Review Article

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2024.58.009151

Adsorbents for the Removal of Heavy Metals from Wastewater: A Review

Humaira Aslam[1], Ali Umar[2], Shehla Honey[1], Mansour Manel[3], Misbah Ullah Khan*[1], Nazia Nusrat[1], Ghulam Ayesha[1], Mustansar Abbas[1], Jehanzeb Sohail[1], Moazam Ali[1], Shumaila Ayuab[1]

[1]*Centre for Nanosciences, University of Okara, Okara 56130 Pakistan*

[2]*Department of Zoology, Faculty of Life Sciences, University of Okara, Okara 56130,*

[3]*Department of Chemistry, University of Picardie, France*

***Corresponding author:** Misbah Ullah Khan, Centre for Nanosciences, University of Okara, Okara 56130 Pakistan

ARTICLE INFO

Received: August 12, 2024

Published: August 27, 2024

Citation: Humaira Aslam, Ali Umar, Shehla Honey, Mansour Manel, Misbah Ullah Khan, Nazia Nusrat, Ghulam Ayesha, Mustansar Abbas, Jehanzeb Sohail, Moazam Ali, Shumaila Ayuab. Adsorbents for the Removal of Heavy Metals from Wastewater: A Review. Biomed J Sci & Tech Res 58(3)-2024. BJSTR. MS.ID.009151.

ABSTRACT

Various industries release their effluents untreated into the water. They have reasonable concentrations of heavy metals that are poisonous or carcinogenic in nature, posing serious health risks to humans and aquatic habitats. Therefore, removal of heavy metal from wastewater is a critical issue. Adsorption technique commonly used for the removal of heavy metals from wastewater because of low cost, ecofriendly and availability Heavy metal removed from wastewater using commercial adsorbents and bio-adsorbents with excellent removal capacity. This review article tries to bring together fragmented information on many adsorbents used for heavy metal removal, with a focus on commercial and natural bio-adsorbents for the heavy metal removal such as, chromium, copper, and cadmium.

Keywords: Heavy Metals; Wastewater; Bio-Adsorbents; Aquatic Habitats; Human's Health.

Abbreviations: USEPA: United States Environmental Protection Agency; IARC: International Agency for Research on Cancer; PPM: Parts Per Million; EDTAD: EDTA Dianhydride.

Introduction

Industrial discharge contain several organic and inorganic contaminants such as heavy metals that are poisonous or carcinogenic and hazardous to human beings and other living species among these contaminants [1]. Heavy metals such as Arsenic (As), lead (Pb), chromium (Cr), zinc (Zn), nickel (Ni), copper (Cu), cadmium (Cd), and mercury (Hg) have greatest concern from diverse sectors [2]. Pigments, metal complexes dyes, insecticides, mordant, bleaching agents and some fixing agents that are used as additives in dyes to enhance dye adsorption on fiber are the source of heavy metal contamination [3]. Heavy metal limitations in wastewater are getting increasingly stringent in advanced economies [4]. For copper (Cu) chromium (Cr), cadmium (Cd), arsenic (As), nickel (Ni), mercury (Hg), zinc (Zn), and lead (Pb), the current maximum contamination level (ppm– mg/mL) in India is 0.25, 0.05, 0.01, 0.050, 0.20, 0.00003, 0.80, 0.006, respectively [5]. Adsorption, chemical oxidation, ultrafiltration, reduction, chemical precipitation, reverse osmosis, and electrodialysis techniques are most commonly used for the removal of heavy metals contamination [6]. Adsorption technique is the best and efficient technique among others, as they have various drawbacks such as, low efficiency, formation of huge concentrations of sludge, sensitive working conditions, and high dispose costs. Due to its well treated effluent quality, design flexibility, reversible process and adsorbent can be renewed, adsorption technology is potentially favored as alternative for the removal of heavy metals [7].

Nuclear power stations, leather tanning, electroplating, and/or the textile industry are all sources of chromium [8]. Chromium (VI) is an oxidizing chemical agent that is naturally carcinogenic and detri-

DOI: 10.26717/BJSTR.2024.58.009151

mental to animals and plants. According to Mohanty et al., chromium exposure induce lung cancer and cancer in digestive system as well as epigastria discomfort, vomiting, nausea, severe diarrhea, and bleeding [9]. Despite the fact that chromium can exist in various oxidation states, (VI) and (III) oxidation states of chromium are most common in industrial effluents. Chromium (III) is less hazardous than chromium (VI) and poses a less threat to the living beings [10]. The United States Environmental Protection Agency (USEPA) set maximum level of chromium in drinking at 0.1 parts per million (ppm) [11]. Cadmium is listed as carcinogen by the USEPA, and it create health risks and problems including bone demineralization either by direct bone destruction or through renal dysfunction [12]. Photographic industries, metal refining processes, mining, smelting, are all major producers of cadmium and classified as a Category-I carcinogen. International Agency for Research on Cancer (IARC) categorize the photographic industries, metal refining processes, mining, smelting Category-I carcinogen, main producers of cadmium and USEPA grouped as B-I carcinogen [13]. Copper is a necessary metal for enzyme synthesis, bone formation and tissue development. However, when taken in excess, copper is carcinogenic and poisonous, cause nausea, headaches, respiratory issues, vomiting, liver/kidney failure, and abdominal pain [14].

Smelting, surface finishing, electrolysis, mining processes, electric appliances, electroplating, and electric components are all the industrial source of copper and The USEPA set copper limit 1.3 ppm in industrial wastes [15]. Nickel is carcinoid metal, causes kidney/ lungs issues, intestinal upset, skin rashes, or pulmonary fibrosis in humans. Although, zinc element is necessary for human body functioning, excessive amounts cause stomach pains, skin irritations, stomach pains, anemia and vomiting [16]. Lead (Pb) is damaging to human health, causing reproductive system, brain, kidney, and liver damage [17]. Mercury disrupt the central nervous system by destroying or alternating the nerve cell functioning, it is neurotoxin therefore dangerous [18]. Mercury (Hg) can cause pulmonary or chest discomfort, and dyspnea if the concentration is surpassed. According to Mohan and Pittman, Arsenic (As) causes lungs, skin, kidney cancer, and bladder cancer as well as muscle weakness, lack of appetite or nausea [19]. Heavy metals have become a severe environmental hazard because of rigorous laws. This review paper examines the numerous commercially available adsorbents and natural bio sorbents that utilized to remove chromium, cadmium, and copper from wastewater over the last few decades. Commercial adsorbents are mass-produced on big scale, e.g., silica gel, activated carbon, alumina, but might very expensive [20].

Natural bio-adsorbents are made of biological materials and quit inexpensive, while choosing an adsorbent for the removal of heavy metal from water, cost analysis is a critical factor to consider [21]. Adsorption process costs is determined by the adsorbent's price, for example, cost of commercial activated carbon is 500rs. /kg while bio adsorbents cost between 4.4 to 36.89 rupees per kg, therefore, bio adsorbents are clearly less than commercial adsorbents [22]. To review relevant studies in this subject up to date, a comprehensive methodology used, and a final evaluation of the most efficient adsorbent(s) made.

Heavy Metals Removal from Wastewater with Adsorbents

Several commercial adsorbents and bio-adsorbents are commonly used to remove heavy metals efficiently from wastewater, some of them are showed in the Figure 1.

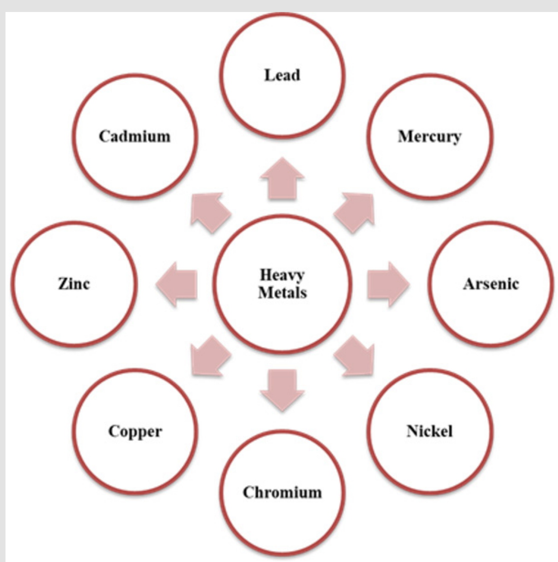

Figure 1: Representation of some heavy metals in wastewater.

 DOI: 10.26717/BJSTR.2024.58.009151

Adsorbents for Chromium Removal those are Commercially Available

Chromium removes by using commercially available absorbent like graphene, carbon nanotubes and activated carbon shown in Figure 2. Nano particles are structured absorbents because of more surface area, increased active sites, and the functioning group present on its surface and also the nano-materials are effective adsorbents to remove heavy metal from waste-water [23]. Graphene is two-dimension carbon-based nano-material with significant chemical stability and large surface area. It available in several forms including reduce graphene oxide, virgin graphene and graphene oxide [24]. The chromium adsorption on graphene oxide discovered as both spontaneous and endothermic. Gopalakrishnan et al. used modified Hummer's process to oxidize graphene to add COOH, functional group C14O, and to the surface [25]. Their study is unique in that just 70 milligrams of graphene oxide was used for the elimination of chromium with the highest adsorption capability of 17.29mg/g that is higher than that of other magnetic adsorbents show in Table 1, such as chitosan coated $MnFe_2O_4$ nanoparticle, core-shell nanowires [26]. Fe_3O_4-polyethyleneimine (PEI)-montmorillonite.7.78 mg/g, 15.4mg/g, and 8.8mg/g, respectively. The graphene-related research that has done summarized.

