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Hydrogels based on 2-Acrylamido-2-Methylpropane Sulfonic Acid: An emerging solution for the sustainable remediation of water contaminated by dyes and heavy metals

Hidrogeles a base de ácido 2-acrilamido-2-metilpropanosulfónico: Solución emergente para la remediación sustentable de aguas contaminadas con colorantes y metales pesados

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Technological innovation: Sustainable alternatives for the elimination of dyes and heavy metals.
Industrial application area: Wastewater treatment, polymeric materials.

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Resumen

El crecimiento acelerado de las actividades industriales y humanas ha traído consigo un aumento significativo en la cantidad de contaminantes vertidos al medio ambiente, especialmente en cuerpos de agua. Entre estos contaminantes, destacan los colorantes sintéticos y los metales pesados, cuya presencia representa una seria amenaza tanto para los ecosistemas acuáticos como para la salud humana. Los colorantes industriales, ampliamente utilizados en sectores como el textil, papelero y alimentario, son compuestos orgánicos recalcitrantes que no se degradan fácilmente por medios naturales. Su acumulación en el agua afecta negativamente la penetración de la luz solar, interfiriendo con procesos esenciales como la fotosíntesis y alterando el equilibrio de la cadena alimentaria. Por otro lado, metales pesados como el plomo (Pb), el mercurio (Hg) y el cadmio (Cd) son altamente tóxicos incluso en concentraciones bajas. Estos elementos pueden bioacumularse en los tejidos de organismos vivos, generando efectos adversos que van desde trastornos neurológicos hasta mutaciones genéticas y enfermedades crónicas. Ante esta problemática, la búsqueda de métodos eficientes, sostenibles y económicos para la remoción de contaminantes se ha vuelto

prioritaria. En este contexto, los hidrogeles han emergido como materiales prometedores para la remediación ambiental debido a su bajo costo de producción, facilidad de síntesis, gran capacidad de hinchamiento en medios acuosos y la presencia de diversos grupos funcionales capaces de interactuar con diferentes tipos de contaminantes. En particular, los hidrogeles formulados a partir de p[ácido 2-acrilamido-2-metilpropano sulfónico] (p[AMPS]) han mostrado un alto potencial para la adsorción de colorantes y metales pesados. Esta capacidad se atribuye a la presencia del grupo ácido sulfónico, que permite un eficiente intercambio iónico. Además, el p[AMPS] presenta buena estabilidad química en un amplio rango de pH y no es tóxico, lo que lo convierte en una alternativa viable y segura para el tratamiento de aguas contaminadas. Esta investigación se enfoca en evaluar la eficacia de hidrogeles de p[AMPS] en procesos de remediación ambiental, resaltando sus ventajas comparativas frente a otras tecnologías convencionales.

Palabras clave: p[AMPS], Colorantes, Hidrogeles, Metales Pesados, Remoción.

Abstract

The accelerated growth of industrial and human activities has led to a significant increase in the amount of pollutants discharged into the environment, especially into water bodies. Among these pollutants, synthetic dyes and heavy metals stand out, their presence posing a serious threat to both aquatic ecosystems and human health. Industrial dyes, widely used in sectors such as textiles, paper, and food, are recalcitrant organic compounds that do not degrade easily through natural means. Their accumulation in water negatively affects the penetration of sunlight, interfering with essential processes such as photosynthesis and altering the balance of the food chain. On the other hand, heavy metals such as lead (Pb), mercury (Hg), and cadmium (Cd) are highly toxic even at low concentrations. These elements can bioaccumulate in the tissues of living organisms, generating adverse effects ranging from neurological disorders to genetic mutations and chronic diseases. Faced with this problem, the search for efficient, sustainable, and economical methods for pollutant removal has become a priority. In this context, hydrogels have emerged as promising materials for environmental remediation due to their low production cost, ease of synthesis, high swelling capacity in aqueous media, and the presence of diverse functional groups capable of interacting with different types of contaminants. In particular, hydrogels formulated from p[2-acrylamido-2-methylpropane sulfonic acid] (p[AMPS]) have shown high potential for the adsorption of dyes and heavy metals. This capacity is attributed to the presence of the sulfonic acid group, which enables efficient ion exchange. Furthermore, p[AMPS] exhibits good chemical stability over a wide pH range and is nontoxic, making it a viable and safe alternative for the treatment of contaminated water. This research focuses on evaluating the efficacy of p[AMPS] hydrogels in environmental remediation processes, highlighting their comparative advantages over other conventional technologies.

Keywords: p[AMPS], Dyes, Heavy Metals, Hydrogels, Removal.

I. Introduction

Rapid Global population growth and improvements in quality of life have led to a notable increase in environmental pollution, mainly affecting the most essential resource for life: water. Despite its abundance on the planet, only a small fraction is suitable for human consumption. Of the total, just 2% is fresh water, and of this, only 0.5% is available for direct use, as the rest is found in polar regions, aquifers, or in an inaccessible form (Bureau of Reclamation, 2020). As a result of industrialization, urbanization, and a lack of awareness about its importance, approximately 80% of the world's population currently faces problems with access to and security of water resources (Mustafa & Hassan, 2024). Some of the main pollutants are dyes and heavy metals, mostly originating from industrial activities. Dyes, widely used in industries such as textiles, paper, and paints, are frequently discharged without prior treatment, generating toxic effects on aquatic life even at low concentrations, altering processes such as photosynthesis and the food chain (Pereira & Alves, 2012; Arun Krishna & Vishalakshi, 2017). It is estimated that these compounds account for between 8% and 20% of water pollution (Alsukaibi, 2022). On the other hand, heavy metals like lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As) also pose a serious threat due to their toxicity, persistence, and bioaccumulation capacity. Since the 1970s, their elevated concentrations have raised concerns about the harmful effects they cause on human health and aquatic ecosystems, affecting soil fertility and causing toxicity, mutagenicity, and carcinogenicity (Karvelas et al., 2003; Kishor *et al*., 2021; Qasem *et al*., 2021). Faced with this situation, multiple techniques have been developed for the removal of pollutants, such as advanced oxidation, photo-Fenton, electrocoagulation, and ozonation in the case of dyes, as well as chemical precipitation for heavy metals (Sharma *et al*., 2018; Malik *et al*., 2019). However, adsorption has gained special relevance for being an effective, simple, and low-cost method. In this context, hydrogels have emerged as promising materials due to their high-water retention capacity, low environmental impact, and versatile applications (Van Tran *et al*., 2018; Weerasundara *et al*., 2021). Particularly, those synthesized with p[2-acrylamido-2-methylpropane sulfonic acid] (p[AMPS]) have demonstrated valuable functional properties. This monomer has an anionic sulfonic acid group that gives it chromophobia, conductivity, ion exchange capacity, and resistance to divalent ions. In addition, its amide group provides stability against hydrolysis, acids, bases, and high temperatures, while its double bond facilitates the formation of copolymers. These characteristics allow the formation of chelates and their binding to both heavy metals and organic dyes, positioning AMPS as a key component in the design of hydrogels for removing pollutants in water (Atta *et al*., 2018).

