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Review

The Potentiality of Reuse Industrial Waste for Diverse Water Treatment - An Overview

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Abstract: The proliferation of different pollutants in waters caused by anthropogenic and industrial activities has become a significant global concern, as they cause many problems, like severe health and environmental harm. Searching for green materials for water removal entirely and efficiently in this context is challenging. In this sense, innovative materials based on industrial waste become an incredible alternative, as they are waste, disposable incorrect in the environment, low-cost, and need to be adequately discharged. Many innovative materials based on industrial waste were performed in the literature, as these eco-friendly alternatives have great potential for many applications, including wastewater treatment. This overview presents various research that demonstrated different innovative materials based on industrial waste, their physicochemical properties, different properties, the adsorption removal, and other wastewater treatment reported based on different models. Based on the literature, we have also demonstrated that innovative materials based on industrial waste exhibit an incredible potential for the adsorption of various pollutants in water, indicating their promising solution of low-cost adsorption removal for wastewater treatment. Finally, this overview shows that these sustainable materials present significant potential for use in wastewater treatment.

Keywords**:** innovative materials, industrial waste, wastewater treatment, organic-inorganic pollutants, sustainability

1. Introduction

Nowadays, the dynamic of the world is really intense and many problems, most of them caused by anthropic actions, such as climate changes and environmental problems, mainly the discharge of water, which reduces the vital not polluting water for all life, provoke a great concerning.[1-3] In this context, searching for potential, low-cost, original materials and profitable water treatment boost research to decrease problems such as water crisis. Different treatments were developed depending on the pollutant, methodology, and cost. In addition, the material used for this water treatment changes these choices.[4]

Moreover, sustainability has been an increasingly frequent pursuit of today's society, especially regarding environmental and economic sustainability. One alternative is the reuse of waste, especially considering the production of new products, as its reuse minimizes environmental problems and provides an economic end to a by-product.[4]

The amount of waste disposable by different industries causes a real disorder in a changing world. Many industries

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disposable different types of waste and the search for an economical way to reuse it is the major challenge of this economic group.[5] Then, the development of new sustainable, low-cost alternative use of industrial waste or co-products using non-classical material is a necessary change. Different types produced a huge amount of waste that has not been able to process, such as metallurgical, foundry, agroindustry, food, and others. Then, reducing these wastes is proposed to provide a better quality of life for the population, as most of them are harmful to human life or occupy a large space in urban areas. However, a large amount of waste produced and the low added value in the market make the search for reuse of these wastes a significant point of research investment to the public.[6]

Additionally, one of the essential supplements of life is water. Water is one of the most essential natural elements, making up animal and plant life in a critical way, as well as having a fundamental role in maintaining the properties of the balanced functioning of the ecosystem. However, some parts of the world still do not have clean water. Although its performance and importance in maintaining life are known, it has been deteriorating exponentially due to contamination provided by anthropic actions.[1,3]

This contamination has recently brought to the fore an increasingly growing concern in society due to the possibility of depletion of such a resource, as in addition to more intense and constant climate changes occurring, the growing deforestation and dumping of waste of all kinds in the water by industries and agriculture have provided a reduction in the level of potable water on the Planet. In this context, unsustainable development paths and governance failures have affected the quality and availability of water resources, compromising their ability to generate social and economic benefits, and the demand for freshwater has been growing. Therefore, unless the harmony between demand and finite supplies is restored, the world will be passing an increasingly terrible global water deficit.[3]

This contamination causes the accumulation of heavy metals, various oils, and organic material in the aquatic environment. More than 700 organic and inorganic pollutants have been found in water along with the microbial population. Among these, specific organic contaminants and metallic ions are considered dangerous due to their high toxicity and carcinogenic nature.[7,8] In this context, a change of attitude becomes necessary in the current situation, which has been encouraging research to minimize these water contamination problems.