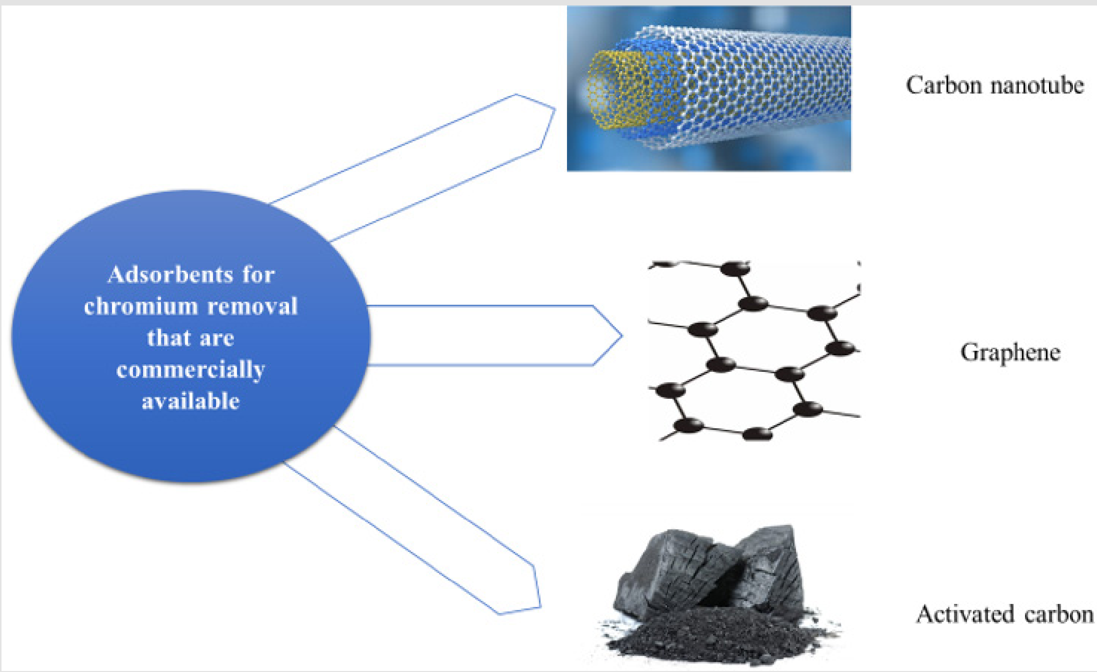

Figure 2: Chromium removal by graphene, activated carbon and carbon nanotube Graphene.

Table 1: Chromium removal by graphene, modified graphine and graphine oxide as an absorbent.

Absorbent	Optimum pH	Contact Time	Best Model	Metal concentration(ppm-mg/L)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Removal %
Zero-valent iron assembled on magnetic Fe_3O_4 graphene nanocomposites	3	120	Langmuir	40-100	101	-	83.8%
Graphene sand composites (GSC)	1.5	90	Langmuir	8-20	2859.38	10	93%
Modified graphene (GN) with cetyltrimethylammonium bromide	2	60	Langmuir	50-100	21.57	400	98.2%
Copolymer of dimethyl aminoethyl methacrylate with graphene oxide	1.1	45	Langmuir	-	82.4	-	93%
Graphene oxide	5	12	Langmuir	52	43.72	-	92.65%
Zero-valent iron decorated on graphene nanosheets	3	90	Langmuir	15-35	-	1.0	70%
Graphene oxide based inverse spinal nickel ferrite composite	4	120	Langmuir	1000	45	0.125-2.5	-

DOI: 10.26717/BJSTR.2024.58.009151

Activated Carbon

In the year 2000, modern industries began producing active carbon. During the years 1900–1901, it used to substitute bone-char in sugar refining business. In the early nineteenth century, crushed activated carbon was commercially produced first time in Europe, utilising wood raw material [27]. Any carbon rich material can be used to make activated carbon due to its fine porous structures and a large internal adsorption surface area [28]. Activated carbon is an excellent adsorbent for the removal of chromium from wastewater. However, due to the high cost of activated carbon from coal, its usage has been limited, and the scientists have been trying to convert inexpensive agriculture waste in to activated carbon. hazelnut shell activated carbon, wood activated carbon, grape stalk, sugarcane bagasse, viticulture industry wastes, lex, pomace, coconut tree sawdust, coconut shell, used activated carbon generated from rubber wood sawdust to remove chromium from wastewater, achieving maximum adsorption capacity i.e., 44 mg/g at an optimal pH 2 [29]. When compared to other studies, their maximum adsorption capacity was higher [30]. Once triggered moso bamboo and/or twice-activated moso bamboo have lower removal efficiency. Because the average pore diameter of bamboo is 20–77 percent smaller than that of other plants, it can be reduced by 20–77percent [31]. Mesopores were mesopores with a diameter of less than 2 nm and a diameter of less than 2nm. Kobya, use hazelnut shell to make activated carbon and the greatest adsorption capacity was 170 mg/g at a pH 1. That is greater than the adsorption pH of other adsorbent ability i.e., wood activated carbon from types and activated carbon from coconut shell 58.5 mg/g, that is 87.6 mg/g. 107.1 mg/g respectively [32] shown in Table 2.

Table 2: Removal of chromium using activated carbon as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Jatropha wood	30-100	360	106.4-140.8	0.6-2	2-10	Langmuir	-
Acrylonitrile divinylbenzene copolymer	30	420	101.2	0.6	2	Freundlich	80%
Green algae Ulva lactuca	5-250	40	10.61-112.36	2	1	Langmuir	98%
Prawn shell	25-125	31.4	100	-	-	Langmuir Freundlich	98%
Pterocladia capillacea	5-100	120	66	3-10	1	Langmuir	100%
Syzygium jambolanum nut carbon	20-100	240	-	5	2	Langmuir	100%
Zizania caduciflora	10-50	48	2.7	0.8	2-3	Langmuir	84.8%
Tamarind wood	10-50	40	-	2	6.5	Freundlich Langmuir	28%

Carbon Nanotubes

Because of their adsorption property, huge surface area, developed mesopores, outstanding mechanical and electrical capabilities, and chemical stability carbon nanotubes are effective adsorbents to remove heavy metal from water [33]. Chemical treatment can also use to improve adsorption capacity, Hu et al. used oxidized multi-walled carbon nanotubes to remove chromium, achieving 100 percent removal at optimal pH of 2.88 [34]. Gupta et al. integrated multi walled carbon nanotubes' adsorptive properties with Fe oxide's magnetic properties [35]. Advantages of the composite include a large surface area, the ability to manage and remove contaminants from the medium by utilizing a simple magnetic technique. At pH 6, a maximum elimination of 88 percent achieved. For chromium elimination, Luo et al. produced multi-walled carbon nanotube nano composites consist of manganese dioxide-iron oxide-acid oxidized [36]. Due to high capacity of adsorption, manganese dioxide is an effective scavenge of aqueous trace metals. However, pure manganese dioxide is not recommended due to its expensiveness and unfavorable chemical and physical properties [37]. At an ideal pH of 2, the aforementioned nanocomposite had maximum capacity of adsorption as 186.9 mg/g and maximum removal as 85 percent [38]. Mubarak et al. (b) used nitric acid ($HNO3$) and potassium permagnate ($KMnO4$) in a 3:1 volume ratio to functionalize carbon nanotubes for chromium removal and compared to removal capability to non-functionalized carbon nanotubes [39].

He discovered that functionalized carbon nanotubes had a maximum adsorption capacity of 2.517 mg/g, and/or non-functionalized carbon nanotubes had a capacity of 2.49 mg/g, and that functionalized carbon nanotubes had a higher removal capacity (87.6%) than non-functionalized carbon nanotubes (83 percent). Mubarak et al. used microwave heating to make carbon nanotubes for a study comparing chromium removal to another heavy metal lead (Pb) [39]. Microwave heating produces a rapid and uniformed heating rate, which speeds up the reaction and increases the yield [40]. At an ideal pH of 8, a maximum capacity of adsorption for chromium was 24.45 mg/g, with a removal efficiency of 95%. The documented use of carbon nanotubes for the removal of chromium (Cr) from waste-water [41] is summarized in Table 3.

DOI: 10.26717/BJSTR.2024.58.009151

Table 3: Removal of chromium utilizing carbon nanotubes as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Nitrogen doped magnetic CNTs	12.81	720	638.56	0.2	8	Langmuir	>97%
Iron oxide multiwalled carbon nanotube nanocomposites	50-300	150	186.9	5	2	Langmuir	85%
carbon composites nanotube and activated alumina	100	240	264.5	2.5	2	Langmuir Freundlich	>95%
Composite of multiwalled carbon nanotube and iron oxide	20	10-60	_	0.1-2	6	_	88%
Carbon nanotube produce microwave heating	2	60	24.45	9	8	Langmuir Freundlich	95%
Oxidized multiwalled nanotubes	2.88	9,900	4.2615	75-1.25	<2	Langmuir Absorption isotherm	100%
Carbon nanotube functionalized using potassium permanganate	1	120	2.47,2.48	6.1	9	Langmuir Freundlich	87.6%
CNT supported activated carbon	0.5	60	9	0.04	2	Langmuir	72%
Nitric acid oxidized carbon nanotube	1	2	0.5	150	7	_	18%
Cigarette filter with NWCNT and graphene	4	_	_	4	_	_	63-79%

Removal of Chromium Via Bio-Adsorbents from Wastewater

Chromium removes from wastewater by different bio-absorbent such as modified coconut waste, wheat bran, surfactant waste, sawdust, sugarcane bagasse, modified orange peel, and eggshell all shown in Figure 3.

Figure 3: Chromium removal by Bio-absorben.

DOI: 10.26717/BJSTR.2024.58.009151

Surfactant Modified Waste

Surfactants have used to modify a variety of agricultural wastes. Surfactants are the compounds that include both lyophilic and lyophobic groups and can form self-associating clusters and it can be anionic, cationic, bears no charge, and/or can be zwitterion based on nature of its hydrophilic groups; due to significant properties surfactant modified adsorbents are better in chromium removal and enhance selective adsorption [42]. The surfactant cetyltrimethyl ammonium bromide was used to modify crush powder carbon manufactured from Moringa oleifera pods and husks [43]. It was observed that, at an optimal pH of 8, this technique enhanced the crush powder carbon removal efficiency, and adsorption capacity (27 mg/g) [44]. Namasivayam & Sureshkumar used hexa-decyltrimethyl ammonium-bromide surfactant that improve chromium removal effectiveness from coconut coir pith [45]. At optimum pH (2), they reported a highest adsorption capacity about 76.3mg/g. Table 4 explain the chromium removal through an absorbent that are surfactant modified waste.

Table 4: Surfactant modified waste used to remove chromium as absorbent.

