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ALTERNATIVE BIOSORBENTS FROM AGRO-INDUSTRIAL WASTE: A REVIEW FOR APPLICATION IN THE REMOVAL OF ORGANIC POLLUTANTS

BIOSORVENTES ALTERNATIVOS A PARTIR DE RESÍDUOS AGROINDUSTRIAIS: UMA REVISÃO PARA APLICAÇÃO NA REMOÇÃO DE POLUENTES ORGÂNICOS

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ABSTRACT

Environmental conservation issues are widespread today because of the scarcity of renewable resources. Faced with this, pollution of water resources becomes a cause for concern, as its treatment is not feasible. As in Brazil there is a significant production of agro-industrial products, its residues also become worrisome if not discarded correctly. As a result of this, the alternative biosorbents that derive from the use of the agro(industrial) residues and that aid in the process of treatment of effluents arise. To solve the problem of water pollution, a viable alternative is the adsorption with the use of alternative biosorbents for removal of undesirable components. In this context, the present work presents a study on the application in the removal of organic pollutants from effluents from alternative biosorbents from agro(industrial) waste.

Keywords: agro(industrial) waste, adsorption, alternative biosorbents.

RESUMO

As questões sobre preservação ambiental são muito difundidas atualmente, devido a ascendente escassez dos recursos renováveis. Diante disso, a poluição dos recursos hídricos torna-se um motivo de preocupação, pois o seu tratamento não é viável. Como no Brasil há uma significativa produção de produtos agroindustriais, seus resíduos também se tornam preocupantes se não descartados corretamente. Em virtude disso, surgem os biossorventes alternativos que derivam do aproveitamento dos resíduos agroindustriais e que auxiliaram no processo de tratamento de efluentes. Para resolver o problema de poluição hídrica, uma alternativa viável é a adsorção com a utilização de biossorventes alternativos para remoção de componentes indesejáveis. Neste contexto, o presente trabalho apresenta um estudo sobre a aplicação na remoção de poluentes orgânicos de efluentes a partir de biossorventes alternativos provenientes dos resíduos agroindustriais.

Palavras-chave: *Resíduos agroindustriais, adsorção, biossorventes alternativos.*

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INTRODUCTION

Agro-industrial waste stands out due to its added value, which after undergoing the processing of its raw materials ends up excelling in the production of renewable fuels, chemical and energy products, among others. Therefore, the problem with waste accumulation ends up being resolved to the detriment of its great availability meaning that contamination of soils and rivers can be avoided (Singh; Jana, 2023).

Currently, the preservation of natural resources is a worldwide concern such as the environmental impacts that arise from the pollution of water resources since their treatment is not viable due to the high cost and their increasing scarcity is a reality. Associated with this, the development of appropriate technologies for the treatment of effluents has been a source of interest lately with the aim of preserving natural resources and complying with norms and legislation on effluent emission standards (Shree; Namasivayam; Pandian, 2023).

Among these technologies, adsorption is one of the few promising alternatives that exist for removing organic pollutants (Iqbal *et al.,* 2023). Moreover, to presenting advantages such as simplicity of operation, application of low-cost materials (such as biosorbents), possibility of regeneration of adsorbents and do not generate toxic waste (Keshta; Yu; Wang, 2023).

LITERATURE REVIEW

AGRO-INDUSTRIAL WASTE

Brazil is characterized by having a considerable production of agricultural products providing a high generation of agro-industrial waste with a round of 250 million tons/year (Souza; Santos, 2003; Azevedo *et al.,* 2023). However, they are not managed correctly being discarded without due treatment helping to contaminate water and soil becoming an environmental liability.

In this context, alternative technologies have been studied for the use of these agro-industrial residues to remove pollutants such as biosorbents in the removal of organic pollutants by adsorption (biosorption) (Yang *et al.,* 2024) providing benefits such as the low cost of the adsorbent material as it is waste and its recycling reducing environmental impacts (Zhang *et al.,* 2022).