In addition, some organic products and metal ions are not biodegradable and persist in the environment for a long time. The most toxic organic pollutants are pesticides, Polynuclear Aromatic Hydrocarbons (PAH), Polychlorinated Biphenyls (PCBs), Polybrominated Diphenyl Ethers (PBDEs), plasticizers, phenols, drug residues, and metallic ions such as arsenic, cadmium, platinum, mercury, and antimony, among others.[9-12] Moreover, only a tiny fraction of these pollutants is a complete treat, most of them (30,000 to 100,000 ton) goes to water and another critical element, causing real damage.[13-16]

In this sense, this overview of research about reusing industrial waste in the last years mainly searches for research that reuses in water treatment using green chemistry. Moreover, at Scopus and Web of Science database is possible to identify an increase in new materials based on industrial waste reuse in recent years (Figure 1), demonstrating the importance of this topic. However, the number of patents and publications is still below what is necessary to view the scenario of global concern.

2. Green chemistry

Green Chemistry and Engineering technologies are "tools" that provide innovative solutions in various sectors of product and process, and application research.[17] Efforts in Green Chemistry and Engineering need to be focused on the central issues for sustainability, which include several factors such as climate change, sustainable energy production, depletion of non-renewable resources, the dissipation of toxic and hazardous materials in the environment, as well as treatment of solid and liquid waste, including water.[18,19]

Anasta & Warner[20] define green chemistry as using parameters that minimize or eliminate the use or production of hazardous substances in the design, manufacture, and application of chemical products. One of the distinguishing features of this concept is the action to make a chemical or process inherently less hazardous.[20] The World Commission defined sustainability on Environment and Development by the United Nations (UN) as an initiative to meet the necessity of the actual generation without compromising the capacity of future generations to meet their necessities.[21]

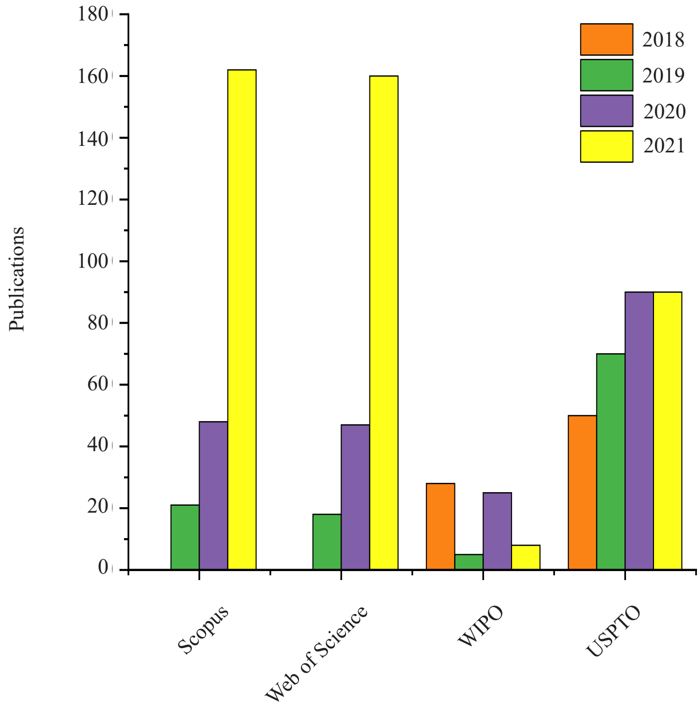

Figure 1. Publications based on industrial waste reuse at the database from Scopus and Web of Science from 2013 to 2020 (By own author)

In this way, combining processes that are less dangerous for living beings and the environment and promoting the production of materials that meet the needs of current and future generations without a significant impact on the environment has become an ever-increasing challenge for materials science, since over the years man has compromised not only his current development but mainly that of future generations who find an unpromising environment for social and work practices, with constant decrease and impacts on natural resources, such as water, as well as an increasing accumulation of waste in the environment.[3,17]

Chemicals and processes must minimize potential hazards from chemicals such as spills, explosions, and fires.[17,20] In this approach, chemical products must be mostly biodegradable, so they do not persist in the environment. The use of unnecessary derivatives should be avoided to reduce the chemical waste that can be generated. As well as the preference for the benefit of raw materials from renewable sources instead of materials from non-renewable sources.[17,20]