Absorbent	Concentration of Metal (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Ideal pH	Best Model	Removal %
Coconut coir pith modified by hexadecyltrimethyl ammonium bromide surfactant	20-60	90	76.3	0.5-6.0	2	Langmuir Freundlich, Dubinin-Raduskhevich	96%
Coconut coir modified by surfactant celtyltrimethyl ammonium bromide	30	120	29.96	1	8	Langmuir	98%

Modified Sugarcane Bagasse

Sugarcane bagasse produced from agricultural wastes that made up of 5% lignin, 50% cellulose, and 27% polyposis. Sugarcane bagasse enriched with phenolic and hydroxyl groups therefore these chemical functional groups from biological polymers can be chemically changed to increase adsorption capability [46]. Bagasse made from fibrous material resting over after crushing and extracting the juice from sugarcane stalks. Sugarcane bagasse made up from the inner pith and outer rind of sugarcane and has utilized in its modified and natural forms. In sugarcane bagasse, Ahmad et al. reported that chromium can be removed by using the Acinetobacter haemolyticus [47], a chromium-resistant reducing bacteria; this bacteria changes Cr (VI) to Cr (III), that is less poisonous than Cr (VI), and more than 90% removal was achieved. EDTA dianhydride (EDTAD), pyromellitic anhydride, sulphuric acid (H_2SO_4), Succinic anhydride, sodium bicarbonate, xanthate, citric acid, ethylenediamine, and other chemicals used to modify sugarcane bagasse. Because these acids are effective chelating agents, they polymerized with sugarcane bagasse to increase number of chelating sites or aid in removal of heavy metal from wastewater. According to a report Garg et al. employed succinic acid to modify sugarcane bagass, reporting a clearance rate of 92 percent at an optimal pH of 2 and in another research [41], Cronje et al. reported >87 percent chromium removal by activating sugarcane bagass along zinc chloride, with an optimal pH of 8.58. The documented usage of sugarcane bagasse as a chromium adsorbent summarize in Table 5.

Table 5: Sugarcane bagasse as absorbent to remove chromium.

Absorbent	Concentration of Metal (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent dose (g/L)	Optimum pH	Best Model	Removal %
Succinic acid modified sugarcane bagasse	50	60	_	20	2	_	92%
Bacteria Actinetobacter haemolyticus found in sugarcane bagasse.	10-100	2,880	_	_	7	_	>90%
Zinc chloride activated sugarcane bagasse	77.5	60	_	6.85	8.58	_	>87%

Wheat Bran Modification

Wheat bran byproduct of agriculture from flourmills that remove heavy metals. It is cost-effective, biodegradable, and contains a variety of nutrients, including fatty acid, protein, dietary fibers, and minerals. It has diversity of organic functional groups and surface area 441 m2/g with fixed carbon concentration 31.78%, it has several functional groups that can bind heavy metals, including carbonyl, phenolic hydroxyl and methoxy [48]. Farajzadeh and Monji revealed that wheat bran can remove chromium with maximal adsorption 93 mg/g and 89% removal rate. Wheat bran changed to boost elimination capability by adding various acids [49]. Thermochemical interaction among acids and wheat bran increased by temperature, used sulphuric acid to modify wheat bran, and displayed chromium removal through adsorption 133 mg/g at ideal pH 1.5. At pH2, tartaric acid utilized to modify wheat bran, resulting in a 51% removal without alteration and a 90 percent removal after alteration. At pH 2.2, the highest adsorption was measured 4.53 mg/g for Cr (VI) without change and 5.28 mg/g of Cr (VI) with change [50]. Table 6 summarizes the reports on the use of wheat bran modification as chromium adsorbent.

Table 6: Wheat bran used as absorbent for removing of chromium.

Absorbent	Concentration of Metal (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Modified wheat bran by sulphoric acid	50,100	300	133	2.0	1.5	Langmuir	99.9%
Modified wheat bran by tartaric acid	52	15,1,440	5.28	20	2, 2.2	_	89%
Wheat bran	20	20	93	80	5	Freundlich	90%

Modified Coconut Waste

Coconut trash employed as adsorbent of chromium-removal. Because of the presence of, it has sorption characteristics, and consists of functional groups including carboxyl and hydroxyl, pith and coir from coconuts. Shells are coconut wastes that can use for removal of heavy metals. A delicate, fluffy biomaterial is coir pith that produced from coconut husks. During the coconut husk fiber extraction procedure (Namasivayam and Sureshkumar) Particularly noteworthy is the figure of 7.5 million [51]. In India, tones of coconut produced each year (Chadha). The raw cellulose content of coir pith is 35%, with 1.8 percent fats. 8.7% ash content, 25.2% resin or lignin, 7.5% pentosans, 25.2 percent lignin and resin, 25.2 percent lignin and resin, 25.2 percent lignin and resin, 25.2 percent Moisture content of 11.9 percent and other compounds of 10.6 percent (Dan) [51]. Modified coir by Namasivayam and Sureshkumar for chromium removal, the surfactant hexadecyltrimethylammonium bromide used. At an optimal pH of 2, the highest removal achieved with this material was found to be greater than 90%, and absorption capacity is 76.3 mg/g. This shows that capacity of absorption after alteration was significantly higher. Similarly, Shen et al. used coconut coir and generated char to remove chromium and indicated maximum reduction about 70% [52]. As an adsorbent for the elimination of chromium, modified coconut waste described in Table 7.

Table 7: Coconut waste used as absorbent for chromium removal.

Absorbent	Concentration of Metal (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Ideal pH	Best Model	Removal %
Coconut coir derived char	10-500	7, 200	70,4	1.0	3	_	70%
Hexad-ecyl-tri-methyl-ammonium Bromide, a surfactant, has altered the coir pith.	20-100	30-90	76.3, 1.24	50	2	Langmuir, Freundlich	>90%

Modified Waste from Orange Peel

Orange peel waste act as absorbent for chromium removal because orange peel includes hemicellulose, lignin, cellulose and pectin [53]. Coordinating functional groups, like phenolic and carboxylic acid groups, are also present in these components and can bind with heavy metals. Orange peel is a desirable adsorbent since it is readily available and affordable. Marn investigated into three main functional group (carbonyl, amine and hydroxyl) affect the removal of chromium by chemically modifying bio adsorbent through methylation acetylation, and esterification specifically inhibit functional groups. As a result, isomerization reduced capacity of removing, indicating carboxylic groups and amines as adsorbent that are crucial for removing of chromium [54]. Adsorption capacity and removing percent found in percentage of single phase (chromium alone) was 51%, and 4.79 mg/g, compared to 79 percent and 7.60 mg/g in binary system (iron and chromium). By incorporating iron nanoparticles into orange peel, López Téllez et al. were able to eliminate chromium. The proportion of this composite was discovered to be the adsorption and elimination capacities were 5.37 mg/g at 71%, respectively compared to pure orange peel, which would be 34 percent higher at 1.90 mg/g Table 8 summarizes the findings, using orange peel waste for chromium removal an adsorbent [55].

Table 8: Orange peel waste used as absorbent for chromium removal.

Absorbent	Concentration of Metal(mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Ideal pH	Best Model	Removal %
Iron nanoparticle composite in orange peel pith	10-50	60	1.90, 5.37	1.0	1	Langmuir	34%, 71%
Pre-treated orange peel	10	260	4.79, 7.60	10.0	3	Langmuir model	54%, 79%
Modified orange peel	0-500	4, 320	40.56	5.0	4	Langmuir	82%

Modified Sawdust

Sawdust is byproduct that produce in huge quantities from solid waste in sawmills. It is mostly made-up cellulose and lignin. Heavy metals can removed by using sawdust as adsorbent, with effective results. Sanding, grinding, Cutting, drilling, and pulverizing wood with saw and other equipment that create small wood particles [56]. Argun et al. used modified oak sawdust treated with hydrochloric acid to remove chromium. This treatment enhances fraction active surfaces while also preventing tannin compounds from evaporating and staining the treated wastewater. The optimum pH is 3 at Cr (VI) remove with greatest efficiency, about 84 %, while adsorption capacity of chromium was 1.70 mg/g. Politi & Sidiras noted a maximum capacity is 20.3 mg/g, 86 percent removal rate at pH 2 using pine sawdust that had been subjected to a 0.11–3.6 N sulphuric acid treatment [39]. Table 9 summarizes `reported usage modified sawdust as chromium adsorbent in wastewater treatment.

Table 9: Sawdust used as absorbent for chromium removal.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Sulphoric acid modified pine sawdust	15-75	24	20.3	4	2	Freundlich	_
Hydrochloric acid modified oak sawdust	0.1-100	0-720	1.70	60	3	Langmuir, D-R isotherms	84%

Modified Eggshell

Despite the fact that chicken eggs are a common everyday staple around the world, they also pose a threat to the ecosystem. In United States, approximately 150,000 tons material is disposed in landfills every year. The mechanical properties of eggshell are exceptional, such as impact resistance, excellent combination of stiffness, toughness, and strength. 95 percent calcium carbonate (two crystal: rhombohedral aragonite and hexagonal calcite), make up 5% organic components. Proteins with amide and amine groups on eggshell surface, may serve as a source of a hardening agent, which strengthens adsorbent and has attraction for chromium. In both modified and unmodified forms, eggshells have been used to remove chromium from water. Calcination at high temperatures used to modify the material. The structure of egg shell changes during carbonization process, due to pores formation brought on by production of carbon dioxide (CO2) gas [57]. Egg shell used to remove chromium, with 93% removal rate at optimal pH 5, while adsorption capacity 1.45 mg/g [58]. PEI used by Liu and Huang to modify eggshell. Through cross-linking interactions between distinct functional groups, PEI functionalizes ESM (eggshell membrane). At an ideal pH 3, PEI-ESM absorption capacity increased by 105% in comparison to the unaltered egg shell, with total removal of 90% and highest adsorption capacity is 160 mg/g. Table 10 provides an overview of the usage of altered egg shell as adsorbent to remove chromium from wastewater [39]. Commercially developed adsorbents for wastewater cadmium removal Cadmium remove by using commercially available absorbent from waste water including mesoporous silica, zeolite, red mud, and chitosan were showing in Figure 4.

DOI: 10.26717/BJSTR.2024.58.009151

Figure 4: Removal of heavy metal by absorbents.