II. Materials and Equipment

This research was conducted using an HP Victus 15 fa1012la laptop, equipped with a 13th-generation Intel Core i7 processor. Data retrieval and synthesis were performed through the analysis of scientific articles obtained from search engines such as Google Scholar, Web of Science®, and Science Direct®, widely recognized platforms in the academic and research fields that allow for the monitoring and constant updating of scientific and technological advances. This study prioritized the analysis of articles related to water contamination, particularly by heavy metals and dyes, as well as reported decontamination techniques. Furthermore, emphasis was placed on the implementation of hydrogels based on 2-acrylamido-2-methylpropanesulfonic acid as an emerging

alternative for the removal of these contaminants.

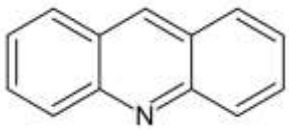
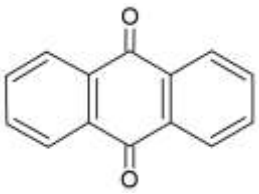
III. Experimental Methods

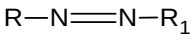
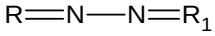
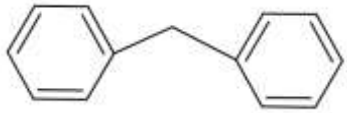
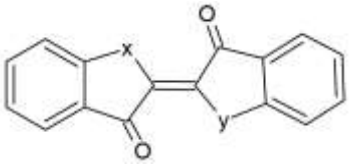
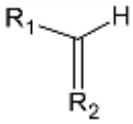
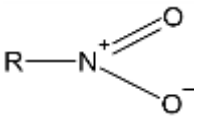
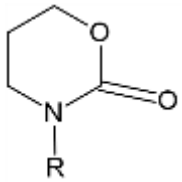
The search engines used in the aforementioned databases focused on keywords and their combination to form specific phrases that would allow for the most accurate and relevant information on the topic in question. Priority was given to information published from the beginning of the 21st century to the present, given that during this period, awareness of water pollution generated by past industrial revolutions, as well as large-scale population development, began to gain relevance.

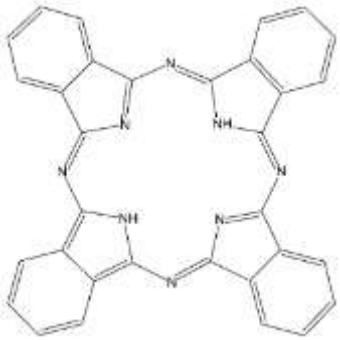
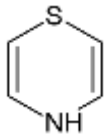
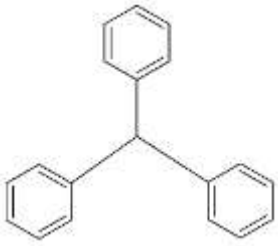
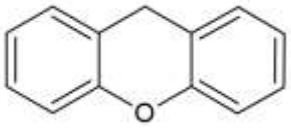
IV. Dyes

Dyes are substances that, over time, have not only contributed color and aesthetics to various materials but have also provided advantages such as resistance to water, light, oxidizing agents, sweat, and microbial attack (Khan *et al*., 2022). Although dyes, pigments, and colorants are frequently used as synonyms, there are differences between them. Pigments are insoluble substances that require a binder to adhere to a surface, whereas dyes are soluble and can be fixed directly onto a material. While dyes can be obtained from natural sources, technological advancements and research have established synthetic dyes as the most widely used in the industry due to their greater durability compared to natural ones (Tang *et al*., 2018). For a chemical compound to be classified as dye, it must contain chromophore groups in its structure, which are responsible for absorbing certain wavelengths of light and giving color to the substance. There are two main systems for classifying dyes (Gürses *et al*., 2016). The first is based on the nature of their chromogens, including acridine, anthraquinone, azo, azine, diphenylmethane, indigoid, methine, nitro, nitroso, oxazine, phthalocyanine, thiazine, triphenylmethane, and xanthene. The second system classifies them according to their application, dividing them into acid, basic, direct, disperse, fiber, reactive, vat, and mordant dyes. Table 1, presents a list of representative dyes according to both classifications.

Table 1. Classification of dyes (own source).

General Structure	Chromogen Sorting	Classification by Application	Name of dye/color index	
	Acrinidine	Acid	Acrinidine Orange	46005
	Anthraquinone	Reagent	Reactive Blue 2	74160

	Azo	Direct	Direct Red 80	35780
	Thiazine	Direct	Direct Blue 1	24410
	Diphenylmethane	Basic	Basic Violet 2	42500
	Indigoid	Acid	Acid Blue 74	73015
	Metino	Basic	Basic Yellow 28	48035
	Nitro	Dispersed	Dispersed Yellow 42	61930
	Oxacin	Solvent	Solvent Yellow 172	47000

	Phthalocyanine	Direct	Direct Blue 86	74180
	Thiazine	Basic	Basic Blue 9	52015
	Triphenylmethane	Basic	Basic Violet 3	42555
	Xanthene	Acid	Acid Red 52	45100

Approximately 7×10^5 tons of synthetic dyes are produced annually worldwide, with the textile industry being the primary consumer (Shabir *et al*., 2022; Singh & Arora, 2011). This industry is the largest generator of dye effluents (54%), contributing more than half of the discharges of this type into the environment. Depending on the type of fabric and dye, almost 200 billion liters of colored effluents are generated per year (Tkaczyk *et al*., 2020).

According to the European Union (2024), the textile sector was the third-largest source of water degradation and land use in 2020. In that same year, an average of nine cubic meters of water (9 m^3), four hundred square meters of land (400 m^2), and three hundred and ninety-one kilograms (391 kg) of raw materials were needed to provide clothing and footwear to each citizen of the EU. Other industries that also generate large amounts of dye effluents from their production processes are dyeing (21%), paper and pulp (10%), tanneries and paints (8%), and dye manufacturing (7%) (Katheresan *et al*., 2018).

Due to their production volume and the composition of their effluents, wastewater from the textile industry has been classified as the most polluted of all industrial sectors (Carmen & Daniel, 2012). Among the dyes used and discarded by this industry, azo dyes are of particular concern (Khattab *et al*., 2020). The United Nations Statistics Division (UNSD), based in New York, estimated that

the global import and export market for dyes containing mainly the azo group (-N=N-) was 680,000 tons in 2011 (Yusuf, 2019). These chemical compounds have been identified as mutagenic, carcinogenic, and genotoxic. It has been reported that workers exposed to azo dyes have a higher risk of developing bladder cancer, splenic sarcoma, and liver carcinomas, as well as chromosomal alterations in mammalian cells, which have been demonstrated in animal studies (Sudarshan *et al*., 2023).

In July 2002, the ETAD published the 19th amendment to the restrictions on the marketing and use of certain azo dyes, in accordance with Directive 2002/61/EC of the European Parliament and of the Council (Shabbir, 2019). It is known that, in dyeing processes, around 15% to 50% of the dyes used are released, which are not fixed to the fibers and end up being discharged in wastewater (Al-Tohamy *et al*., 2022). While some textile factories treat these effluents to degrade or remove the dyes before discharge, others directly discharge untreated wastewater into bodies of water, contaminating clean and colorless water. Several studies have confirmed that concentrations below 1 ppm are sufficient to generate turbidity (Pereira & Alves, 2012) and an unpleasant odor (Liu, 2020). Table 2, presents the permitted values for the discharge of water contaminated by dyes.