In this sense, waste materials provided by diverse industrial types are scientifically and industrially attractive because they present different characteristics, such as functional groups for the development of chemical interactions with metal ions, and organic compounds.[22,23] These industrial waste can be provided by natural sources like foods, cellulose industry, or agroindustry and have chemical groups, providing a polyelectrolytic character that allows for various chemical modifications, in addition to the ability to form flexible materials (hydrogels) that form networks, which swell in water instead of dissolving in it and therefore can retain extremely high amounts, large amounts of the aqueous medium relative to its own mass. The formation of hydrogen bonds between water molecules and the functional groups of the polymeric network leads to the absorption of water from 10 to 100 times its weight and this allows a variety of applications.[23,24]

Therefore, the project's objective must be durability directed to the product, not immortality. Meeting needs and minimizing excess should be considered a design priority, and multicomponent products should be designed to mitigate impacts caused during processing.[25] The integration and interconnectivity with the available energy and material flows must be designed to reduce the effects caused on the environment and choose more sustainable chemical routes with rationed use of materials that impact the environment should be selected.[25]

Alizadeh et al.,[26] Zheng et al.[27] performed new conductive hydrogels based on nanocellulose and graphene-based on green chemistry for various applications. The mechanical behavior and electrochemical conduction were improved.

Makvandi et al.[28] produced hydrogels based on carbohydrates with silver nanoparticles incorporated using corn silk extract and a green chemical route. Liang et al.[29] synthesized a carbon dot based on a facile and green chemical route using the hydrothermal process with gelatin from animal bones and skin and water. Their carbon dots presented a blue emission and little size with a low time (3 hours) at 200 °C using an autoclave.

Then, the reuse of industrial waste is scientifically and industrially attractive, as it is available in large quantities and has excellent potential for use due to its low cost, representing practically unexplored resources.

3. Industrial waste

Nowadays, there are many types of industrial waste. This different waste, most of the time, is discharged in the wrong way. One example is industrial effluents, these wastes are provided from various origins. One of these hazardous wastes is the pigment used by the textile industry. These organic wastes show a terrible problem in water, even in low concentration, as their recalcitrance chemistry reduces sunlight penetration in deep water, causing difficulty in the biological work in this environment.[30-32]

In addition, the COVID-19 pandemic causes much other waste provided by human biosafety security against the virus. However, the foundry industry supplies one of the most environmentally degraded wastes. The foundry industry possesses various operations that impact the environment in different ways. Many of these operations generate microparticles that affect the environment and cause much human health damage. One of these damages is silicosis, caused by lung degradation, which causes death very soon.[33,34]

Moreover, various potentials industrial wastes are a critical problem. One of them is the waste from the petroleum industry. The petroleum industry is one of the world's leading energy production sources, and more than 93.7 million barrels are consumed daily. However, this industry is subject to oil spill accidents and environmental disasters. During 1970-2015, more than 40 million barrels of oil were spilled into the sea, resulting in economic, ecological, and environmental damage, such as water contamination.[35]

The negative impacts of oil spills on ecosystems and their long-term effects, as well as the contamination of the aquatic system by agrochemicals, lead researchers to develop new materials that can remove contaminants through the adsorption process in an attempt to minimize the consequences caused by environmental damage. Many recent studies report the latest advances in adsorption methods for removing organic contaminants, using low-cost materials, easy availability, and handling, with their characteristics or to be developed to become efficient in the removal processes.[36-38]

In this context, Almeida et al.[39] propose a reuse of this RC catalyst residue in water treatment. In their research, this RC was incorporated into a polyurethane matrix to produce a new composite for pesticide adsorption (atrazine, ATZ). The presence of nitrogen in ATZ structure that in low pH is protonated is chemically attracted by a positive charge in RC catalyst. In addition, the porosity in the composite provides a site for the adsorption process, which increases the potential for the reuse of this waste.

According to the Agency for Toxic Substances and Disease Registry (ATSDR), more than 3,000 sites are causing human health risks because of pollutants disposal in the environment. Moreover, most of them (close to 20%) cause problems in health human after long-term, which causes significant concern, as the real problems only appear after a long time.[40,41]

The World Health Organization (WHO) appointed that 15% of waste generated by healthcare activities is considered toxic for all life, and close to 16 billion are discharged inadequately.[42] In addition, although waste is produced directly by industry, other waste is provided by human uses after industry production. Thus, concern about industrial waste, directly or indirectly, is a real problem in an ever-changing world.

