interactive. Implantable materials that generate a specific response Viable. Implantable materials that are treated by the body like normal tissue and are reabsorbed. Reimplantation. Implantable materials consisting of native tissue, developed in vitro from cells obtained from the patient. The compatibility index is also considered, which tells us how suitable or not of that material, to be used as a biomaterial in a living being, taking into account its application.	Dental materials are known to be used on humans for long or short periods of time, are similar to other specialized materials used in orthopedics, cardiovascular surgery, plastic surgery and ophthalmology, are in close contact with various human tissues. For example, in dentistry the following biocompatibility tests are performed: Group I or primary tests. Group II or secondary tests. Group III or evidence of preclinical use. (Anusavice, 1996).
Biodegradability	It is the resistance of a substance to be decomposed into the chemical elements that compose it by the action of living organisms, usually microorganisms, under environmental conditions. The higher the biodegradability; easier to decompose.	In implants, biodegradability is important as it avoids a second surgery to remove the implant, ensures that the biomaterial is chemically stable and has an electrical behavior suitable for its application. A bone fixation plate should do its job for 6 months or more. A heart valve should flex 80 times per min without rupturing for the patient's lifetime (expected to be for 10 years or more). A hip joint should not fail under heavy loads for more than 10 years.

Source: Own Elaboration

Due to the properties and characteristics of biodegradability, it makes them very versatile to be used in many functions of our daily lives.

Applications of biomaterials

Biomaterials have evolved according to the needs and problems generated by the human being, they are very useful since they can be used in different areas. Therefore, they must be evaluated with some specific parameters so that they truly fulfill the function for which they were designed and generate a benefit. It is essential to have a mixture of chemistry, nanotechnology, engineering and design to be able to create a biomaterial that can replace a human need without affecting the environment. (Ramirez *et al*., 2016) Biomaterials combine medicine, biology, physics, chemistry, sustainable development engineering and materials science. (Duffo, 2012).

In the area of health, biomaterials are those natural or synthetic substances whose mission is to replace a part or some function of our body, in a safe and physiologically acceptable way, can help the proper functioning of the human body, the main types of biomaterials that have been applied in the field of regenerative medicine, include natural and synthetic polymers, bioactive ceramics and composite materials, such as gels and cell matrices, even to grafts improved with stem cells and organ design, as well as other applications of biomaterials include diagnostics (gene sets and biosensors), medical supplies (blood bags and surgical tools), therapeutic treatments (implants and medical devices) and emerging regenerative medicine (skin and cartilage designed by tissue) (Lo Presti *et al*., 2021). They can be classified in different ways: according to their chemical composition, in biometals, biopolymers, bioceramics, biocomposites and semiconductors; according to their origin, in natural and synthetic. Another more practical way to classify them are implantable devices, which are implanted over time in the human body to replace a function, and non-implantable devices, which include probes and catheters, among others. Table 3.5 lists the classification of biomaterials and Table 3.6 presents the classification of biomaterials by generations in the health sector.

Table 3.5 Classification of biomaterials according to type

According to its origin	According to its nature	Depending on the body's own response
Natural Synthetic	Metals Polymers Ceramic Compounds Biopolymers	Inert Bioactives Reimplanted Biodegradable Non-degradable

Source: Own Elaboration

Table 3.6. Classification of biomaterials through generations in the health sector

Generation	Type of Biomaterial	Application	Example
First	Inert	Replace damaged tissues with minimal receptor toxicity response	Metal implants Dental ceramic materials
Second	Bioactive and biodegradable	Interaction with the biological environment to improve the response, progressively degrading in the new tissue	Bioactive glass Compositos (polymer-ceramic)
Third	Functionalized	They are able to stimulate a cellular response at the molecular level	Biomaterials with extracts Biomaterials with functionalized surface
Fourth	Functionalized and intelligent	Stimulate specific cells to help the body heal itself	Polypyrrole-based biomaterials Biomaterials with hydroxyapatir

Source: Reyes et al., 2019

Table 3.7 presents biomaterials in the health sector and Table 3.8 describes some biomaterials and their use in the health sector.

Table 3.7 Applications of biomaterials in the health sector

Biomaterial	Application
Medical implants	These include heart valves, stents, and grafts; artificial joints, ligaments and tendons; hearing loss implants; dental implants; and nerve-stimulating devices. Methods to promote healing of human tissues, including sutures, clips, and staples for wound closure, and dissolvable dressings.
Regenerated human tissues	As biomaterial supports or scaffolds, bioactive cells and molecules, such as bone regeneration hydrogel and a lab-grown human bladder.
Molecular probes and nanoparticles	They break down biological barriers and aid in cancer diagnosis and therapy at the molecular level.
Biosensors	They are used to detect the presence and amount of specific substances and to transmit that data, such as blood glucose monitoring devices and brain activity sensors.