Table 2. Standards allowed for the discharge of water contaminated by dyes (own source).

Factor	Permitted Standard (Katheresan *et al*., 2018)	Permitted Standard NOM-065-ECOL-1994
Biological Oxygen Demand (BOD)	< 30 mg/L	--
Chemical Oxygen Demand (COD)	< 50mg/L	<300 mg/L
Fats and oils	---	<40 mg/L
Colour	< 1ppm	---
pH	6-9	6-9
Suspended solids	< 20 mg/L	< 200 mg/L
Settleable solids	---	< 1 ml/L
Temperature	< 42 ºC	---

V. Cytotoxicity and Ecotoxicity of Dyes

The entry of effluents containing dyes into rivers, lakes, seas, or aquifers represents a serious pollution problem, as these compounds are persistent and xenobiotic substances in the environment (Muthu & Khadir, 2021). Initially, dyes absorb and reflect sunlight that penetrates the water, which interferes with the growth of aquatic species and hinders photosynthesis (Oladoye *et al*., 2022). In addition, these pollutants can penetrate the food chain, leading to bioaccumulation and an increase in toxicity, mutagenicity, and carcinogenicity. They can also increase the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD), affecting the ecological balance of water bodies (Arun Krishna & Vishalakshi, 2017).

An important example of this is algae, which are specimens highly sensitive to pollutants compared to other organisms used in aquatic toxicological tests (Rojíčková & Maršálek, 1999). An increase in the concentration of dyes in water can inhibit the growth of *Spirulina platensis* and reduce its nutritional value. In particular, the dye Reactive Red 180 alters the trophic chain in water bodies,

creating an environmental imbalance. Likewise, the dye indigo reduces growth and biomass production, in addition to modifying the morphological structure of freshwater microalgae such as *Scenedesmus quadricauda* (Dutta *et al*., 2024).

While aquatic systems are usually the most affected, the terrestrial and atmospheric environments also suffer repercussions due to the emissions generated by the textile industry (Roy Choudhury, 2014). Most wet processes in this industry release gaseous emissions; in the dyeing and printing sectors, the gases produced have been identified as the second most important source of pollution (Alsukaibi, 2022). Likewise, leaks and spills of toxic compounds from the textile industry, along with prolonged irrigation and the use of contaminated sludge, contribute to soil contamination with dye residues (Ardila-Leal *et al*., 2021). These contaminants, both organic and inorganic, pose a significant risk due to their allergenic, mutagenic, and carcinogenic properties. Furthermore, they alter the physicochemical characteristics of the soil, increasing its vulnerability to erosion, reducing its productivity, and affecting plant growth, which negatively impacts agricultural production (Islam & Mostafa, 2019).

In general, the presence of dyes in water constitutes a serious threat to biodiversity and public health (Rathi *et al*., 2021). The consumption of water contaminated with dyes poses a significant risk to human and animal health (Lellis *et al*., 2019). Many of these compounds and their degradation products have been associated with carcinogenic effects, mainly related to intestinal cancer and brain abnormalities in fetuses (S. Khan & Malik, 2014). Table 3, presents some of the main conditions caused by exposure to water contaminated by dyes.

Table 3. Conditions generated by exposure to water contaminated by dyes (Kishor et al., 2021) (own source).

Affection	Description
Allergic reactions	Contact dermatitis, eye, skin and respiratory tract irritation.
Respiratory Diseases	Difficulties in the respiratory system due to inhalation of contaminated particles.
Toxic effects on living organisms	Textile dyes and wastewater affect plants, rats, fish, mollusks, microorganisms and mammalian cells, causing mutagenic and cytotoxic effects. Some azo dyes, such as Acid Red 85, can release genotoxic and carcinogenic aromatic amines, such as benzidine. When ingested, these compounds can be reduced in the intestine by the anaerobic microflora and azoreductases present in the intestinal wall or in the liver, generating free amines with toxic potential (Mathur *et al*., 2012)
Damage to vital organs	These pollutants can primarily affect the liver, kidneys, brain, nervous system, and reproductive system in both humans and animals.

VI. Heavy Metals

Heavy metals represent a significant source of pollution in terrestrial water bodies. Since the early 1970s, there has been growing concern about the various effects these elements have on human health and aquatic ecosystems (Karvelas *et al.,* 2003). They are defined as a group of elements with atomic weights between 63.5 and 200.6 atomic units (Zhao *et al*., 2016). Their presence in the environment is due to both anthropogenic activities (such as the textile, mining, chemical, and agricultural industries) and natural processes (erosion and weathering of

rocks, volcanic activity, and other biogeochemical processes) (Elgarahy *et al*., 2021).

The most common pollutants include cadmium (Cd), zinc (Zn), lead (Pb), chromium (Cr), nickel (Ni), copper (Cu), vanadium (V), platinum (Pt), silver (Ag), tin (Sn), and titanium (Ti) (Qasem *et al*., 2021). Table 4, presents the heavy metals that are discarded by various industries. These pollutants can be transported over long distances through wastewater, persisting in the environment for long periods. Their presence poses serious risks to the health of living organisms, in addition to affecting soil fertility and reducing the photosynthetic activity of aquatic plants. This, in turn, can generate anoxic conditions in aquatic ecosystems, endangering fauna and flora (Kishor *et al*., 2021).

Table 4. Heavy metals generated by various industries (Shrestha *et al*., 2021) (own source).

	Heavy metal													
Industry	Al	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn	Co	Fe	Mn	Where are they generated?	Reference
Trash			x	x	x	x	x	x	x			x	Bleaching process.	Bajpai, 2015
Agricultural (Fertilizers)	x	x	x	x	x	x	x	x	x				Application on soils	Mortvedt, 1996
Oil refinery	x	x	x	x			x	x	x	x			Accepted sludges derived from petroleum	Singha & Deka, 2024
Steel		x	x	x	x	x	x	x	x	x			Mainly in 3 zones: 1) coke processing plant, (2) blast furnace and (3) storage area.	Zhang *et al*., 2021
Pharmacist		x	x	x	x		x	x	x				Drug synthesis.	Okoro *et al*., 2023
Textile			x	x	x		x	x	x		x		Use in oxidizing agents, metal complex dyes, stripping agents, fastness improvers, and finishing products.	Zeiner *et al*., 2007

VII. Cytotoxic Effects of Heavy Metals

Heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), and chromium (Cr) are highly toxic to humans, aquatic life, and the environment. In general, in humans, heavy metals interfere with essential cellular functions and cause irreversible damage to organs because they interfere with enzymatic and metabolic processes. In addition, some metals can cause cognitive impairment, oxidative stress, and damage to cell membranes, as well as to proteins and DNA, which results in severe damage in target organs (Qasem *et al*., 2021). Heavy metals can not only be ingested through contaminated water, but they have also been reported to accumulate in various food sources, such as vegetables, cereals, fruits, fish, and shellfish, due to their absorption from the soil and surrounding water (Sall *et al*., 2020). Furthermore, the simultaneous presence of heavy metals and organic pollutants in water can inhibit plant growth and negatively affect the microbial population (Ajiboye *et al*., 2021).