4. Wastewater treatment

Water is at the heart of sustainable development. It is one of the resources that delivers a range of services, lends itself to supporting poverty reduction, and aids economic and environmental growth. From food and energy security to human and all environmental health, water improves social well-being and inclusive growth, affecting the livelihoods of millions.[43]

In the world, 97% of water is related to the sea (salt water), and only 3% is sweet water (from rivers). In addition, only 2% is appropriated for human consumption. The lack of water supply, sanitation, and hygiene has caused an enormous cost to the health and well-being of the population, in addition to representing a tremendous financial cost, including a considerable loss of economic activity. To ensure universal access, there is a need for accelerated progress in disadvantaged groups to ensure non-discrimination in water supply, sanitation, and hygiene services. Investments in water and sanitation services have resulted in a substantial economic gain in developing regions. The return on investment has been estimated to be in the range of US$ 5 to US$ 28 per dollar invested, equivalent to US$ 53 billion per year over five years. This amount represented less than 0.1% of the world GDP in 2010.[43]

Thus, enabling adequate water treatment strategies is essential to ensure the quality of consumed water. Different methods of water treatment proposals have been evaluated depending on the contaminant, including chemical precipitation, membrane separation, evaporation, electrolysis, bioremediation, catalysis, and adsorption, among others. However, many of these methods are not efficient and are relatively expensive. In this approach, searching for more effective and cost-compatible processes has been the purpose of several studies.[44]

Several processes have been developed to improve the material removal process and provide better selectivity in the removal. The chosen depends on the type of pollutant, cost, availability, selectivity, and other parameters.[45] Various techniques were used for wastewater treatment, photocatalytic, adsorption, chemical precipitation, membrane filtration, and others. However, some of these methods may be ineffective for removing traces of large volumes of wastewater and have shortcomings such as high maintenance costs, generation of toxic sludge, and complicated procedures involved in treatment.[46,47] For this reason, a selective treatment process is required for the capture/immobilization of specific materials and the reuse of waste.

In this sense, a widely used process is adsorption. This process has the advantage over other techniques that it uses commercially accessible equipment, has low waste generation, is possible to recover metals, in addition to the possibility of reusing the adsorbent and, depending on the adsorbent material used in the process, can become a cost-competitive method for industrially treating effluents.[32,45]

4.1 *Wastewater treatment by adsorption*

Adsorption is a separation process in which specific phase components are transferred to the surface of an adsorbent solid.[48] The adhered material is called adsorbate, and the adsorbent is the solid surface to which it is added.[49] There are systems where the adsorption process is accompanied by absorption, with fluid penetration in the solid phase, the term sorption being more appropriate, which encompasses both methods.[50] Adsorption occurs mainly on the pore walls or at specific sites within the particle and may involve physical and/or chemical processes.[51]

Most recent research is interested in searching for low-cost materials for wastewater treatment. Then, a material that suffered several modifications in the last years was activated carbon, a low-cost source that can be used as an incredible adsorbed material.[52] Suteu & Zaharia[53] used ashes to absorb methylene blue pigments in water. Their results showed that the pH influences the adsorption process. Kaetz et al.[54] used a low-cost material provided by agro-industry waste to adsorb chemical oxygen in water, and their results were very high, with over 94% of adsorption. Similarly, Mor et al.[55] performed a new inorganic phosphate from the waste agro-industry to adsorb toxic chemical reagents in water. Their results were fascinating.

Wakkel et al.[56] produced a new low-cost lignocellulosic adsorbed from agro-industry waste to adsorb cationic dyes. Their results show that cationic adsorption was a spontaneous and endothermic process. Muniz et al.[57] produced a new natural coagulant based on agro-industry waste to adsorb oxygen chemicals in the water. Their results demonstrated a high okra dosage (2 $g.L^{-1}$) at the basic medium. Kanawade & Gaikwad[58] performed a sugarcane bagasse ash material to adsorb acid orange II, their results were very high compared with other ashes used in the literature.

