International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Chromium Adsorptive Removal From Industrial Wastewater Using Various Reactive Media- A Mini Review

Gobusaone Mokokwe[a]*, Emmanuel Karabo Mpodi[b] ,Topoyame Isaac Makoi[c]

[a,b]*Botswana International University of Science &Technology, Faculty of Engineering and Technology, Bag16, Palapye, Botswana*

[c]*Botswana University of Agriculture and Natural Resources, Faculty of Natural Resources, Private Bag 0027, Gaborone, Botswana*

[a]*Email: mokokwemokokwe @gmail.com*, [b]*Email: ekmpodi@gmail.com*, [c]*Email: tmakoi@buan.ac.bw*

Abstract

Effluents from industries frequently contain a variety of chromium ions such as hexavalent chromium and trivalent chromium which can adversely pose threats to terrestrial and aquatic life. Hexavalent chromium is more toxic than trivalent chromium thus need to be removed from effluents. Adsorption is a water and wastewater treatment technology which plays a significant role in the removal of heavy metals including chromium from effluents. In this review paper, the performance of distinct inexpensive reactive bio adsorbents and other adsorbents used by different researchers was reviewed. The findings from different studies indicated that most of the adsorbents for the removal of chromium are technically uncomplicated and mostly had outstanding performance. Factors frequently and seldom used for selection of best media for adsorption were also reviewed. Although, many researchers have proven that most of media have outstanding performance, there is still paucity of information on the effects of practical issues such as mechanical strength of media, its toxicity and leachability, abrasion on adsorption capacity. Findings also shown that sodium hydroxide is the best regeneration eluent. The findings of different studies in this review have demonstrated that different low-cost bio adsorbents can be employed in industrial wastewater treatment processes to remove chromium.

Keywords: Adsorbents; Adsorption; effluents; toxic.

----

* Corresponding author.

1. Introduction

Water is the most important and widespread natural resource in the universe needed for supporting all forms of life and affect development of industries [1]. Heavy metals are necessary for all existing organisms in minute amounts for our bodies to function very well. For instance, manganese is required for the metabolism of carbohydrates and the synthesis of fats vital for a healthy reproductive system. It also has some association with the development of organs and tissues [2-4]. Copper plays a role in homeostasis of iron and zinc [5]. However, the use of water in industries has increased and generated huge volumes of effluent water. Such huge volumes of water contain excessive concentrations of heavy metals that contaminate waterbodies such as lakes, rivers and groundwater posing health threats to human and the environment [6]. Wastewater may also contain nutrients, which can stimulate the growth of aquatics plants, and could also contain toxic compounds with high teratogenic, mutagenic and carcinogenic ability. For these reasons, the immediate removal of toxic contaminants from wastewater sources is necessary for the protection of man and the environment. The main source of pollution of chromium is anthropogenic processes from industries and natural activities such as volcanic eruptions and weathering of rocks, natural forest fires [7]. The other sources and toxicity of chromium metal ions are listed in (Table 1). The threshold limit of chromium is required to remain at low concentrations to alleviate these detrimental health effects posed by effluents enriched with chromium. Stringent laws and regulations have been established by regulatory bodies such as the United States Environmental Protection Agency (USEPA).European Union (EU), World Health Organization (WHO) and locally, Botswana Standards (BOS) have developed regulations to control the level of heavy metal concentrations in wastewater. Moreover, USEPA developed regulations for the Maximum Contaminated Level (MCL) of toxic heavy metals in effluent water [8]. Some crops are most likely than others to absorb non-nutrient toxic substances including heavy metals from the soils. To overcome the entrance of heavy metals into our bodies through food, Food Agriculture Organisation (FAO) and other countries have set thresholds of maximum recommended concentration levels of heavy metals in irrigation water (Table 2). Conventional treatment techniques employed for the removal of heavy metals from wastewater include chemical precipitation [9], flocculation and coagulation [10], reverse osmosis [11], membrane filtration [12], electrodialysis and evaporative recovery. These methods have been long used to treat wastewater prior to releasing it into aquatic bodies [13]. However, these wastewater treatment methods are associated with high maintenance and operation costs. Chemical precipitation methods are reliable but on the other hand, require voluminous settling tanks for precipitation of alkaline sludge and subsequent treatment by separation is required [14]. The reduction of maintenance, operation, and sludge disposal costs is required by adopting other alternatives [15]. Among all these technologies, adsorption is one of the simplest, economically viable, and effective techniques useful for the removal of heavy metals from effluents. It is defined as a process whereby a substance travels from a liquid or gaseous phase and establishes a superficial monomolecular layer on the solid or liquid phase [16]. Adaption of novel technologies in water and wastewater treatment such as the utilization of novel adsorbents in heavy metal removal is gradually evolving. The main challenge faced by various researchers using adsorption technology is the paucity of appropriate information about the selection of low cost and high heavy metal retention adsorbent media. Various adsorbents have been investigated and evaluated through batch and column experiments. Most of the investigations were done using bio adsorbents for the elimination of chromium from industrial wastewater. For example, [17-18]. Activated carbon (Ac) is mostly used as an adsorbent due to its high adsorption capacities, but it has notoriety for high production prices. These sorbents are also however associated with high regeneration costs and possess low physical and mechanical strength, thus likely to fail due to hydrostatic forces encountered in the bed. Rapid industrialization has generated waste materials such as activated carbon, clinker ashes, smelter slags, and fly ashes. Globally, many of such adsorbents have been investigated for wastewater treatment. Though the researchers have been investigated, there are some paucity of information on the leachability and toxicity potential of such media, practical issues such as wear resistance, and a compressive strength of media. In response, such cost-effective, abundant and environmentally favourable adsorbents need to be applied for the removal of heavy metals into consideration such aforementioned seldom investigated factors. An evaluation of heavy metal adsorption capacities of various media has been investigated through laboratory and column experiments [19-21]. The review focuses on the use of various reactive novel adsorbents used for the removal of chromium from wastewater. This review paper investigates the main characteristics considered during the selection of adsorbent for chromium removal, mainly hexavalent chromium. The review also investigates the physiochemical process parameters influencing the performance of different reactive media on adsorption of chromium from effluents.