In response to these risks, environmental monitoring agencies have established permissible limits for the concentration of heavy metals in drinking water, setting a maximum of 12 µg/L due to their harmful effects (Muya *et al*., 2016). Wastewater has not been the exception; over time, various wastewater regulations have been developed to minimize human and environmental exposure to hazardous chemicals. These regulations set limits on the types and concentrations of heavy metals that may be present in discharged wastewater (Barakat, 2011). Table 5, details the maximum permissible effluent limits established by the World Health Organization (2022), as well as the health problems that these metals can cause in case of prolonged exposure, demonstrating the importance of their removal.

Table 5. Concentrations allowed for the discharge of heavy metals (own source).

Heavy metal	Maximum permitted limits on effluents (mg/l)	Diseases it generates	Reference
Aluminum (Al)	0.9	Neurogenerative diseases (Alzheimer's, epilepsy and autism). In babies, their central nerves and bones can be affected.	Alasfar & Isaifan, 2021
Arsenic (As)	0.01	Chronic arsenic that includes dermal lesions such as hyperpigmentation and peripheral hypopigmentation. Cancer of the lungs, skin, and bladder	Ng, 2005
Cadmium (Cd)	0.003	Nephrotoxic (renal tubular damage), bone damage. After prolonged or high exposure, the tubular lesion may progress to glomerular damage with decreased glomerular filtration rate and eventually to renal failure.	Järup & Åkesson, 2009
Chromium (Cr)	0.05	Nausea, diarrhea, liver and kidney damage, dermatitis, internal bleeding, and breathing problems. It can build up in the placenta and affect the fetus.	Shrestha *et al*., 2021
Copper (Cu)	2	Anemia, abdominal pain, peripheral neuritis, degeneration, atrophy of the muscles, greenish line on the dental margins of the gum as well as hair can have the same coloration, Wilson's disease, chalccosis lentis.	Shrestha *et al*., 2021
Cobalt (Co)**	---	Prolonged contact can generate heart disease, oxidative stress, neurotoxic effects, liver and kidney toxicity, inflammatory effects, metabolic alterations, genotoxicity and carcinogenic potential.	Dolomatov *et al*., 2019
Iron (Fe)*	---	Hemochromatosis, diseases related to the heart and central nervous system, cirrhosis of the liver, diabetes, nausea,	Das *et al*., 2023
Mercury (Hg)	0.006	Cardiovascular, hematological, and Pulmonary, as well as in the digestive, immune systems, nervous, reproductive and endocrine systems.	Rice *et al*., 2014
Manganese (Mn)	0.08	Neurotoxic. Cardiovascular problems, as well as liver problems.	O'Neal & Zheng, 2015
Nickel (Ni)	0.07	Allergy, cardiovascular and kidney disease, pulmonary fibrosis, lung cancer and nasal. Mitochondrial problems and oxidative stress.	Genchi *et al*., 2020
Lead (Pb)	0.01	Cardiovascular disorders, blindness, hallucinations, odd bone development, anemia, kidney failure, memory loss and decreased IQ.	Raj & Das, 2023
Zinc (Zn)*	---	Lethargy, focal neuronal deficits, nausea, vomiting, epigastric pain, diarrhea, and prostate cancer.	Plum *et al*., 2010

* Not a health concern at levels that cause problems of acceptability in drinking water.
** "Guidelines for drinkingwater quality".

VIII. Water Treatment

A conventional drinking water treatment plant includes units for coagulation, flocculation, sedimentation, filtration, and disinfection (Nasier & Abdulrazzaq, 2021). In the first and second techniques, heavy metals and dyes are removed; however, they show several disadvantages such as the generation of large amounts of sludge, the use of costly chemicals (which can also be harmful), and limited removal efficiency. In the last phase, other techniques are incorporated, many of which have been studied for the removal of dyes, such as advanced oxidation (Fenton processes, ozonation), the use of surfactants, and electrocoagulation, among others (Sharma *et al*., 2018) (Table 6). For the elimination of heavy metals, the most used methods have been chemical precipitation and ion exchange (Malik *et al*., 2019). However, there is a technique capable of removing both contaminants simultaneously: adsorption. In this process, various materials have been studied for the elimination of contaminants, such as activated carbon, zeolites, and clays. Although they have shown promising results, they have limitations such as low selectivity, reduced efficiency, and limited use cycles (Wang *et al*., 2019). Due to this, hydrogels have begun to gain relevance in this field, thanks to their high absorption capacity, which allows them to retain large amounts of contaminants. In addition, many hydrogels are biocompatible and biodegradable, which makes them ecological and safe for the environment. Another key benefit is their ease of regeneration, which allows their reuse over multiple treatment cycles. Hydrogels can also be chemically modified to increase their selectivity towards specific contaminants, improving their effectiveness. Their ease of handling and processing allows them to be adaptable to different treatment systems, such as adsorption columns and membranes. Furthermore, some hydrogels allow the recycling of contaminants, which favors their recovery and reuse. Finally, their stability in various environmental conditions, such as changes in temperature and pH, makes hydrogels effective in a variety of aqueous environments, even in complex wastewater (Van Tran *et al*., 2018).

Table 6. Additional techniques for the removal of dyes and heavy metals (own source).

DYES			
Technique	**Advantages**	**Objectives**	**Disadvantages**
Electrochemical oxidation and reduction	Color processing, COD, BOD and TSS are effective, the process is flexible and adaptable.	Dyes other than cationic dyes	High consumption of energy, iron and prices.
Electrocoagulation/ Electric Flotation	Low investment, strong handling ability, hydrophobic dye, high fade efficiency.	Disperse dyes, Vat dyes, sulfur dyes	Low decolorization capacity of hydrophilic dyes, low COD removal efficiency, chemical sludge production, secondary pollution.
Photocatalytic oxidation	The catalyst is small, the treatment effect is good, and the reaction time is short.	Synthetic dyes, recalcitrant, with aromatic structures and/or azo groups.	High catalytic converter price and reuse problems, low light energy utilization and complex reactor

Fenton Oxidation	Fenton reagents have both oxidation and coagulation effects.	Azo, triphenylmethane, thiazine, and anthraquinone dyes	Process conditions are "harsh", the cost of operation is high, and excess sludge is produced.
Ozonization	Small area, easy automatic control, easy to adjust, no sludge, no secondary pollution.	Direct dyes, acid dyes, Basics dyes, reactive dyes	High cost and unsatisfactory COD removal rate
Anaerobic Processes	The fading effect is good, the residence time is short.	Azo dyes.	It produces a large amount of aniline, the biological toxicity of the effluent increases.

HEAVY METALS			
Technique	**Advantages**	**Objectives**	**Disadvantages**
Chemical precipitation	High efficiency for heavy metals, simple and economical processes, fast, controllable and adjustable, compatible with other processes.	Pb^{2+}, Cd^{2+}, Cu^{2+}, Zn^{2+}, Cr^{3+}, As^{5+}, among others.	Generation of toxic sludge, highly sensitive to pH, expenditure on reagents,
Ion exchange	High selectivity, efficiency, reusable, fast and controllable	Pb^{2+}, Cd^{2+}, Cu^{2+}, among others.	Initial cost, lifetime of resins, limited to specific ions.