Source: Own Elaboration

Table 3.8. Uses of biomaterials

Biomaterial	Uses
Titanium alloys	Joint replacement
Stainless steel	Joint replacement
Polyethylene (PE)	Joint replacement
Hydroxyapatite	Repair of bone defects
Teflon, Dacron	Artificial tendons and ligaments
Titanium, Alumina (Al_2O_3), Calcium phosphate ($CaPO_4$)	Dental implants
Stainless steel	Fracture fixation plates
Cobalt alloys with chromium	Fracture fixation plates
Polymethylmethacrylate	Bone cement
Stainless steel, Dacron	Heart valves
Teflon, Polyurethane (PUR)	Catheter
Polyurethane (PUR)	Artificial heart
Polyacrylonitrile, cellulose	Artificial kidney
Silicone gum	Ventilators
Hydrogels, silicone-acrylate	Contact lenses
Silicone and collagen composite materials, cellulose, polyacrylonitrile	Insoles for skin repair
Collagen, hydrogel	Cornea
Calcium phosphate ceramics	To repair certain intraosseous defects, they are non-toxic, biocompatible with the body and do not significantly disrupt the levels of calcium and phosphorus in the blood. It is a material classified in bioceramics that are hard and degrade very slowly, it is usually necessary to combine them with biodegradable polymers to achieve better results. This type of implants are used to promote bone recovery in fractures, for example, it has been observed that these biomaterials with mesenchymal stem cells can promote rapid and perfected tissue regeneration in certain animals, a biomaterial is not only a mineral or compound, but a mixture of organic and inorganic elements that try to find the perfect balance to achieve their functionality.
Bioactive crystals	They are ideal for certain regenerative processes at the bone level, their degradation rate can be controlled, they secrete certain ionic materials with osteogenic potential and have a more than correct affinity meeting with bone tissue. For example, studies have shown that some bioactive crystals promote the activation of osteoblasts, bone tissue cells that secrete intercellular matrix that give bone its hardness and functionality.
Resorbable bicortical screws	Resorbable plates and screws based on polylactic and polyglycolic acids, increasingly replace the hard titanium elements that brought so many problems when welding injuries. For example, polyglycolate is a strong, non-rigid material, does not fray and offers good safety as an abutment during suturing. These materials outperform titanium as they cause less patient discomfort, are more economical and do not require surgical removal.
Biomaterial patches	The National Institute of Biomedical Imaging and Bioengineering is developing alginate patches, based on brown algae, as therapeutic sealants to treat lung infiltrations from trauma, surgery, or conditions such as pneumonia and cystic fibrosis. The results of these technologies are promising, as alginate patches respond well to pressures similar to those exerted by the lungs and aid tissue regeneration in these organs so essential for life.
Hydrogel bandage	The use of hydrogel would act as an ideal film to prevent infection and degradation caused by environmental conditions in the wound. In addition, it could be dissolved at the rate of certain controlled procedures and expose the injury without the mechanical stress that this entails, this would improve the hospital stay of patients with severe burns.

Source: Own Elaboration

Another aspect that is of great interest and that today is creating a great impact around the world are bioplastics, however, the price of bioplastics is still high so that they can displace traditional plastics, because of this it is necessary to design strategies to obtain at a similar cost, So the price of biopolymers depends on several factors; production costs, yield of the polymer obtained and processing costs. On the economic front, it is estimated that the global market value of orthopedic biomaterials will reach around US$26 billion by 2026 and grow at a CAGR of over 10.0% over the forecast time, making this market highly attractive to both researchers and companies looking to provide such solutions to the market. (CIQA).

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Conclusions

In the application of the biosorbents of any contaminant, it is conditioned by the type of material, pH, temperature and contact time, the type of contaminant must be considered to obtain a better biosorption efficiency, however it is important to mention that according to the bibliographic review a large part of the reported studies have been carried out in batch, Therefore, it is necessary to carry out more research focused on all the factors that affect biosorption, to do it on a pilot scale, industrial and considering economic processes with a focus on recovering the biomaterial and having better environmental sustainability. Therefore, the revised biosorbents and biomaterials can be considered as a treatment alternative for the biosorption of contaminants.

As for biomaterials, they are indispensable to improve human health and quality of life due to the wide spectrum of physical, mechanical and chemical properties, as well as one of the determining factors for the acceptance of new biomaterials for this type of applications is their useful life. Today, biomaterials technology is being focused on composite biopolymers, in such a way that it promotes a great effort to investigate how biomaterials work and how to perfect them.

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