Table 1: Some sources and toxic effects of chromium on health of human [7]

Heavy metal	Sources	Health effects	References
Chromium (VI)	Electroplate effluents, leather tanning, textiles effluents, metallurgical effluents, wood preservatives, pigments and paints.	Carcinogenic, teratogenic, epigastric pain, mutagenic, severe diarrhoea, tumours in lungs, vomiting, nausea.	[7],[22- 23]

Table 2: Maximum-recommended-concentration level (μg/L) of hexavalent chromium in irrigation water established by Food and Agriculture Organisation (FAO), Portugal and Canada [24].

Heavy metal	FAO	Portugal	Canada
Chromium(IV)	100	100	8Hexavalent chromium Cr(VI)

2. Conventional techniques for the removal of heavy metals from wastewater

Different wastewater treatment technologies have been investigated for the removal of chromium from wastewater, to comply with the maximum permissible concentrations according to the environmental regulation, and to minimise the toxic effects of heavy metals after discharge into aquatic bodies. The mostly used conventional treatment technologies for the removal of heavy metals from wastewater include chemical precipitation, flocculation, solvent extraction, coagulation, ion exchange, adsorption, ultra-filtration, reverse osmosis, membrane filtration, electrodialysis, evaporative recovery as well as adsorption [25-26].The same technologies have been investigated in removal of chromium.

2.1 Chemical precipitation

This water treatment method is regarded as one of the most applied methods in the removal of heavy metals from inorganic effluents because it is simple to operate [27]. This conventional technique leads to formation of heavy metals precipitates such as; hydroxides, phosphates, sulphide, and carbonates (i.e. these precipitates are insoluble). From hence the dissolved metals solution is reacted with a precipitant, finer particles are produced in chemical precipitation. The precipitants, coagulants, and flocculation processes are used to enlarge the size of fine particles to be removed as sludge [28]. Hydroxide treatment is the commonly used precipitation technique because it is a relatively simple, inexpensive precipitant (lime), and ease of automatic pH control. The solubility of distinct metal hydroxides is reduced for pH in the range of 8.0 to 11.0 [29]. The use of coagulants in the precipitation process increases cost of operation, as this require chemical storage and sludge treatment. An example of a simple general chemical reaction elucidating chemical precipitation is as follows in the equation below;