Neves et al.[59] used RC catalyst residue from petroleum cracking to oil adsorb. They produced a new composite using silanes grafted into RC, their results were incredibly high. In addition, Tashima et al.[60] produce a similar material to construction engineering. Therefore, the literature is sparse on new materials from other industrial waste, for example, the foundry industry, which indicates that this way to reuse industrial waste to produce innovative eco-friendlies is still a challenge.

Among the most diverse adsorption processes, biosorption has been seen as a green solution in environmental applications such as wastewater treatment. Among the most diverse adsorption processes, biosorption has been seen as a green solution in environmental applications, such as effluent treatment. In this sense, much research has focused on biological or biocompatible adsorbents, as they have great adsorption capacity and are available in abundance. In the removal of metal ions, for example, the use of these biosorbents for removal is not based on a single mechanism, but several that are quantitatively and qualitatively different depending on the biosorbent used and the metal.

In that regard, much research has focused on biological or biocompatible adsorbents, as have great adsorption capacity and are available in abundance.[61] In this context, a huge number of industrial wastes were used in biosorption for water treatment. Such as different zeolites from mineral industrial waste with low-cost production (US$ 50 to 200) used from removed azeotropes, xylene, ethyl benzene, and others.[62]

4.2 *Water treatment by chemical and biochemical modifications*

Many chemical modifications can be performed in different wastes to improve their ability to wastewater treatment. For example, the introduction of hydrophobic groups into chitosan presented advantages. One of them is that these hydrophobic groups contribute to the solubility in an organic medium, and the presence of ester groups in these derivatives is hydrolyzed by enzymes such as lipase, which is a great advantage to biochemical water treatment. Furthermore, the glycosidic bond of the chitosan derivative is also degraded by glycosidases.[63] Due to the different reactivities of two hydroxyls and amine groups into chitosan, acylation can be modulated to specific sites. These hydrophobic modifications into the chitosan chain provide new physicochemical properties, such as gel formation, polymeric vesicles, Langmuir-Blodgett films, liquid crystals, membranes, and fibers.[63]

Another modification that has gained a lot of space is the carboxymethyl chitosan due to its synthesis facility and the great diversity of applications.[63] Carboxymethyl chitosan is a chitosan derivative that is obtained from a carboxymethylation reaction, producing three different carboxymethyl chitosan (N-carboxymethyl chitosan, O-carboxymethyl chitosan, and N,O-carboxymethyl chitosan).[64] This modification has the advantage over chitosan primarily based on its more comprehensive pH range. In addition, the carboxymethyl chitosan possesses good water solubility, unique physical, chemical, and biological properties, hydrodynamic volume, low toxicity, good biocompatibility, and the ability to be modified and produce films, hydrogels, and fibers.[65] Borsagli & Borsagli[4] synthesized O-carboxymethyl chitosan with different proportions of NaOH, using two different solvents (methanol and ethanol). These differences result in a distinct degree of substitution, although selective adsorption of ions chromate and cadmium. Similarly, they demonstrated that carboxymethyl chitosan's solubility is associated with the chemical groups and pH (Equations 1 to 4).

$$CHI - NH_2 + H^+(aq) \rightarrow CHI - NH_3^+ \quad (1)$$

$$CHI - NH_3^+ + OH^-(aq) \rightarrow CHI - NH_2 + H_2O \quad (2)$$

$$CHI - CH_2COOH_{(s)} + OH^-(aq) \rightarrow CHI - CH_2COO^-(aq) + H_2O_{(l)} \quad (3)$$

$$CHI_{NH_3^+}^{CH_2COOH} \xrightarrow{+OH^-} CHI_{NH_3^+}^{CH_2COO^-} \xrightarrow{+OH^-} CHI_{NH_2}^{CH_2COO^-} \quad (4)$$

$$pH_1 < pH_2 < pH_3$$

These chemical modifications, with the introduction of new chemical groups, provide a range of applications such as in the pharmaceutical, cosmetic, biomedical, biotechnological, agricultural, food industries, mainly in the treatment of water, paper and textiles.[66,67] They can be performed through cross-linking and conjugation, offering several alternatives for chemical modification, such as the insertion of functional and active chemical groups, through covalent bonds with amine or hydroxyl groups, making their final application in water treatment more viable.[68]