ADSORPTION PROCESS

Adsorption is a physicochemical process that involves the mass transfer of one or more components (adsorbates) from the liquid phase to the surface of the solid phase (adsorbents), that is, it promotes the junction of the fluid with a given solid surface. Thus, adsorbents are solids that, through physical-chemical interactions can maintain the solute on the surface certain substances present in the solution separating them from other unwanted components (Das *et al.,* 2023). Furthermore, the way in which the adsorbates are superficially fixed under the adsorbents determines the adsorption classification (Atkins; Paula, 2013).

Physical adsorption or physisorption: the intermolecular forces involved between the adsorbate molecules and the atoms that make up the absorbent surface are Van der Waals forces, where the molecules are weakly bound to the surface and adsorption enthalpy of the order of 20 at 40 kJ mol^{-1}, being a reversible phenomenon where the deposition of multiple layers of adsorbate on the adsorbent surface is normally observed quickly reaching equilibrium (Sadegh *et al.,* 2024).

Chemical adsorption or chemisorption is an irreversible process that involves chemical interactions between the adsorbed fluid and the adsorbent solid, with effective exchange of electrons between them, forming a single layer on the solid surface, in which a considerable amount of energy is released (of the order of a chemical reaction) and enthalpy of the order of 40 - 400 kJ mol^{-1}. Therefore, the study of the adsorption mechanism for removing organic pollutants via adsorption is carried out using adsorption isotherms (Yang *et al.,* 2024).

METHODOLOGY

ADSORPTION ISOTHERMS

Adsorption isotherms can be defined as the equilibrium relationship between the concentration of the adsorbate in the liquid phase and the adsorbent, at a given temperature, the main ones being (Geankoplis, 2009):

Langmuir isotherm

The Langmuir isotherm is used to describe the monolayer adsorption process, representing a simpler theoretical model, and portraying chemical adsorption at different sites (Langmuir, 1918). Thus, it considers the following aspects:

a) adsorbate molecules are chemically adsorbed by a number of well-defined sites;

b) each site can only retain a single molecule;

c) all sites are energetically equivalent;

d) there are no interactions between molecules adsorbed on neighboring sites.

Freundlich isotherm

It consists of the isotherm used for heterogeneous adsorption systems, with no possibility of a monolayer, since the adsorbate molecules do not present a significant interaction. Thus, the isotherm demonstrates a logarithmic distribution of active sites (Debnath; Das, 2023).

Sips isotherm

It is a combination of the Langmuir and Freundlich isotherms, where at low concentrations of adsorbate the isotherm reduces to Freundlich and at high concentrations to Langmuir as it assumes adsorption in monolayers (Aguareles; Barrabés; Myers, 2023).

ADSORBENT MATERIALS

Effective adsorption depends on the adsorbent material used, and this in turn depends on its characteristics. Its most important characteristic is the ability to retain the contaminant on its surface resulting from the distribution and volume of the pores and surface area (Qiao; Zhou; Du, 2024). It must also have other characteristics such as stability at different pHs have good mechanical resistance, be capable of adsorbing specific solutes and its adsorption capacity must be significant (Geankoplis, 2009).

Among the main commercial adsorbent materials, activated carbon, silica gel, synthetic polymers, zeolites, and resins stand out, highlighting activated carbon, which has been used on a large scale. However, many of these materials are characterized by their high cost, which ends up making the process unfeasible, resulting in research into alternative biosorbents (Benvenuti *et al.,* 2019; He *et al.,* 2023). As a result, the search for alternatives to conventional methods that present low costs and high efficiency encouraged scientific research on the use of biosorbents in adsorption systems (biosorption) (Farias *et al.,* 2022).

RESULTS AND DISCUSSION

BIOSORPTION AND BIOSORBENTS

Biosorption can be defined as an alternative method of removing compounds, metals and particles from solutions using natural materials with biological origin, biosorbents (Farias *et al.,* 2022). When forms with metabolic activity are used as biosorbents (microorganisms or plants) contaminant removal systems become more complex involving metabolic routes. Whereas, when there is no metabolic action, such as agricultural residues removal is established by physicochemical processes that occur between adsorbate and adsorbent (Saldarriaga *et al.,* 2021).