Hydrogels were designed by Wichterle and Lim in 1954 and are considered highly porous, three-dimensional polymeric networks that can swell up to 400 times their original weight and retain more than 20% of their dry weight upon contact with a liquid (Shalla *et al*., 2019). The removal of contaminants occurs by two main mechanisms: chemisorption and physisorption (Yang *et al*., 2021). Chemisorption is an irreversible process, since chemical bonds are formed between the adsorbent and the adsorbate. Unlike physisorption (Figure 1), which is proposed as a reversible process, controlled by physical forces such as hydrogen bonds, Van der Waals interactions, hydrophobic interactions, electrostatic interactions, and ion exchange (Weerasundara *et al.,* 2021). These materials present several advantages for their application, among which are optimal durability during swelling and storage, high biodegradability without the generation of toxic compounds before, during, or after their elimination, a neutral pH after hydration in water, they are odorless and colorless, in addition to presenting high photostability, and the ability to rehydrate, which allows their application in water treatment and environmental remediation (Weerasundara *et al*., 2021). In practice, the selection of hydrogels is based on criteria such as material cost, environmental impact, stability, absorption rate, reusability, and adsorption efficiency (Seida & Tokuyama, 2022). A hydrogel is usually composed of one, two, or more polymers, and its synthesis is mainly carried out by two routes: chemical or physical (Table 7). The crosslinking of the polymeric chains can occur through thermocondensation, self-assembly, non-covalent interactions, or covalent interactions (Samaddar *et al*., 2019). In addition, their classification depends on factors such as morphology, synthesis materials, preparation method, and response in the environment (Laftah *et al*., 2011).

Table 7. Hydrogel synthesis routes (Ahmaruzzaman et al., 2023) (own source).

Chemical synthesis route	Physical synthesis route
* Chemical cross-linking	*Ionic interaction
* Grafting	*Hydrogen bridges
*Polymerization via free radicals	* Heat-induced aggregation
*Condensation polymerization	*Hydrophobic interactions
*Photopolymerization (high energy (UV/Y rays) and low energy (visible/near IR))	*Crystallization

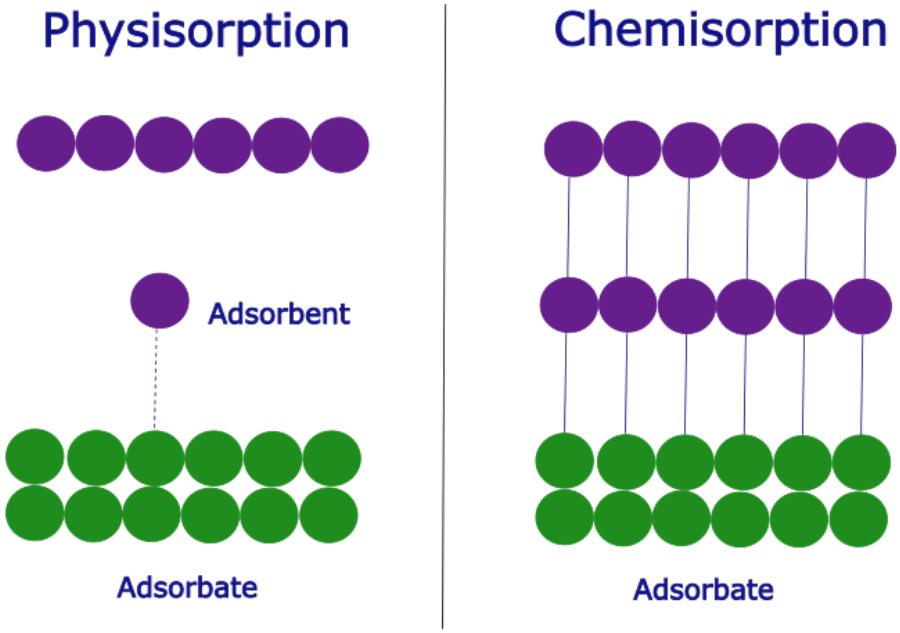


Figure 1. Chemisorption and physisorption processes.

Acrylamides are one of the most used monomers in the synthesis of hydrogels for the removal of dyes, because they have highly reactive functional groups (–OH, N–H, –$CONH_2$), which allows their interaction with various molecules (Shalla *et al*., 2018). In addition, these monomers possess key properties that favor their application in the adsorption of contaminants, such as their high hydrophilicity (Gorji et al., 2016), ease of polymerization, chemical and thermal stability, as well as their compatibility with other polymers to form composites. Some examples of polymers derived from acrylamides are polyacrylamide, *N,N*-dimethylacrylamidepropylmethacrylamide hydrochloride, and *N*-(3-aminopropyl)methacrylamide hydrochloride, among others (Zhang *et al*., 2021).

Within this group, 2-acrylamido-2-methyl-1-propanesulfonic acid (AMPS) stands out, a monomer widely studied in the synthesis of hydrogels. The chemical structure of this monomer confers several favorable characteristics for its use in the removal of environmental contaminants. The anionic sulfonic group gives it electrical conductivity, ion exchange capacity, and stability in the presence of divalent ions, while the amide functional group provides high stability against hydrolysis, as well as resistance to acids, alkalis, and high temperatures. In addition, the active double bond facilitates addition and polymerization processes, allowing the synthesis of copolymers (Li *et al*., 2024). Although it has been reported that the monomeric form can cause negative

health and environmental effects, it is important to highlight that p[AMPS] (Figure 2) does not generate toxic byproducts during its synthesis and has a high capacity to form chelates and bind to heavy metals and organic dyes, making it a promising material for the treatment of water contaminated with dyes and heavy metals. (Figure 3) (Atta *et al*., 2018).

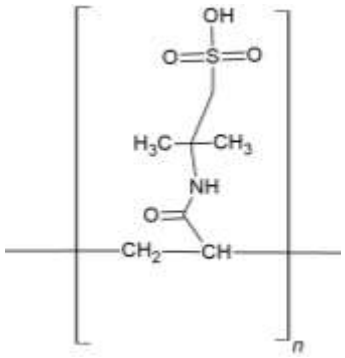


Figure 2. p[AMPS] Structure (own source).