4.3 *Water treatment by catalysis*

The contamination of the environment, mainly the water, has recently brought to light an increasingly growing concern in society. Most of this contamination is caused by hazardous materials, as dyes. Aiming at removing dyes, the water treatment may be performed by many different methods, like photocatalytic. The methodology depends on the material used, type of pollutant, cost, among other parameters.[44,45,68,69]

The luminescence of a diversity of materials is the major property for various applications, including water treatment. This characteristic is related to electron radiative combinations and defects on materials' surfaces.[70-73] In this context, Li et al.[74] synthesized a new carbon dot based on a facile chemical route using waste from the mineral industry based on alkali-assisted electrochemical oxidant fabrication. These carbon dots presented photo emission at blue, green, brown and yellow radiation and were used for photocatalytic water treatment using dyes as a model.

Similarly, Liu et al.[75] produced a carbon dot based on agroindustry waste for photocatalytic activity in water treatment. The quantum efficiency was close to 16% at 420 nm, showing a solar conversion of 2% of energy with great stability. In this sense, Wang et al.[76] developed a carbon dot using overcooked barbecue meat, these carbon dots presented an incredible quantum yield (40%) in the green wavelength and performed a great photocatalytic activity. Hazarika and Karak[77] designed catalytic degradation by a kinetic mechanism of benzene, pesticide and phenol using carbon dots by the food waste industry doped by TiO_2. In this research, the pseudo-first-order presented the best model for benzene and phenol.

4.4 *Other wastewater treatments*

Another wastewater treatment was used using industrial waste. In this context, Soares et al.[78] made a new material based on mineral industry waste for the photocatalytic oxidation process of wastewater from the textile industry. Their results were very high using 60 mg of catalyst, over 98%. El-Gendy & Nassar[79] performed a review demonstrating the potential of using bio-waste to make magnetitic nanoparticles for wastewater treatment. Their review explained that these materials are sustainable, low-cost, and environmentally friendly for this wastewater treatment.

Zhou et al.[80] made a new carbon dot from watermelon waste (Food industry) to photocatalytic process based on carbonization. Their results showed that the carbon dots demonstrated an incredible luminescence property based on their small size (2 nm). Moreover, Zhou et al.[81] made a new bio-thiol based on Carbon dots using citric acid from agro-industrial waste. Their carbon dots showed a size of 2.2 nm and high luminescence.

The biological process of wastewater treatment has increased in the last few years. One of these biological processes is the bacterial process from industrial sludge. Industrial sludge is an excellent potential material to produce anaerobic bacteria that can degrade different organic pollutants in water. They can be made in a facile method using industrial sludge, the main effluent produced by industries.[82]

Although the many other types of wastewater treatment, the adsorption process is still the most used for wastewater treatment, mainly because of the facility to produce new adsorbent materials, the reusability of adsorbent, the handling process, and the potential of application to various pollutant.[2,4]

5. Types of industrial wastes

There are various types of industrial waste. In this direction, Davies[82] reported that only in the UK the industrial waste volume is close to 7 times higher than domestic garbage. In Brazil, these numbers are not accessible, but data from the Petrobras industry in 2015 showed that 196 million tons of waste from this industry were reused.[83] However, many other industries have still discharged their waste inappropriately.

5.1 *Agro-industrial waste*

The most used industrial waste in the last years was agro-industrial waste from different sources. The potential carbon source of these agro-industrial waste allows them may be used in further wastewater treatment, such as producing carbon dots for the photocatalytic process,[84,85] cellulose nanocrystal adsorbent,[86,87] nano-graphene oxide for the photocatalytic oxidative process,[88,89] microplastic adsorbent,[90] and many others.

One of the most exciting materials from agro-industry waste is chitin. This biopolymer can be modified into one of the most biopolymers used, chitosan. This biopolymer is highly used in various wastewater treatments. Morais et al.[91] developed chitosan spheres to absorb methyl orange in the aqueous medium, analyzing the equilibrium and kinetics. The research showed that the isotherm was a mix of Freundlich and Langmuir, but the Langmuir behavior exceeded Freundlich when the pH increased. Mahamoodian et al.[92] studied the adsorption of methyl orange using a nano-composite based on chitosan and carbon nanotube. Their research analyzed contact effect, pH, temperature, and dosage. The results showed that the adsorption was spontaneous and endothermic.