Table 10: Chromium removal by modified eggshell as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Egg shell	5-30	90	1.45	3.5	5	Freundlich	93%
Egg shell modified using PEI	100	10-1,440	160	10-40	3	Langmuir	90%

Mesoporous Silica

Mesoporous silica is an organized material that has a regular two-dimensional hexagonal network of channels. Mesoporous silica is efficient at removing cadmium due to its large surface area and pore size (2–10 nm). Chemical modifications to mesoporous silica can include amino-carbonyl, sulfonic acid, and carboxylic acid groups. Javadian created polypyrene type mesoporous silica for removal of cadmium (99.2%) at ideal pH. 8, while SBA-15 silica was functionalized by ethylenediamine. two-dimensional arrangement of channels in organized substance SBA-15 has pores diameters ranging from 7 to 10 nanometers. At pH. >4.5, elimination discovered to be 98%. Chromium also removed from wastewater using mesoporous pore silica that had functionalized and by functionalized by mercaptopropyl and aminopropyl. When amorphous silica and silica were modified with 2-meracaptopyridine having absorption capacity 97 mg/g and 205 mg/g while researchers obtain absorption 43.16 mg/g for chromium [59]. Table 11 lists the available information on mesoporous silica ability to remove chromium from wastewater.

Table 11: Chromium removal by mesoporous silica as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Amino functionalized mesoporous silica	5-300	1,440	93.30	1.11	_	Langmuir	100%
Polyamine functionalized	100	2,880	_	_	5.5-7	_	70%
Silica functionalized with mono amino	25	1,440-2,880	12.36, 14.61, 28.10	20	<8	Langmuir	80%
Amino functionalized silica	50	120	18.25	5	5	Langmuir	90%
Modified SBA-15 by Iminodiacetic acid	50-1,000	1,440	_	4.0	5.6	Langmuir	99.8%

Chitosan

Chitosan found naturally as polysaccharides, is produced by chitosan through N-deacetylation and present in crustaceans [60]. it is most powerful absorbents for heavy metal elimination, its readily derivative, biodegradable, cheap and hydrophilic. It has hydroxyl and amino groups, which can combine with heavy metals to produce chelates, it has advantage of being affordable, but it also has drawbacks such as soluble in acidic environment, mechanically feeble, and potentially leaking carbohydrates during utilized as its raw form. Chitosan has stabilized using cross-linking agents; however, this has reduced its ability to adsorb. 'Ion imprint technique.' used to achieve better adsorption capacity and stability. The goal of this study is to develop a novel adsorbent for the removal of cadmium, a chitosan/ TiO2 composite treated with thiourea to imprint magnetic ions. At an ideal pH of 7, this material's highest adsorption capability was estimated 256.41 mg/g. Coating method employing ceramic alumina has also been used to alter chitosan. Coating makes binding sites more accessible and improves mechanical stability. At optimum pH 6, the highest adsorption was estimated 108.7 mg/g, with highest removing ability 93.76%. Chitosan coated using activated carbon had a 52.63 mg/g adsorption capacity with 100% removal at ideal pH of 6 [61]. Table 12 shows heavy metal removal statistics from wastewater using chitosan as adsorbent.

Table 12: Chromium remove by chitosan used as absorbent.

Absorbent	Concentration of Metal (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Electro spun nanofiber membrane of PEO	50-1,000	120	248.1	_	5	Freundlich, Langmuir and Dubinin-Radushkevich	72%
Chitosan beads with cross-linked polyaniline	40-220	120	145	4.5	6	Langmuir	99.6%
Magnetite chitosan treated with -ketoglutaric acid	100-500	90	201.2	0.04	6	Langmuir	93%
O-carboxymethyl functionalization of chitosan	675	1,440	_	_	10	_	95%
Nano-hydroxyapatite/ chitosan composite	100-500	90	92, 122	5.0	5.6	Freundlich, Langmuir	92%
Multi-walled carbon nanotubes modified with chitosan	_	_	_	_	6-7	_	>90%

Zeolite

Zeolite is most effective absorbent for removing of cadmium, because it made from hydrated interconnected tetrahedral of silica and alumina, strong ion exchange properties, hydrophilic in nature and large surface area [62]. Modified zeolite has greater capacity than native zeolite. Many techniques can used to modify zeolite, for example, nanosized zeolite has accessible pores, making it better suited to heavy metal removal. NaX nano zeolite is a frequently used nanosized zeolite adsorbent (H_2O: SiO_2: Al_2O_3: Na_2O molar ratio 190: 4.0: 1.0: 5.5 respectively) for removing of cadmium. Microwave heating method used to synthesize NaX nano-zeolite, electro spun polyvinyl acetate polymer and then evaluated cadmium potential for composite nanofibers. At ideal pH 5, removal rate was 838.7 mg/g, with an 80 percent removal rate. Choi et al. changed zeolite by substituting exchangeable positive charge including potassium, sodium, calcium

 DOI: 10.26717/BJSTR.2024.58.009151

and magnesium, or for Si (IV)-Al (III) sites lattice, due to the negative charge [62]. When compared to non-modified adsorbents, zeolite modified with magnesium has several benefits, such as low cost, huge pore size (40-50 nm), non-toxicity, and abundance. At an optimal pH of 7, this Mg-modified adsorbent removes more than 98 percent of cadmium. Furthermore, Mg zeolite's adsorption capacity was shown 1.5 times greater than zeolite that modified with potassium (K) and sodium (Na), and greater than natural zeolite by 1.5–2.0 times. Many businesses utilize coal as a fuel, but as a byproduct, fly ash produced which pollutes the environment and presents disposal challenges.

Due to its low cost, fly ash can utilized for the hydrothermal process to create zeolite. Fly as was transformed by javadian, into an absorbent that is amorphous alum silicate having potential for cadmium absorption is 26.246 mg/g at an ideal pH. of 5 and 84% removal rate. Visa used a hydrothermal technique with sodium hydroxide to transform fly ash into zeolite for cadmium removal [63]. The researchers discovered that at an optimal pH of 7-8, this product eliminates more than 80% of cadmium due to its high surface area and abundance of micropores. Table 13 explains the removal of cadmium through zeolite parameters.

Table 13: Chromium removal by zeolite as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Zeolite	25-100	90	_	25	6	Freundlich	76%
Natural zeolite	9-90	1,440	9	-	5	Freundlich	71%
Synthetic zeolite A	100-2,000	180	315.65	1.0	-	Freundlich and D-R	-
Oil shale into zeolite	100	60-1,440	95.6	-	7	Sips	-
Fly ash zeolite	1124.1-3372.3	1,440	57-195	10	6.6	Langmuir	95.6%

Red Mud

Gupta and Sharma describe red mud as a byproduct of aluminum industry that can be used as absorbent to remove cadmium from wastewater. Red mud has the benefits of being affordable and accessible as well as having a high capacity to remove cadmium; however, it has a few disadvantages, including the challenge of dealing with wastewater produced during red mud activation prior to application and the challenge of red mud renewal after application [64]. Red mud, on the other hand, Zhu et al. created red mud a new adsorbent that remove cadmium [65]. It found that the adsorption mechanism against granular red mud is endothermic and spontaneous in nature 52.1mg/g maximum adsorption capacity. PH levels of 3 to 6 have reported. Gupta and Sharma, on the other hand, also employed red mud that remove cadmium from contaminated wastewater, with 100% removal achieved the lowest level. 1:78-105 to 1:78-104 Molar concentration, while 60. At the greater concentration, 65 percent elimination achieved. (1:78 104 to 1:78 103 Molar) at the ideal pH between four and five Ma et al. employed a $CaCO_3$-dominated model. Mud that is red (containing $CaCO_3$) during cadmium removal from contaminated wastewater, the heavy metals enhanced degree of saturation at binding site from particle of red mud, while percentage of HCH_3COO-extractable metal [66].

Cadmium Removal Using Bio-Adsorbents

Bio-absorbent use to remove cadmium from waste water including apple pomace, powered olive stones, rice husk, and coffee residue shown in Figure 2.

Coffee Residue

Coffee grounds have found to be an effective adsorbent for removing cadmium from wastewater. As an example, Coffee residues were employed by Boonamnuayvitaya et al. Cadmium remove by clay mixing to make an adsorbent give negative charge that facilitates cadmium elimination, removal and complexation adsorbent is made up of amine group, carboxyl and hydroxyl [67] (Figure 5). Features of 500W pyrolysis (temperature) offers a particle size and a maximum adsorption capacity) 4mm in diameter a proportion of coffee residue to total weight. The best acceptable clay blend found to be 80:20. Oliveira et al. used coffee husks as part of their research. The maximal adsorption capacity of this material observed to 6.9 mg/g, at optimal pH 4 by clearance rate 65–85%. Some researchers made an adsorbent by coffee beans, soaking and degreasing in methanol and water. The ready-made with 90% efficiency, coffee beans material functioned as exchange of cation. pH 8 is the best pH for removal. At an optimal concentration of 15.65 mg/g, more than 80% of the substance is removed [68]. A pH of7 all data on cadmium removal shown in Table 14. Coffee residue used as an absorbent (Figure 6).

 DOI: 10.26717/BJSTR.2024.58.009151

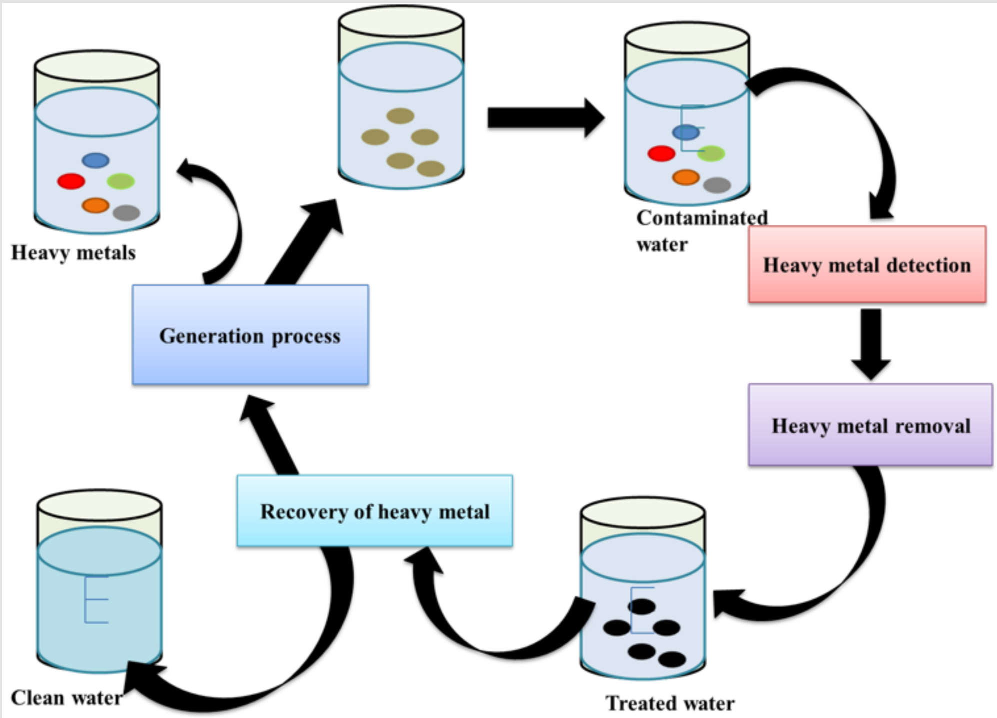

Figure 5: Representation of the process of wastewater treatment by removal heavy metal.