Metal+ Hydroxide ↔Metal precipitation

2.2 Flocculation and Coagulation

The measurement of Zeta potential is the mechanism in which flocculation –coagulation method is depending on as measure to describe the electrostatic influence between pollutants and flocculation-coagulation agents [30].In this process, the coagulation is used to reduce the net surface charge of colloidal particles to stabilize the electrostatic repulsion of the process [31]. The flocculation process continually increases the particle sizes to individually separate and distinct particles. This is achieved through additional collisions and interaction with inorganic polymers formed by the organic polymers added [32]. Particles removed by filtration, straining as soon as discrete particles are flocculated into larger particles. The removal of trace metals from industrial wastewater by coagulation/flocculation process was studied by [33]. The authors examined the effectiveness of the polymer addition to the coagulation process for the removal of nickel and other heavy metals. The researchers also, conducted experiments using the standard Jar test procedure to determine the performance of both ferric chloride and organic polymer (a non-ionic polyacrylamide) individually and ferric chloride-polymer combination. The results indicated that it was possible to remove metals in a considerable amount from wastewater. However, just like chemical precipitation, flocculation and coagulation process have main drawbacks which include the production of sludge, application of chemicals, and transfer of toxic compounds into the solid phase. These methods have impact colloidal removal at filtration with large pore sizes and help in cost of \$0.3–0.6 per kg of Chemical Oxygen Demand (COD) for aluminium electrodes as well as \$0.1–0.2 per kg COD for iron. However, the latter indicates approximately \$14,000 annually for a 5,000 m3 per day plant removing 50 mg/L of COD which is quite expensive compared to other techniques [34].

2.3 Ion Exchange

Ion exchange is a water and wastewater treatment technology that involves the reversible exchange of ions between soluble ions in a liquid phase and solid phase. This method is widely applied in water and wastewater treatment softening technology, whereby magnesium, calcium as well as polyvalent cations undergo exchange with sodium [35]. The technology is also used to remove particular water contaminants such as barium, nitrates, radium, and arsenic (As). The treatment of water and wastewater using ion exchange is achieved by passing raw water through a bed of resins made of polymerized organic compounds. Once the ion exchange resins become exhausted, regeneration is required. To accomplish the regeneration process, rapid backwashing of resins is done to remove fine particles that strained out of water production. Brine is also added to backwash flow. Concerns with low efficiency of contaminant removal during regeneration, selective removal contaminants make the ion exchange method unfavourable.

2.4 Membrane Filtration

There are different types of membrane filtrations. These systems include; microfiltration, ultrafiltration, and Nanofiltration. Microfiltration and ultrafiltration are normally used for the removal of turbidity and suspended solids. The method is effective for the removal of cadmium (Cd (II)) and Zinc (Zn (II)) in alkaline conditions (pH 9.0) using diethylaminoethyl cellulose [36]. However, concerns about the high cost of equipment and maintenance cost make the method unsuitable. Moreover, the membrane filtration process is also associated with the generation of sludge, thus making the method unfavourable [37]. The costs obtained in current research and developments [38] indicated a capital cost of $10,000 and for a 1.51 m^3d^{-1} for the ultrafiltration system.

2.5 Biological Methods

The removal of heavy metals from wastewater by biological methods involves the use of biological techniques. According to [29], microorganisms play a vital part in settling solids in the solution during the elimination of pollutants from effluents. These organisms are employed in activated sludge, trickling filters, and lagoons or stabilization ponds. Some other biological techniques include biosorption, biopolymers, and by-products. Biological treatments are environmentally friendly, the best techniques in pollutant removal and it’s cheaper. However, the biological method requires enough volatile fatty acids by supplementation of carbon in the fermentation zone which is quite labour-intensive.

2.6 Floatation

Floatation involves the use of surfactants which plays a role in causing non-surface active materials to become surface active. Surface-active materials form a product that is scavenged by foaming the solution through a gas. The studies of removal of heavy metals using foam techniques have been documented by several researchers [39]. The merits of the floatation method include its simplicity, production of minute, concentrated sludge. Concerns on the reduction in floatation efficiency due to an increase in ionic strength and particle size in solution make the method unfavourable.

2.7 Reverse osmosis and Nanofiltration

Reverse osmosis is a water treatment technology that removes contaminants from effluents by involving pressures to force molecules of water through a semipermeable membrane. Materials widely used in these processes are cellulosic derivatives and polyamide derivatives. This is an efficient removal method, but the membranes frequently degrade due to chlorine and are associated with difficulty in cleaning or regeneration [40]. Nanofiltration work by the principle of charge exclusion and retention of certain ions. The separation of uncharged organic species is influenced by the distribution of pores in a filter and the size of the membrane. The use of this technique is limited since it is expensive [20]. For instance, it is estimated that the capital cost of infrastructure and pre-treatment system is \$321/ (m3·d) [41].

2.8 Adsorptive removal of chromium from wastewater

The widely used method for scavenging heavy metals from wastewater is chemical precipitation. However, the utilization of chemicals and upsurge in quantities of sludge, requiring regular disposal make the precipitation method undesired. An alternative novel technology that does not require expensive chemicals and regular maintenance is required. Consequently, novel adsorbents with high adsorptive capacity, eco-friendly, and easy to handle, not requiring the use of chemicals and regular maintenance are needed. The investigation of various types of adsorbent media such as sorbents (activated barks, leaves, roots), natural materials (red mud, sands), and waste products (fly ash, copper smelter slag) have been done.