Biosorbents have a cell wall with cellulose macromolecules denoted in microfibers that are followed by lignin, pectin, and hemicellulose due to this fact, macromolecules exhibit functional groups in their structure such as aldehydes, carboxylic acids, alcohols, ethers, ketones, and phenols, performing the function of causing metal ions to bind to them (Saldarriaga *et al.,* 2021). The intensity of adsorption efficiency is linked to the physicochemical characteristics of the adsorbent and the properties of the adsorbate. The way in which the substances interact with the adsorbent depends on the biosorbent being used and the conditions of the environment (He *et al.,* 2023).

The following advantages can be highlighted for the use of alternative biosorbents such as (a) low operational cost at the expense of being leftover agricultural waste; (b) low transportation costs, due to the fact of having a regionalized origin; (c) preparation for its use does not require expensive chemicals; and (d) have high efficiency for treating effluents with low concentrations of metal ions (Benvenuti *et al.,* 2019). In this context, in order to provide an overview of the use of biosorbents in the adsorption process, a search was carried out on digital platforms, limiting the words biosorbents and their uses, encompassing review work in the period from 2017 to 2023, as shown in Table 1.

Table 1 - Research on alternative biosorbents and their applications from 2017 to 2023.

Biosorbent	Application	Reference
Coconut fiber	Removal of copper (II)	Nascimento, 2018
Moringa oleífera	Removal of cadmium ions from water	Santana, 2017
Pine nut shell	Color removal from textile effluent	Silva *et al.,* 2018
Saccharomyces cerevisiae	Recovery of phenolic compounds in white tea samples	Sena, 2017
Chlorella vulgaris microalgae	Lanthanum biosorption for use in the separation of rare earths	Heidelmann *et al.,* 2017
Sugarcane bagasse	Decontamination of solutions containing zinc	Gambarato; Silva, 2017
Algae biomass	Nuclear waste management	Gupta *et al.,* 2018
Bone waste modified with lanthanum	Removal of fluoride from solutions	Mukherjee; Halder, 2018
Seaweed	Removal of toxic components	Bilal *et al.,* 2018
Banana peel	Removal of arsenic from contaminated water	Dadwal; Mishra, 2017
Corn cob	Removal of heavy metals in wastewater	Habineza *et al.,* 2017
Microbes	Removal of heavy metals from water	Ayangbenro, Babalola, 2017
Papaya seeds	Removal of chromium (IV)	Van; Thu, 2019
Carica papaya	Removal of copper (II), and lead (II)	Genchi *et al.,* 2020
Apricot stone	Removal of copper (II)	Chai *et al.,* 2021
Peach stone shells modified with citric acid	Removal of chromium (IV)	Karić *et al.,* 2022
Pomegranate peel charcoal	Color removal from textile effluent	Chong *et al.,* 2023

The most commonly used technological unit on an industrial scale is ion exchange for processes involving adsorption with pollutants, which consists of cylindrical columns filled with spherical adsorbent particles such as apricot stone and pomegranate peel charcoal and resin of the (stationary phase) with the fluid containing the pollutant as the mobile phase (Chai *et al.,* 2021; Chong *et al.,* 2023). Furthermore, the operating cycle is normally based on two columns containing fixed beds in series, in an alternating form of saturation and regeneration. In this sense, during the saturation phase, the mobile phase containing the pollutants passes through the column and the solutes contained therein are retained for the stationary phase. In the regeneration process, a strong electrolyte is used in the adsorbent, allowing reuse again.

CONCLUSION

Given the arguments presented and recent research carried out on the topic of the proposed work, it can be concluded that the use of new technologies in favor of the environment presents significant results such as alternative biosorbents used to remove water contaminants for the treatment of these effluents. Its use can be justified by its low cost, as it is waste, combined with its efficiency in removing contaminants.

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