Figure 6: Schematic diagram of surfactant-modified waste.

Table 14: Chromium removal by coffee residue as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Coffee beans	6-202	1,440	3.80	10	8	Langmuir	90%
Coffee residue with clay	25-250	30	17.5-17.9	10	1.6-2.5	Langmuir	88-92%
Coffee grounds from cafeterias	10-700	120	15.65	9	7	Langmuir	>80%
Coffee husks	50-100	4,320	6.9	6.7	4	Langmuir	65-85%

Rice Husk/ Rice Hulls

Rice husk is byproduct in rice factory that rich in silica, cellulose, lignin, hemicellulose and mineral. It consists of different groups that favorable for cadmium coordination and elimination include –Si-H, Si-O-Si, and -OH, because it is inexpensive and readily available, it could be beneficial as a cadmium adsorbent [39] (Figure 7). The basic chemicals used for rice husk modification and increase absorption capacity are sodium carbonate, epichlorohydrin, and sodium hydroxide. Rice hulls changed by stirring it continuously through sodium hydroxide at least 24 hours and observe that it had a cadmium adsorption capacity of modified rice hulls is 125.94 mg/g, that was greater than nonmodified rice hulls. Rice husk that has been treated at an ideal pH of 12, show maximum removal at 99% was observed using phosphate. Srivastava and colleagues used pore area of mesoporous rice hulls about 80% (percentage of unoccupied rice husk area) and described as 23.3% reduction in cadmium, as well as several other metals. Heavy metals at ideal pH 6, grafted with polyacrylamide rice husk to removal of cadmium, and 85% cadmium removed. A pH of 9 was found to be optimal, Table 15 summarizes the findings, the removal limits for cadmium sequestration, and rice husk is used in this recipe [58] (Figure 8).

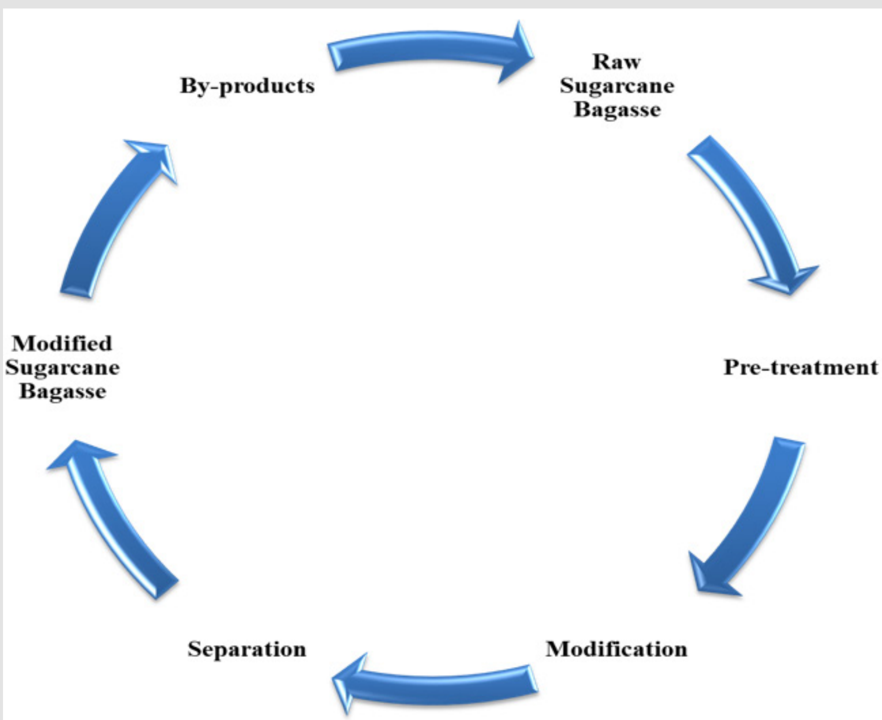

Figure 7: Schematic diagram for the process of modifying sugarcane bagasse typically involves several key steps.

DOI: 10.26717/BJSTR.2024.58.009151

Figure 8: Schematic diagram modified wheat bran for the removal of heavy metals from wastewater involves specific steps to prepare the bran and then utilize it for adsorption.

Table 15: Chromium removal by rice husk as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Sulphoric acid treated rice husk	50, 100	60	41.15-38.76	1.0	4	Langmuir	-
Rice husk ash	10-100	5	3.04	1-10	6	Freundlich, Redlich-Peterson	29.8%
Activated rice husk	8.9-89 M	20	-	4.0	6	Dubinin-Radushkevich, Langmuir	97%

Apple Pomace

Apple pomace, a byproduct in apple juice factories, is frequently dumped in huge amount at industrial site [69]. According Chand, apple (solid leftover part) comprises 95% flesh (wt. %), 2–4% seed (wt.%), and 1% (wt.%) stem. The solid residual fraction of the apple obtained after processing known as apple pomace. Apple pomace a term us for solid portion of apple that remains after process. Quercetin-3-galactoside (1.61g/kg), caffeic acid (0.28 g/kg), phloretin-20-xyloglucoside (0.17g/kg), 3-hydroxyphloridzin (0.27 g/kg), epicatechin (0.64 g/kg), and phlorizin (1.42 g/kg), make whole apple pomaces from 7.24 g kg1, due to carbonyl group, amine and polyphenols apple pomace function as metal chelator [39] (Figure 9). Surface area of material increases by chemically modifying apple pomace through succinic anhydride using a straightforward ring opening method but different reports indicates that when less amount of apple pomace used as absorbent then surface area increases 16% [58]. At ideal pH of 4, adsorption capacity of non-modified apple pomace is 4.45mg/g that 20 times less than modified apple pomace capacity which is 91.74mg/g, due to this 70% removal done with non-modified form while 90% with modified form. In related investigation, some researchers added xanthate moiety to apple pomace that produce an adsorbent. At ideal pH of 4, it was observed that maximum absorption capacity of xanthate was 112.35mg/g, while removal capacity was 99.7%. According to this investigation, chemically altered apple pomace with xanthate remove high amount of cadmium than succinic anhydride. Table 16 displays data on cadmium removal from apple pomace when used as an adsorbent (Figure 10).

DOI: 10.26717/BJSTR.2024.58.009151

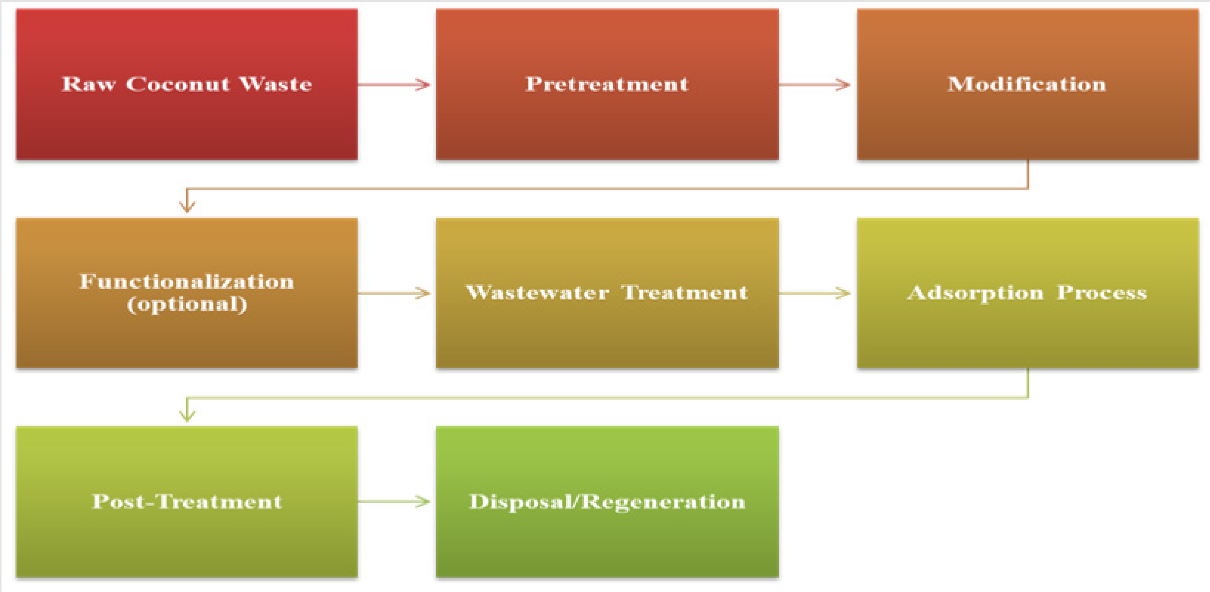

Figure 9: Simplified diagram to represent the process.