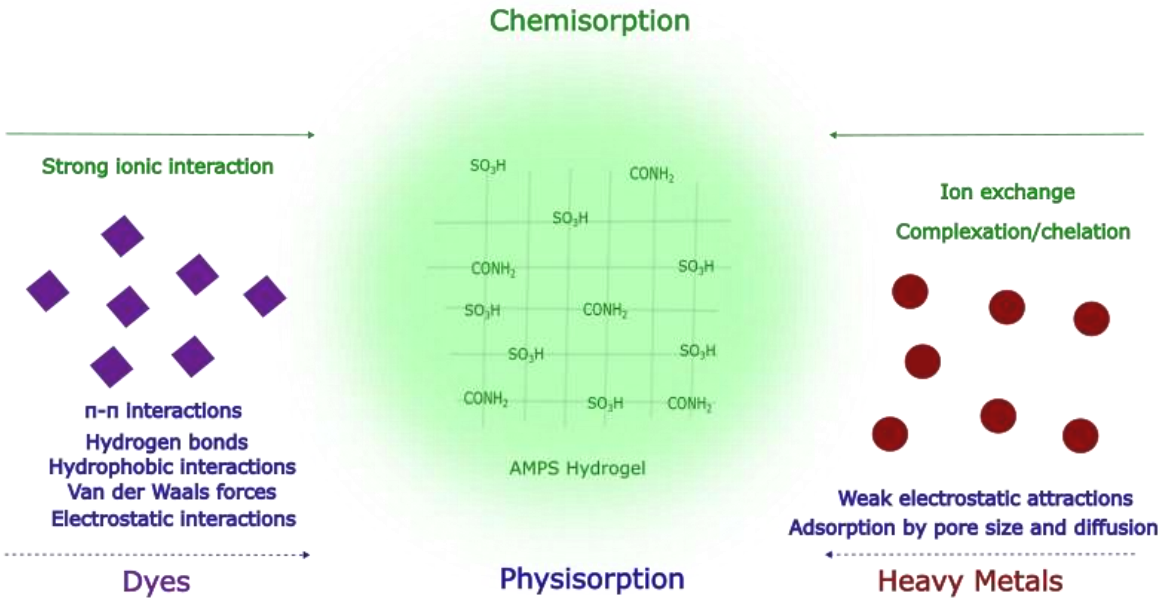


Figure 3. Contaminant removal processes from an AMPS-based hydrogel (own source).

In this area, it is also important to highlight the factors that can influence the removal of dyes and heavy metals through adsorption.

As is known, heavy metals are small cations with a high charge density, while dyes are complex molecules that may or may not be polar. Therefore, in this case, for the removal of heavy metals, functional groups such as -NH_2, -SH or -OH are preferred, which allow coordination/complexation, or ionic exchange between the adsorbent and the adsorbate, and as far as dyes are concerned, the -SO_3^- and -NH_3^+ groups are important (π–π stacking, hydrogen bonding, hydrophilic interactions); however, a hydrogel that may contain functional groups such as -COOH can remove both contaminants through electrostatic interactions. Likewise, pH is a relevant factor, mainly for heavy metals, because it controls hydrogel protonation and metal speciation. Adsorption is optimal at moderate pH (Tohamy et al., 2023); However, regarding dye removal, the effect can be moderate (affects hydrogel charge and dye ionization) (Huang et al., 2018).

Pore size is also important; a small pore favors the diffusion of heavy metals within the hydrogel, while for hydrogels, a large and

rigid structure allows slower diffusion and requires highly swollen or porous hydrogels.

An equally important factor is temperature, which in dyes often increases adsorption if the process is endothermic (cationic dyes), but depends on the dye (Huang et al., 2018). However, regarding heavy metals, it may enhance endothermic processes (increases diffusion and adsorption) (Shah et al., 2018).

IX. p[AMPS]-Based Hydrogels for Dye Removal

In 2009, Karadağ *et al*. synthesized two hydrogels using acrylamide (AAm) with AMPS, and AAm with AMPS as a comonomer with polyethylene glycol (PEG), via free radical polymerization for the adsorption of Basic Blue 17. The results showed that the combination of AAm with AMPS was crucial for dye absorption, as the hydrogel composed solely of AAm was unable to adsorb it. Furthermore, they found that a higher concentration of AMPS in the composite resulted in better adsorption. On the other hand, the dye removal capacity of the hydrogels decreased with an increase in PEG. The hydrogels reported maximum adsorption efficiencies and capacities of 74.56% (33.61 mg/g) and 97.60% (27.83 mg/g), respectively. To complement their work, Karadağ *et al*. performed a similar analysis in 2014, but this time incorporating Montmorillonite (MMT), a mineral that not only reduces production costs but also improves swelling capacity, hydrogel resistance, and its mechanical and thermal stability. The combination of MMT with AAm/AMPS and AAm/AMPS/PEG generated removal efficiencies from 90.33% to 95.70%, with maximum adsorption capacities of $3.16x10^5$ - $3.5x10^5$ mol/g, respectively.

In 2017, Bera *et al*. developed a hydrogel based on poly(acrylamide-co-2-acrylamido-2-methylpropane sulfonic acid) (poly(Am-co-AMPS)) to remove methyl violet and fuchsine, using free radical polymerization. AMPS, being an ionic monomer, increases the hydrophilicity and polarity of the hydrogel, which improves the adsorption capacity. The authors demonstrated that adsorption is dependent on pH (with maximum adsorption at pH ≈ 7) and ionic strength. In this study, the concentration of AMPS was varied, finding that the most efficient composition was 90/10 mol (Am-AMPS), reaching a qE of 221.8 mg/g. Additionally, they highlighted that the hydrogels can efficiently remove dyes regardless of the dye concentration and the pH of the medium.

In 2018, Atta *et al*. decided to implement metal oxides (magnetite, cuprous oxide) into a hydrogel based on a copolymer of AMPS and N-isopropylacrylamide (AMPS/NIPAm) to convert it into a magnetic material and thus promote the removal of methylene blue. The synthesis of the hydrogel was carried out via free radicals, and the oxides were incorporated through solutions of ferric chloride hexahydrate with sodium sulfite ($FeCl_3 \cdot 6H_2O$-Na_2SO_3), thus generating Magnetite (Fe_3O_4); and copper(II) chloride dihydrate with hydroxylamine ($CuCl_2 \cdot 2H_2O$-NH_2OH), synthesized to generate Cuprous Oxide (Cu_2O). With these two substances, two types of hydrogels were designed: AMPS/NIPAm/Fe_3O_4 and AMPS/NIPAm/Cu_2O, respectively. By adding Fe_3O_4 particles to the hydrogel, the adsorption and diffusion of methylene blue were facilitated, which allowed electrostatic or dipole-dipole interactions with the AMPS/NIPAm networks. It was observed that the maximum adsorption for AMPS/NIPAm/Cu_2O, AMPS/NIPAm/Fe_3O_4, and AMPS/NIPAm was 235 mg/g, 820 mg/g, and 428 mg/g, respectively, which allowed concluding that Cu_2O was not the best compound for the removal of cationic dyes.

In 2021, Omer *et al*. fabricated a hydrogel based on polyvinyl alcohol (PVA) and poly(2-acrylamido-2-methylpropane sulfonic acid) (PAMPS) for the removal of methylene blue. The suggested mechanism for the adsorption of the dye on the adsorbent surface is based on electrostatic interactions between both species. The results showed that the addition increased the removal up to 70% by increasing the PAMPS content up to 5% m/v. The removal of the dye reached 86% at pH = 8 with a qE of 12.65 mg/g at 25°C. As the temperature increased, the adsorption also improved; at 40°C, the qE reached 14.37 mg/g, with a removal of 97.5%. In that same year, Karadağ *et al*. made another contribution with a hydrogel based on propenamide/2-acrylamido-2-methyl-1-propanesulfonic acid/guar gum/clinoptilolite (P(PrAm/AMPS/CLP/GG)) to adsorb Basic Violet 1. This study reported maximum removal percentages of 96.25% with a qE of $2.3x10^{-5}$ mol/g. It was highlighted that these hydrogels can also be used in various areas such as biomedicine, controlled drug release, agriculture, and the environment, which has boosted their popularity and study. Table 8, shows advances in the removal of dyes using AMPS hydrogels.