Similarly, Allouche et al.[93] studied the adsorption of methyl orange using chitosan biomass. In addition, they used infrared spectroscopy to understand the mechanism of methyl orange adsorption by chitosan biomass. The maximum adsorption capacity was reached at 60 minutes, and the pH was equal to 3.0. The value of adsorption capacity found was 29 $mg.g^{-1}$.

In addition, chitin, chitosan, and their derivatives have been widely used in this proposal. Chiou & Li[94] made a new cross-linked chitosan bead using epichlorohydrin, glutaraldehyde, and ethylene glycol diglycidyl ether to adsorption process of reactive red 189. They demonstrated that this material with epichlorohydrin conferred a tremendous high capacity (1,802-1,840 g/kg).

Abdollahi et al.[95] made a new sponge-like nano-composite using human hair, bovine bones, and clay for heavy metal adsorption in wastewater. Their sponge-like structure showed over 95% nickel and cobalt adsorption. Roy Choudhury et al. performed a new membrane using clay-to-metal ions adsorption. Like Abdollahi et al.,[95] Googerdchian et al.[96] made a new adsorbent using bovine bone to adsorption process, their removal efficient adsorption of 200 $mg.g^{-1}$.

Another potential waste is the rice bagasse from agro-industrial. Srivastava et al.[97] used this bagasse to remove heavy metals from water, mainly cadmium and zinc. Their results demonstrated that the rice bagasse had nonselective behavior for one of these heavy metals. Amponsem et al.[98] showed that their nano-composite produced using rice bagasse from Ghana presently has a higher adsorption behavior for remediation.

5.2 *Ceramic industrial waste*

Another interesting industrial waste is ceramic industrial waste. As ceramic waste is mainly composed of different oxides, these materials have an incredible adsorption characteristic. Enesca & Isac[99] made a new honeycomb ceramic adsorbent material from ceramic industry waste. Their result demonstrated a stable material to use in the adsorption process. Chen et al.[100] performed a new hierarchical porous zeolitization ceramsite using industrial waste. Their material can be used in wastewater treatment.

5.3 *Petroleum industrial waste*

Almeida et al.[101] performed different types of composite foam using RC catalysts from petroleum industry waste. Their results demonstrated high adsorption of trifluralin pesticide at pH 5.0 (70%) and an increase to 83% using 400 mg of adsorbent. Therefore, the pure catalyst RC showed higher adsorption of 95.3%, which indicates the potential to use this waste from the petroleum industry.

According to Afonso et al.,[102] the RC catalyst is formed by silicon oxide, kaolin, zeolite, and aluminum oxide. Chen et al.[100] have already shown that these compounds have a potential for adsorption. In addition, this RC presented a high surface area, which provides incredible potential to the site for adsorption.[101] Then, these results showed the high potential to use this petroleum industry waste for wastewater treatment.

6. Conclusion and future perspectives

This overview exposed a range of research on using various industrial wastes for water treatment, their green chemistry, their potential and their chemical modifications. These unequaled industrial wastes present multiple properties and characteristics that allow them many applications, including water treatment. The different industrial wastes affect their characteristics, which implies different properties, altering the adsorption process and other processes used in the water treatment proposal of this overview. Different types of industrial waste have been widely investigated to use in water treatment, such as mineral wastes, agroindustry wastes, petroleum wastes, ceramic wastes, and others. Extensive literature demonstrates their potential, the wastewater removal mechanism, the influence of pH, temperature, dosage, dye concentration, synthesis, source, and other essential parameters. Therefore, despite this vast and incredible literature, it is still lacking to find innovative works involving industrial waste material from innovative industries, as agro-industrial waste is the most used material in water treatment. Moreover, these industrial wastes exhibit an incredible potential for removing the diversity of organic dyes, metallic ions in water, indicating their promising solution of low-cost, sustainable, and eco-friendly material for wastewater treatment.

Ethics approval and consent to participate

All authors give their consent to participate and confirm their ethics approval.

Consent for publication

All authors give their consent for publication.

Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article [and/or] if necessary to share.

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Author contributions

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Conflict of interest

The authors declare that they have no competing interests.

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