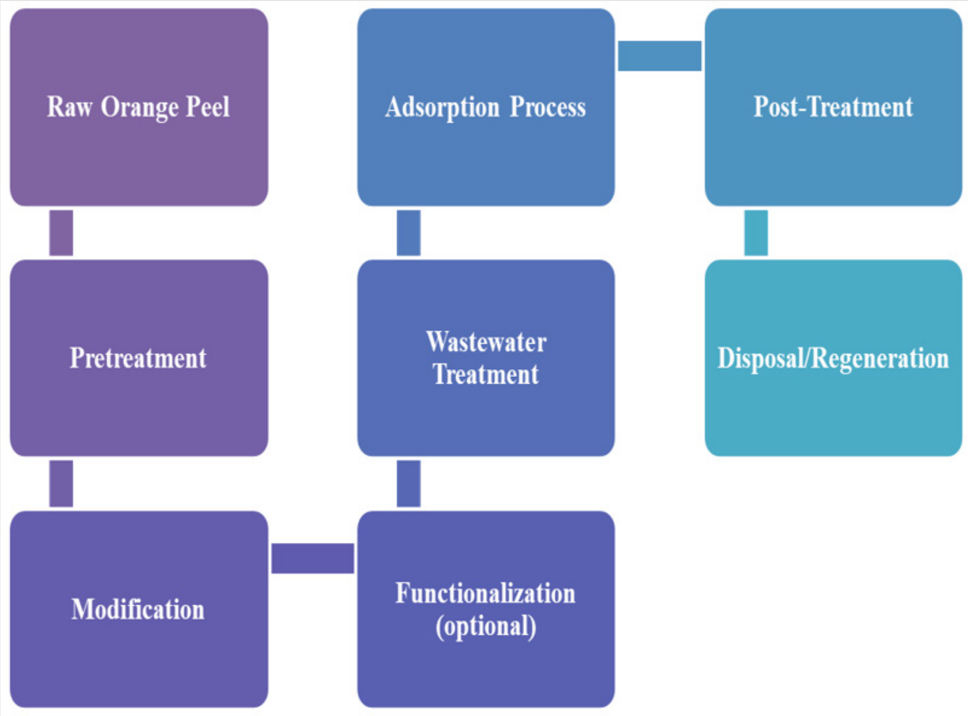

Figure 10: Simplified diagram to represent the process.

Table 16: Apple pomaces remove chromium as absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Xanthate moiety into apple pomace	10-120	5-60	112.35	0.2-8	4	Langmuir	99.7%
Succinic anhydride modified apple pomace	10-80	10-180	4.45, 91.74	0.8-40	4	Langmuir	70%, 90%

Powdered Olive Stones

Olive stone are by product of oleic industry that present in countries that produce olive oil and has potential to use as absorbents for cadmium removal [70] (Figure 11). Olive stone mixed with succinic anhydride, sodium hydroxide, nitric acid and sulphuric acid to increase absorption. Olive stone chemically functionalized by adding succinic anhydride to succinate moieties which have strong attachment for cadmium [70]. This absorbent prepared by addition of succinic anhydride with lignocellulosic matrix in basic medium treated with toluene. This substance has absorption capacity 200 mg/g at ideal pH 4, while maximum capacity of olive stone reported 128.2 mg/g. Aziz et al used concentrated sulphuric acid for handling of olive stone and neutralized with sodium hydroxide (NaOH 0.1N). Blazquez treated olive stones with different parameters to observe the removal rate of cadmium. However, it was observed that at ideal pH 11, removal capabilities of particles rise up to 90% and maximum capacity of absorption reached about 20 minutes, which is greater than equilibrium time that attained during removal of cadmium used olive stones made by olive cake and zncl2 [71] (Figure 12). Olive stone can converted into activated carbon by using H_2O_2, H_3PO_4, and $ZNCl_2$ that increase absorbent surface area and pore distribution.

Kula et al. Used zinc chloride (20%) as activating agent for removal of cadmium and discovered that 90% cadmium remove as compare to untreated olive stone containing optimum pH of 9, which is shown in Table 17. Obregon Valencia observed that activated carbon is prepared from olive fruit stone and carbon aquaje with sulphuric acid solution having absorption capacities 9.01 mg/g and 8.14 mg/g and remove cadmium 68% and 61% respectively [39]. Adsorbents for copper removal from wastewater that commercially available A commercially available absorbent called alumina shown in Figure 3 to remove copper from wastewater.

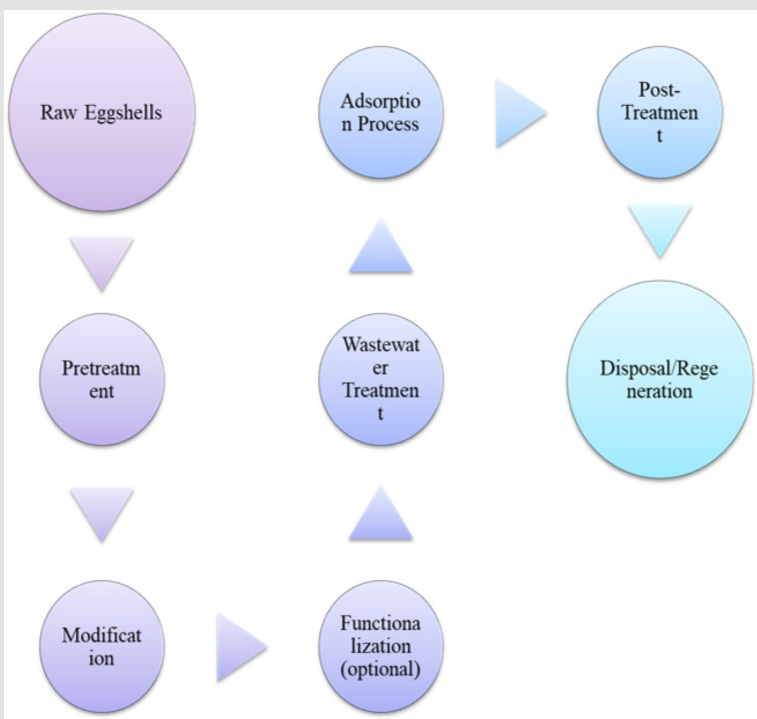

Figure 11: Simplified diagram to represent the process.

Figure 12: Cadmium removal by commercially available absorbent.

Table 17: Chromium removal by using powered olive stone as an absorbent.

Absorbent	Metal Concentration (mg/L)	Contact Time (min)	Absorbent Capacity (mg/g)	Absorbent Dose (g/L)	Optimum pH	Best Model	Removal %
Olive stone waste	33-16,861	60	-	13.33	5.5-6	Langmuir and Freundlich	49.2%
Microwaved olive stone activated carbon	20	7	11.72	0.25-2	5	Langmuir	95.32%
Olive cake	100	1,440	65.4	0.3	6	Langmuir and Freundlich	66%
Activated carbon from olive stones	56-562	200	17.665	6	5	Redlich-Peterson	23%
Zinc chloride activated olive stone	15-45	60	-	20	9	Langmuir and Freundlich	95%

Alumina

Several authors have used alumina to remove copper from waste water, by loading alumina nanoparticles into cation exchange for removal of nickel and copper [72]. Nanoparticle is absorbent due to abundance of metal coordination sites that use in Freundlich isomerism due to its adsorption capacity 31.3mg/g for copper removal. Using a phase inversion technique, Ghaemi created matrix membrane containing different concentration of alumina nanoparticles and pes (polyether sulfone). Matrix membrane has higher water permeability when compare with pure pes membrane that added small nanoparticles due to this increase hydrophilicity and porosity. Porosity and hydrophilicity rise because of this. In comparison to the pes membrane, the mixed matrix membrane has demonstrated to remove 60% of copper from wastewater (around 25 percent). Mahmoud removed copper from waste water by using three alumina absorbent that were basic, acidic and neutral in nature and its surface was changed by adding 1-nitroso-2-napthol as cation [39]. After modification, alumina absorbent is more resistant to heat degradation and acid leaching. The adsorption capacities of basic alumina were 28.59 mg/g, neutral 28.58 mg/g and acidic 27.96 mg/g. Traditional slides including silica, clay and fly ash have non-uniform pores with hardly any absorption potential. Rengraj et al. developed protonated mesoporous and animated alumina for removal of copper [73]. In traditional materials, mesoporous alumina provides number of advantages including constant size distribution, high stability, large surface area, capacity to absorb metal and sponge like pore structure. The porous capacity of protonated silica is 14.5349 mg/g that compare with animated alumina 7.9239 mg/g, maximum absorption observed in alumina due to hydrogen and copper ions that present between ion exchange.

 DOI: 10.26717/BJSTR.2024.58.009151

Factors that Influence Adoption of Heavy Metals

Many factors influence the effectiveness of adsorbents during heavy metal removal from wastewater including pH, stirring speed, temperature, initial concentration, contact time and adsorbent dosage [74]. The removal of heavy metal percentage increase as stirring speed, initial concentration, contact time, temperature and adsorbent dose increases [75].

Future Heavy Metal Removal: Perceptions and Challenges

The bio-adsorbents employed to remove chromium, cadmium, and copper in this review paper are low-cost adsorbents that can used in place of commercially available adsorbents. In different experiments, it has found that removing heavy metal increase effectiveness of wastewater after modification. However, research in this field still in progress but recent research used regenerate absorbents; commercialize absorbents and modification (less heat, base and acid) to improve bio-absorbents. Furthermore, wastewater has large amount of chemicals and absorbents due to this it become challenges to maintain pH during removal of heavy metal.

Conclusion

This article demonstrates the potential of heavy metal removal such as, copper, chromium, cadmium from wastewater by commercial and agricultural adsorbents. Removal of heavy metal from wastewater has been explored using a variety of adsorbents; Graphene sand composite (2,859.38 mg/g), activated alumina and carbon nanotubes composite (264.5 mg/g), and PEI functionalized eggs shell (160 mg/g) for chromium are some adsorbents that shows maximize adsorption capabilities. Alpha-ketoglutaric acid-modified magnetic chitosan (201.2 mg/g), green coconut shell powder (285.7 mg/g), electrospun nanofibre membrane of PEO/chitosan (248.1 mg/g), NaX nanozeolite (838.7 mg/g), succinic anhydride-modified olive stones (200 mg/g) for cadmium. Furthermore, maximum values for different parameters such as pH, time, contact and adsorbent dose compared for copper, chromium, and cadmium removal from wastewater. The range of ideal pH values discovered; 4-7 for cadmium, 4.5-6 for copper and 1-2 for chromium. Similarly, for maximal elimination of cadmium, chromium, & copper, the ideal contact time is 5 to 120 minutes for cadmium, 120 to 9,900 minutes for chromium, and 120 minutes to 12 hours for copper. Moreover, for the best results, adsorbent dose should be between 0.75 to 10 g/L. Respectively, for chromium, cadmium and copper, 0.01–4.5 g/L, 0.25–1 g/L, 0.25–1 g/L adsorption data founded to be suit for Langmuir and Freundlich models in general, indicating multilayer and single adsorptions behavior (Figures 13 & 14).