Table 8. Advances in dye removal using p[AMPS]-based hydrogels (own source).

Hydrogel	Used Dye	% Removal	q_E (mg/g)	pH	Reference
AAm/AMPS	Cresilo Blue		3000	7	Akkaya *et al*., 2009
	Safranina T		1306		
P(MAA-co-AMPS)	Yellow Basic 28	98.6	500	8	Nesic *et al*., 2015
	Red Basic 46	89	462.9	6	
poli(AA-co-AMPS)/MMT	Methylene Blue	---	215	10	Hosseinzadeh & Khoshnood, 2016
CS/P(AMPS-co-AM)	Methylene Blue	---	1,538.50	5.8	Yu *et al*., 2016
	Malachite Green		917.4		
p(AMPS)-P. squamosus (Huds.) Fr	Toluidine Blue	73.2	40.9	8	Dudu *et al*., 2017
	Alizarin Red S	0.2	0.1	10	
	Galocianina	0.6	0.1	8	
P(AA-co-AMPS)/KL	Methyl Orange	---	506	7	Tang *et al*., 2018
PePnUMA-co-AMPS	Methylene Blue	---	769.2	5	Abdulwahid *et al*., 2021
	Fucsinic acid		1666.7	7	
	Congo Red		2358.2	9	
pec/poly(MA-co-AMPS)	Methylene Blue	---	448.4	7	Ilgin, 2022
XG-g-p(AMPS-co-AAm)	Methylene Blue	98.85	384.62	8	Mohafezatkar Gohari *et al*., 2022
Quitosano-g-P(AA-co-AMPS)	Crystalline violet	91	2023	6	Phonlakan *et al*., 2023

q_E: Maximum Adsorption Capacity.

X. p[AMPS]-Based Hydrogels for Heavy Metal Removal

In 2009, Ozay *et al*. synthesized a hydrogel based on AMPS via UV photopolymerization, which was subsequently doped with ferric

oxide (Fe_2O_3) to impart magnetic properties and facilitate the removal of heavy metals such as Cd^{2+}, Co^{2+}, Fe^{2+}, Pb^{2+}, Ni^{2+}, Cu^{2+}, and Cr^{3+}. The results showed that the maximum adsorption capacities were 140.85 mg/g, 117.65 mg/g, 109.89 mg/g, 140.84 mg/g, 114.94 mg/g, 117.65 mg/g, and 90.91 mg/g, respectively, for the metals mentioned. The research highlighted that hydrogels doped with metal oxides are promising for environmental applications due to their ability to swell and develop charges in various aqueous media, which facilitates the adsorption of metal ions for the remediation of contaminated water. Furthermore, the materials can be designed with adjustable characteristics, such as amphoteric hydrogels for the removal of species with opposite charges, or particles of different sizes for more efficient removal.

In 2011, Atta *et al*. developed a hydrogel based on crosslinked acrylonitrile/acrylamidoxime/2-acrylamido-2-methylpropane sulfonic acid (AN/AAx/AMPS) via free radical polymerization for the removal of Cd^{2+}, Cu^{2+}, and Fe^{3+}. The results showed that the use of AAx improved the adsorption of heavy metals, although its concentration and the pH of the medium influenced the removal. It was identified that the optimal pH for the adsorption of Cd^{2+} and Cu^{2+} was 5, and 2.5 for Fe^{3+}. The maximum adsorption capacities were 250 mg/g for Cd^{2+} and 200 mg/g for Cu^{2+} and Fe^{3+}. In 2013, Wang and Liu generated a hydrogel consisting of a mixture AMPS and triethylene glycol divinyl ether (DVE-3) (AMPS/DVE-3) via UV photopolymerization. They reported that the swelling and adsorption of metal ions increased with pH and AMPS content. The removal of Cu^{2+}, Cd^{2+}, and Pb^{2+} was optimized at pH=5, and the adsorption capacities were 1.5 mmol/g, 0.9 mmol/g, and 2 mmol/g, respectively. The authors concluded that the adsorption of metal ions is spontaneous, exothermic, and with positive entropy.

In 2017, Çelik *et al*. investigated the development of a hydrogel based on p(3-Methoxypropyl) acrylamide p(MPA) enriched with AMPS p(MPA-co-AMPS), to which they added cells of *Thamnidium elegans* to increase the retention of heavy metals. Using Cd^{2+} as a metallic ion, they achieved a maximum adsorption capacity of 123.76 mg/g, reaching 68.25 % removal, which represented an increase of 20-66 % compared to the hydrogel composed only of p(MPA-co-AMPS). In 2020, El-saied & Motawea developed a hydrogel composed of P(2-Acrylamido-2-methyl-1-propanesulfonic acid)/Nickel ferrite ($PAMPS/NiFe_2O_4$) via graft polymerization, intended for the removal of Cu^{2+}. A removal percentage of 83% was reported, with a qE of 22.81 mg/g at pH=5.75. This hydrogel was notable for its functional grouping, which facilitated the combination of valence through the mutual exchange or electrons between the adsorbed ions.

Recently, in 2021, Li *et al*. synthesized a hydrogel based on acrylamide (AM) and AMPS (PAM-PAMPS) for the removal of Pb^{2+} via crosslinking. This hydrogel presented a maximum adsorption capacity of 541.90 mg/g, developed specifically to be selective towards that metal ion. The characterizations showed that the $–SO_3H$ and $–NH_2$ groups in PAM-PAMPS generated synergistic effects in the adsorption of Pb^{2+} through ion exchange and coordination, respectively, reaching a removal rate of approximately 89% at pH=5. Table 9, shows other advances in the removal of heavy metals using AMPS.

Table 9. Advances in the removal of heavy metals using p[AMPS]-based hydrogels (own source).

Hydrogel	Heavy metal	% Removal	q_E (mg/g)	pH	Reference
CMC/AMPS	Mn^{2+}	---	46.8	5	El-Hag Ali, 2012
	Co^{2+}		60.6		
	Cu^{2+}		75.3		
HEA/AMPS	Fe^{3+}	---	80.4	2	Li *et al*., 2013
	Pb^{2+}		208	6	
	Cr^{3+}		103		
	Cd^{2+}		167		
	Cu^{2+}		105		
	Fe^{3+}		123	2	
SA-g-P(AA-coAMPS)/APT	Pb^{2+}	---	1016.77	8	Zhu *et al*., 2014
Poli(EGDMA-AMPS)	Fe^{3+}	97.6	60.24	2.74	Çavuş *et al*., 2016
	Cu^{2+}	42	3.07		
	Zn^{2+}	22.6	1.62		
	Ni^{2+}	42.9	0.74		
Poli(EGDMA-AMPS)	Hg^{2+}	---	363.55	6	Wang *et al*., 2016
NaAlg-g-poly(AMPS-co-AA-co-AM)	Pb^{2+}	---	534.25	7	Mohammad *et al*., 2017
	Cd^{2+}		258.6		
	Ni^{2+}		187		
	Cu^{2+}		224.5		
CMC-g-AMPS	Cu^{2+}	---	86.21	5	Panchan *et al*., 2018
	Pb^{2+}		102.04	5	
	Fe^{3+}		33.56	2	
P(AMPS-co-VDT)	Cu^{2+}	---	175.75	7	Wan *et al*., 2020
CS-g-P(AA-co-AMPS)	Cu^{2+}	90	232.6	5	Meetam *et al*., 2024
NTA-co-AM/AMPS	Cr^{6+}	96	98.7166	3	Thiyagarajan *et al*., 2024

q_E: Maximum Adsorption Capacity.