Figure 13: Bio-absorbent as cadmium removal.

 DOI: 10.26717/BJSTR.2024.58.009151

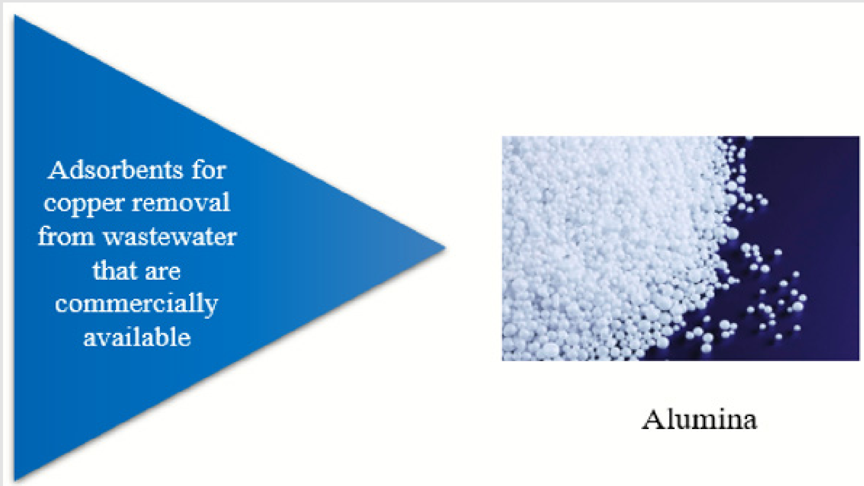

Figure 14: Copper removal absorbents.

Furthermore, the costs of bioadsorbents and commercials were evaluated, commercial activated carbon cost 500 rupees/kg therefore, bioadsorbents cost between Rs. 4.4-36.89 rupees/kg, that is significantly low cost than commercial adsorbents (Gupta & Babu). Bioadsorbents offer advantages, being inexpensive, readily available, engineering applicability, regenerated, and having technical feasibility, and affinity to remove heavy metals.

References

1. Ashar A, et al. (2022) Remediation of Metal Pollutants in the Environment, in Advanced Oxidation Processes for Wastewater Treatment. CRC Press 223-234.
2. Xiang H, Xiaobo Min, Chong Jian Tang, Mika Sillanpää, Feiping Zhao (2022) Recent advances in membrane filtration for heavy metal removal from wastewater: A mini review. Journal of Water Process Engineering 49: 103023.
3. Velusamy S, Anurag Roy, Senthilarasu Sundaram, Tapas Kumar Mallick (2021) A review on heavy metal ions and containing dyes removal through graphene oxide-based adsorption strategies for textile wastewater treatment. The Chemical Record 21(7): 1570-1610.
4. Singh A, Dan Bahadur Pal, Akba Mohammad, Alaa Alhazmi, Shafiul Haque, et al. (2022) Biological remediation technologies for dyes and heavy metals in wastewater treatment: New insight. Bioresource Technology 343: 126154.
5. Rani C E, G A Anila, K Kavitha (2019) Glycolipid Biosurfactant from Indigenous Pseudomonas sps. isolated from Kandigai, Kanchipuram District For the Removal of Cr (III). 4(1).
6. Pan Z, L An (2019) Removal of heavy metal from wastewater using ion exchange membranes. Applications of ion exchange materials in the environment 25-46.
7. Tran N N, Escriba Marc, Mohammad Mohsen Sarafraz, Quoc Hue Pho (2023) Process Technology and Sustainability Assessment of Wastewater Treatment. Industrial & Engineering Chemistry Research 62(4).
8. Palsania P, M A Dar, G Kaushik (2022) Bioremediation Strategies for Removal of Chromium from Polluted Environment, in Bioremediation of Toxic Metal (loid) s. CRC Press 216-236.
9. Murugavelh S (2013) Studies on bioreduction of cr (VI) using environmentally significant microorganisms.
10. Coetzee J J, N Bansal, E M Chirwa, (2020) Chromium in environment, its toxic effect from chromite-mining and ferrochrome industries, and its possible bioremediation. Exposure and health 12: 51-62.
11. Kinuthia G K, Veronica Ngure, Dunstone Beti, Reuben Lugalia, Agnes Wangila et al. (2020) Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. Scientific reports 10(1): 8434.
12. Obasi P N, B B Akudinobi (2020) Potential health risk and levels of heavy metals in water resources of lead–zinc mining communities of Abakaliki, southeast Nigeria. Applied Water Science 10(7): 1-23.
13. Fathi L, Adel Mirza Alizadeh, Farinaz Esmi, Samaneh Dezhangah, Mohammad Reza Mehrasbi, et al. (2023) Determination of lead and cadmium in fruit juice: occurrence and risk characterisation in Iranian population. International Journal of Environmental Analytical Chemistry 1-15.
14. Sharif M, Muhammad Aziz Ur Rahman, Bilal Ahmed, Rao Zahid Abbas, Faiz Ul Hassan (2021) Copper nanoparticles as growth promoter, antioxidant and anti-bacterial agents in poultry nutrition: prospects and future implications. Biological Trace Element Research 199(10): 3825-3836.
15. Wang Y, J Kang, Y Q Chen, R H (2019) Sensitive analysis of copper in water by LIBS–LIF assisted by simple sample pretreatment. Journal of Applied Spectroscopy 86: 353-359.
16. Briffa J, E Sinagra, R Blundell, (2020) Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon 6(9): e04691.
17. Jyothi N R, (2020) Heavy metal sources and their effects on human health. Heavy Metals-Their Environmental Impacts and Mitigation.
18. Roe K, (2022) An alternative explanation for Alzheimer's disease and Parkinson's disease initiation from specific antibiotics, gut microbiota dysbiosis and neurotoxins. Neurochemical Research 47(3): 517-530.
19. Quiroga M M B, M I Juncà, N A Merino, (2021) Study of the effect of the LDH cations precursors in the removal of arsenic in aqueous solution. Water Science and Technology 83(10): 2518-2525.

DOI: 10.26717/BJSTR.2024.58.009151

20. Wu F, Tuo Zhao, Ying Yao, Tao Jiang, Bing Wang, et al. (2020) Recycling supercapacitor activated carbons for adsorption of silver (I) and chromium (VI) ions from aqueous solutions. Chemosphere 238: 124638.

21. Mathew S, Jovita Carrol Soans, R Rachitha, M S Shilpalekha, Siddegowda Gopalapura Shivanne Gowda, et al. (2022) Green technology approach for heavy metal adsorption by agricultural and food industry solid wastes as bio-adsorbents: A review. Journal of Food Science and Technology 60: 1923-1932.

22. Shafiq M, A Alazba, M Amin, (2018) Removal of heavy metals from wastewater using date palm as a biosorbent: a comparative review. Sains Malaysiana 47(1): 35-49.

23. Kumari P, M Alam, W A Siddiqi (2019) Usage of nanoparticles as adsorbents for waste water treatment: an emerging trend. Sustainable Materials and Technologies 22: e00128.

24. Ibrahim Y, Vijay S Wadi, Mariam Ouda, Vincenzo Naddeo, Fawzi Banat, et al. (2022) Highly selective heavy metal ions membranes combining sulfonated polyethersulfone and self-assembled manganese oxide nanosheets on positively functionalized graphene oxide nanosheets. Chemical Engineering Journal 428: 131267.

25. Yang W, M Cao, (2022) Study on the difference in adsorption performance of graphene oxide and carboxylated graphene oxide for Cu (II), Pb (II) respectively and mechanism analysis. Diamond and Related Materials 129: 109332.

26. Gunasekaran B M, John Bosco Balaguru Rayappan, Ganesh Kumar Rajendran, Gopu Gopalakrishnan, Noel Nesakumar et al. (2022) Electrochemical Sensing of Arsenic Ions Using a Covalently Functionalized Benzotriazole-Reduced Graphene Oxide-Modified Screen-Printed Carbon Electrode. ChemistrySelect 7(25): e202201169.

27. Sher F, Sania Zafar Iqbal, Shaima Albazzaz, Usman Ali, Daniela Andresa Mortari, et al. (2020) Development of biomass derived highly porous fast adsorbents for post-combustion CO2 capture. Fuel 282: 118506.

28. Ani J, K G Akpomie, U C Okoro, L E Aneke, O D Onukwuli, et al. (2020) Potentials of activated carbon produced from biomass materials for sequestration of dyes, heavy metals, and crude oil components from aqueous environment. Applied Water Science 10: 1-11.

29. Saletnik B, Grzegorz Zaguła, Marcin Bajcar, Maria Tarapatskyy, Gabriel Bobula, et al. (2019) Biochar as a multifunctional component of the environment-a review. Applied Sciences 9(6): 1139.

30. Kwak J H, Md Shahinoor Islam, Siyuan Wang, Selamawit Ashagre Messele, M Anne Naeth, et al. (2019) Biochar properties and lead (II) adsorption capacity depend on feedstock type, pyrolysis temperature, and steam activation. Chemosphere 231: 393-404.

31. Lo S F, Song Yung Wang, Ming Jer Tsai, Lang Dong Lin (2012) Adsorption capacity and removal efficiency of heavy metal ions by Moso and Ma bamboo activated carbons. Chemical Engineering Research and Design 90(9): 1397-1406.

32. Burakov AE, Evgeny V Galunin , Irina V Burakova, Anastassia E Kucherova, Shilpi Agarwal et al. (2018) Adsorption of heavy metals on conventional and nanostructured materials for wastewater treatment purposes: A review. Ecotoxicology and environmental safety 148: 702-712.

33. Sajid M, Mohammad Asif, Nadeem Baig, Muhamed Kabeer, Ihsanullah Ihsanullah et al. (2022) Carbon nanotubes-based adsorbents: Properties, functionalization, interaction mechanisms, and applications in water purification. Journal of Water Process Engineering. 47: 102815.

34. Elell MHA, Emad S Goda, Mohamed A Gab Allah, Sang Eun Hong, Yared G Lijalem et al. (2022) Biodegradable Polymeric nanocomposites for wastewater treatment, in Advances in nanocomposite materials for environmental and energy harvesting application. Springer p. 245-298.

35. Shokoohi R, Abdollah Dargahi , Roya Azami Gilan , Hasan Zolghadr Nasab , Dariush Zeynalzadeh et al. (2020) Magnetic multi-walled carbon nanotube as effective adsorbent for ciprofloxacin (CIP) removal from aqueous solutions: isotherm and kinetics studies. International Journal of Chemical Reactor Engineering 18(2).

36. Lu W, Jinhua Li , Yanqing Sheng, Xinshen Zhang, Jinmao You, et al. (2017) One-pot synthesis of magnetic iron oxide nanoparticle-multiwalled carbon nanotube composites for enhanced removal of Cr (VI) from aqueous solution. Journal of colloid and interface science. 505: 1134-1146.

37. Li M, Shaoping Kuang, Yan Kang, Haoqin Ma, Jiahao Dong, et al. (2022) Recent advances in application of iron-manganese oxide nanomaterials for removal of heavy metals in the aquatic environment. Science of The Total Environment 819:153157.

38. Tatarchuk T, Mariana Myslin, Ivanna Lapchuk , Alexander Shyichuk , Arun Prasad Murthy et al. (2021) Magnesium-zinc ferrites as magnetic adsorbents for Cr (VI) and Ni (II) ions removal: Cation distribution and antistructure modeling. Chemosphere 270: 129414.

39. Agarwal M, K Singh (2017) Heavy metal removal from wastewater using various adsorbents: a review. Journal of Water Reuse and Desalination 7(4): 387-419.

40. Suresh A, Alaguabirami Alagusundaram, Ponnusamy Senthil Kumar, Dai Viet Nguyen Vo, Femina Carolin Christopher, et al. (2021) Microwave pyrolysis of coal, biomass and plastic waste: a review. Environmental Chemistry Letters 19: 3609-3629.

41. Vanshpati R, JK Shrivastava, R Baghel, Chromium (VI) Removal from Waste Water using Low-Cost Adsorbent-Review. 7(10):112-131.

42. Varade SR, (2020) Foaming Behavior of Aqueous Solutions of a Zwitterionic Surfactant in the Presence of Salts: Analysis of Specific Ion Effect and Synergism. 176-180

43. Krishnani KK, Veera Mallu Boddu, Rajkumar Debarjeet Singh, Puja Chakraborty, Ajit Kumar Verma et al. (2023) Plants, animals, and fisheries waste mediated bioremediation of contaminants of environmental and emerging concern (CEECs)–A circular bioresource utilization approach. 30: 84999-85045

44. Gupta S, S Sireesha, I Sreedhar, Chetan M Patel, KL Anitha (2020) Latest trends in heavy metal removal from wastewater by biochar based sorbents. Journal of Water Process Engineering. 38: 101561.

45. Singh PP, Ambika (2018) Environmental remediation by nanoadsorbents-based polymer nanocomposite. New polymer nanocomposites for environmental remediation. Elsevier pp. 223-241.

46. Shabbirahmed AM, Dibyajyoti Haldar, Pinaki Dey, Anil Kumar Patel, Reeta Rani Singhania et al. (2022) Sugarcane bagasse into value-added products: a review. Environmental Science and Pollution Research 29(42): 62785-62806.

47. Malaviya P, A Singh (2016) Bioremediation of chromium solutions and chromium containing wastewaters. Critical reviews in microbiology 42(4): 607-633.

48. Thaçi BS, ST Gashi (2019) Reverse osmosis removal of heavy metals from wastewater effluents using biowaste materials pretreatment. Pol J Environ Stud 28(1): 337-341.

49. Bayuo J (2021) An extensive review on chromium (vi) removal using natural and agricultural wastes materials as alternative biosorbents. Journal of Environmental Health Science and Engineering 19(1): 1193-1207.

50. Soetaredjo F, et al. (2019) Applications of Biosorption in Heavy Metals Removal, in Bioremediation. CRC Press p. 61-98.

51. Namasivayam C, M Sureshkumar (2008) Removal of chromium (VI) from

 DOI: 10.26717/BJSTR.2024.58.009151

water and wastewater using surfactant modified coconut coir pith as a biosorbent. Bioresource technology 99(7): 2218-2225.

52. Nur E Alam M, Md Abu Sayid Mia, Farid Ahmad, Md Mafizur Rahman (2020) An overview of chromium removal techniques from tannery effluent. Applied Water Science 10(9): 205.
53. Pavithra S, Gomathi Thandapani, Sugashini S, Sudha PN, Hussein H Alkhamis et al. (2021) Batch adsorption studies on surface tailored chitosan/orange peel hydrogel composite for the removal of Cr (VI) and Cu (II) ions from synthetic wastewater. Chemosphere 271: 129415.
54. Nazarzadeh Zare E, Ackmez Mudhoo, Moonis Ali Khan, Marta Otero, Zumar Muhammad Ali Bundhoo et al. (2021) Smart adsorbents for aquatic environmental remediation. Small 17(34): e2007840.
55. Khalith SM R Rishabb Anirud, R Rishabb Anirud, Raghavendra Ramalingam, Sathish Kumar Karuppannan, Mohammed Junaid Hussain Dowlath et al. (2021) Synthesis and characterization of magnetite carbon nanocomposite from agro waste as chromium adsorbent for effluent treatment. Environmental Research 202: 111669.
56. Sahmoune MN, AR Yeddou (2016) Potential of sawdust materials for the removal of dyes and heavy metals: examination of isotherms and kinetics. Desalination and Water Treatment. 57(50): 24019-24034.
57. Isa YM, Paul Musonge, Yusuf Makarfi Isa, Moisés García Morales, Ana Sayago (2020) The application of eggshells and sugarcane bagasse as potential biomaterials in the removal of heavy metals from aqueous solutions. South African Journal of Chemical Engineering 34(1): 142-150.
58. Renu M Agarwal, K Singh (2017) Methodologies for removal of heavy metal ions from wastewater: an overview. Interdisciplinary Environmental Review 18(2): 124-142.
59. Khalifa ME, Ehab A Abdelrahman, Mohamed M Hassanien, Wesam A Ibrahim (2020) Application of mesoporous silica nanoparticles modified with dibenzoylmethane as a novel composite for efficient removal of Cd (II), Hg (II), and Cu (II) ions from aqueous media. Journal of Inorganic and Organometallic Polymers and Materials 30: 2182-2196.
60. Elieh Ali Komi D, MR Hamblin (2016) Chitin and chitosan: production and application of versatile biomedical nanomaterials. International journal of advanced research 4(3): 411-427.
61. Alizadeh B, M Delnavaz, A Shakeri (2018) Removal of Cd (II) and phenol using novel cross-linked magnetic EDTA/chitosan/TiO2 nanocomposite. Carbohydrate polymers 181: 675-683.
62. Choi HJ, SW Yu, KH Kim (2016) Efficient use of Mg-modified zeolite in the treatment of aqueous solution contaminated with heavy metal toxic ions. Journal of the Taiwan Institute of Chemical Engineers 63: 482-489.
63. Kobayashi Y, Fumihiko Ogata, Chalermpong Saenjum,Takehiro Nakamura, Naohito Kawasaki (2020) Removal of Pb2+ from aqueous solutions using K-type zeolite synthesized from coal fly ash. Water 12(9): 2375.
64. Taneez M, C Hurel (2019) A review on the potential uses of red mud as amendment for pollution control in environmental media. Environmental Science and Pollution Research 26: 22106-22125.
65. Huang W, Shaobin Wang, Zhonghua Zhu, Li Li, Xiangdong Yao, Victor Rudolph, et al. (2008) Phosphate removal from wastewater using red mud. Journal of hazardous materials 158(1): 35-42.
66. Ma Y, Chuxia Lin, Yuehua Jiang, Wenzhou Lu, Chunhua Si et al. (2009) Competitive removal of water-borne copper, zinc and cadmium by a CaCO3-dominated red mud. Journal of hazardous materials. 172(2-3): 1288-1296.
67. (2022) Middle East respiratory syndrome: global summary and assessment of risk. World Health Organization.
68. Skorupa A, M Worwąg, M Kowalczyk (2023) Coffee Industry and Ways of Using By-Products as Bioadsorbents for Removal of Pollutants. Water 15(1): 112.
69. Krasowska M, Małgorzata Kowczyk Sadowy , Ewa Szatyłowicz , Sławomir Obidziński (2023) Analysis of the possibility of heavy metal ions removal from aqueous solutions on fruit pomace. Journal of Ecological Engineering 24(3): 169-177.
70. García Martín JF, Manuel Cuevas,Chao Hui Feng, Paloma Álvarez Mateos, Miguel Torres García et al. (2020) Energetic valorisation of olive biomass: Olive-tree pruning, olive stones and pomaces. Processes 8(5): 511.
71. Shrestha R, Sagar Ban, Sijan Devkota, Sudip Sharma, Rajendra Joshi et al. (2021) Technological trends in heavy metals removal from industrial wastewater: A review. Journal of Environmental Chemical Engineering 9(4): 105688.
72. Ali M, M E Hoque, S K Safdar Hossain, MC Biswas (2020) Nanoadsorbents for wastewater treatment: next generation biotechnological solution. International Journal of Environmental Science and Technology 17: 4095-4132.
73. Xu H, (2021) Elaboration of laccase T. cross-linked ultraporous aluminas for Remazol Brilliant Blue R removal., Université Paris-Nord-Paris XIII.
74. Tamjidi S, A Ameri (2020) A review of the application of sea material shells as low cost and effective bio-adsorbent for removal of heavy metals from wastewater. Environmental Science and Pollution Research 27: 31105-31119.
75. Natrayan L, S Kaliappan, C Naga Dheeraj Kumar Reddy, M Karthick, N S Sivakumar et al. (2022) Development and Characterization of Carbon-Based Adsorbents Derived from Agricultural Wastes and Their Effectiveness in Adsorption of Heavy Metals in Waste Water. Bioinorganic Chemistry and Applications 2022: 1659855.

ISSN: 2574-1241

DOI: 10.26717/BJSTR.2024.58.009151

Misbah Ullah Khan. Biomed J Sci & Tech Res