XI. OTHER ACID MONOMERS

Other existing acid monomers used for the removal of dyes and heavy metals include itaconic, maleic, and acrylic acids. The Table 10 provides a comparison between each of these.

Table 10. Other acid monomers (own source).

Caracteristic	AMPS	Itaconic Acid	Maleic Acid	Acrilic Acid
Full name*	2-Acrylamido-2-methylpropane sulfonic acid	2-Methylenebutanedioic acid	Cis-butenedioic acid	Propenoic acid
Molecular* formula	$C_7H_{13}NO_4S$	$C_5H_6O_4$	$C_4H_4O_4$	$C_3H_4O_2$

Main functional groups to allow the remotion of contaminants	Sulfonic group	Dicarboxylic	Dicarboxylic	Carboxylic
pKa*	1.62	3.6-4	1. 1.94 2. 6.23	4.2
Chemical stability	Very high (sulfonic group not easily hydrolyzed)	Lower, sensitive to hydrolysis (Stawski & Polowiñski, 2005)	Can form anhydrides and isomerize (Gaylord, 1975)	Good, though can polymerize spontaneously (Nuyken, 2004)
Swelling capacity in hydrogels	Very high, even in saline media	High in water, but strongly pH-dependent (Milosavljević et al., 2010)	Moderate, decreases in acidic media due to protonation (Bajpai, 2001)	Moderate-high, pH-dependent (Sheikh et al., 2009)
Advantages	High absorption over wide pH range, stable charge, highly hydrophilic	Biodegradable, two carboxylic groups useful for crosslinking (Duquette et al., 2019)	Good for copolymerization, two carboxylic groups sites. (Jamali et al., 2023)	Very cheap, easy to polymerize, good hydrogel base (Dudu et al., 2021)
Disadvantages	Expensive monomer	Lower chemical stability, pH-dependent (Stawski & Polowiñski, 2005)	Can form cyclic structures, less stable. (Lang et al., 1963)	pH-sensitive, lower retention in saline media (Alvarez-Lorenzo & Concheiro, 2002)

* information obtained through nist.gov.

XII. NOMENCLATURE

CS/P(AMPS-co-AM), chitosan/P(2-acrylamido-2-methyl-1-propanesulfonic acid-co-acrylic amide); P(AA-co-AMPS)/KL, poly(acrylic acid-co-2-acrylamido-2-methyl-1-propanesulfonic acid)/kaolin; P(MAA-co-AMPS), methacrylic acid (MAA)-co-2-acrylamido-2-methylpropane sulfonic acid (AMPS); XG-g-p(AMPS-co-AAm), graft of acrylamide (AAm) and 2-acrylamido-2-methylpropane sulfonic acid (AMPS) on xanthan gum (XG); chitosan-g-P(AA-co-AMPS), chitosan grafted with poly(acrylic acid-co-2-acrylamido-2-methyl-1-propanesulfonic acid); (pec/poli(MA-co-AMPS), pectin/poly(methacrylic acid-co-2-acrylamido 2-methylpropane sulfonic acid); poly(AA-co-AMPS)/MMT, poly(acrylic acid-co-2-acrylamido-2-methylpropanesulfonic

acid)/montmorillonite (MMT); p(AMPS)-P. squamosus (Huds.) Fr, Poly 2-acrylamido-2methylproanosulfonic acid-Polyporus squamosus; AAm/AMPS, Acrylic acid/2-acrylamido-2-methylpropane sulfonic acid; (PePnUMA-co-AMPS), acrylamide, HEMA, N-isopropylacrylamide and perylene-5-ylpent-3-yno-2-methylprop-2-enoate-co-2-methyl-2-(prop-2-enoilamino) propane-1-sulfonic acid; SA-g-P(AA-coAMPS)/APT, graft of poly(acrylic acid-Co-2-acrylamido-2-methyl-1-propanesulfonic acid) of sodium alginate/attapulgite; CTS-g-P(VIM-co-AMPS), chitosan-g-poly(vinylimidazole-co-2-acrylamido-2-methylpropane sulfonic acid); P(AMPS-co-VDT), poly(2-acrylamido-2-methylpropane sulfonate sodium (AMPS-Na+)-co-2-vinyl-4,6-diamino-1,3,5-triazine (VDT)); NTA-co-AM/AMPS, N-tert-amyl acrylamide-co-acrylamide/AMPS; CMC-g-AMPS, graft of 2-acrylamido-2-methylpropanesulfonic acid to carboxymethylcellulose; NaAlg-g-poli(AMPS-co-AA-co-AM), poly(2-acrylamido-2-methylpropanesulfonic acid-co-acrylic acid-co-acrylamide) grafted onto sodium alginate; CS-g-P(AA-co-AMPS, poly(2-acrylamido-2-methyl-1-propanesulfonic acid) grafted with chitosan; HEA/AMPS, 2-hydroxyethyl acrylate/2-acrylamido-2-methylpropane sulfonic acid; CMC/AMPS, Carboxymethylcellulose/2-acrylamido-2-methylpropane sulfonic acid; Poli(EGDMA-AMPS), poly(ethylene glycol dimethacrylate-2-acrylamido-2-methyl-1-propanesulfonic acid).

As could be seen throughout this review, AMPS is a relevant substance for the synthesis of hydrogels, as good results have been found in the maximum adsorption capacities for the removal of dyes and heavy metals. It is expected that investigations will continue, now with an environmentally friendly approach, through the incorporation of natural polymers, allowing a "green" implementation of treatment methods and thus participating in the new circular economy.

XIII. Conclusions

The development of new methods for decontaminating water is crucial not only for ensuring the quality of life for people but also for protecting the flora and fauna of our ecosystems. As demonstrated in this review, adsorption techniques are very promising for this purpose, as they allow the removal of contaminants without generating products or byproducts that could worsen the situation. In this context, hydrogels present themselves as a viable and effective alternative, both environmentally and economically, since their production is accessible and based on simple processes that do not require high costs or complicated operating conditions. The production of hydrogels from p[2-acrylamido-2-methylpropane sulfonic acid] (p[AMPS]) has opened new doors for research and innovation, always with the goal of improving their properties. It has been proven that this polymer, along with the copolymers that include it, is highly effective in removing contaminants and heavy metals, achieving in some cases an improvement in adsorption of more than 90%. The sulfonic acid group in AMPS confers notable characteristics such as conductivity, ion exchange capacity, and resistance to divalent ions. Additionally, the amide group in its structure improves its stability against hydrolysis and provides resistance to both chemical and thermal conditions. The presence of an active double bond in its chemical structure facilitates polymerization, allowing the creation of copolymers, which expands their applicability and effectiveness in removing contaminants, as observed in the mentioned studies. All this has proposed the use of p[AMPS]-based hydrogels as an alternative for sustainable water decontamination and remediation.

XIV. Acknowledgments

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