Table 3: Results from some previous studies of distinct sorbents used for adsorption of chromium and other metal ions

Adsorbate	Adsorbent	Optimum pH	Optimum contact time (hrs or mins)	%Cr Removal	References
Cr (VI)	commiphora myrrha bark	-	360mins	75-80%	[18]
Zn, Cr, Ni	Corn cob	5.4	4.18 hrs	95.05%	[17]
Cr (VI)	Acacia Nilotica Leaf	2	90 mins	96%	[42]
Cr(VI)	Mango, Neem, Eucalyptus	2	180mins	90%	[43]
Cr (VI)	Chemically activated Syzygium cumini leaves	3-4	90mins	96%	[1]
Cr	Eucalyptus bark	2	-	-	[44]
Cr (VI)	Bark of Acacia albida and leaves of Euclea schimperi	2	-	97.39%	[45]
Cr (VI)	Agricultural wastes (Rice husk, sugar cane bagasse, Tulsi Leaf &branches, coconut shell and coir and fly ash)	-	-	23.340% Tulsi leaf,81.999% for Coconut shell	[46]
Cr (VI)	Neem Leaves		-	60%	[47]
Cr	Azadirachta indica (Neem) leaf powder	7	5hrs	-	[48]

The data from previous studies indicate that sorbents and waste products and by-products perform better than natural materials (Table 3). In 2017,[1] conducted a study on removal of Chromium (VI) from aqueous solutions using chemically activated Syzygium cumini leaves Carbon Powder as an adsorbent. In this study, several investigations have been made to optimize various physicochemical parameters such as pH, adsorbent dosage, and initial chromium concentration and contact time. The results of the study indicated that the maximum adsorption (96%) was attained at room temperatures under acidic condition of pH 3-4 with a contact time of 90 minutes and the maximum amount of adsorbent dosage was 1.0 g per 50 mL of 100mg/L chromium (VI) solution. From this investigation, it was concluded that the activated Syzygium Cumini leaves carbon powder can be used as a low cost alternative media for removing the Chromium (VI) from industrial effluents and aqueous solutions. In 2014, [17] studied the removal of Zinc, Chromium and Nickel from industrial wastewater using Corn cobs. From their experiments they studied the effects of parameters such as pH, contact time and removal efficiency of the adsorbent. The results for the removal of chromium shown that adsorption equilibrium was obtained in 4.18 hours at pH 5.4 with the best chromium removal efficiency of 95.05%.Some of the studies on sorption of chromium done by different authors across the world using various adsorbent are summarised in (Table 3).

2.8.1 Frequently used factors for the selection of reactive adsorbents for passive treatment systems

Adsorbent particle size, porosity, mineralogy, and elemental composition do influence the selection of adsorbent media. Mineralogy and elemental composition of media among such factors have been extensively used to determine the potency of different media in adsorption. The presence of calcium and aluminium silicates, oxides of iron, clay minerals such as illite, montmorillonite, carbonates, and quartz play an important role in adsorption. For example, [49] used calcined brick powder for adsorption of Chromium and Nickel ions. The maximum efficiency of 81% was attained at pH 2 for Cr (VI) and 75.40% were achieved at pH 4 for Ni (II). Results indicated that calcined or oxidized brick powder exhibits good adsorption characteristics. Moreover, the presence of calcium carbonates plays a significant role in the adsorption of heavy metals as per what [50] have done. The size of the adsorbent particle influences the adsorption capacity of adsorbents. It is very important to select the best size of particles for practical use. Normally adsorption of heavy metals tends to decrease when large particles are used and vice versa. [51] highlighted that decrease in adsorption capacity is ascribed to a decrease in adsorbent surface area with an upsurge in particle size whereas a decrease in particle size yields large surface area thus more availability of active sites for adsorption.

2.8.2 Adsorbent characteristics seldom used for selection reactive media

Practical issues such as abrasion potential of media, regeneration, permeability, leachability, and toxicity of media, and the influence of natural pH of media on adsorption have not been substantially investigated (Table 4).

Table 4: Examples of media features seldom used for the selection of media

Media characteristic	Effect on performance of adsorbents	Reference
Leachability	Media leachability increase toxicity of solution, thus limiting its use.	[52]
pH of media	Adsorption takes place at low p H. High pH leads to precipitation.	[53]
Regeneration	Lowers replacement and disposal costs of media.	[54]
Abrasion	Reduce sorption capacity of media.	[55]
Permeability	High porous and permeable adsorbents yield high sorption capacities.	[56]

2.8.3 Adsorbent Regeneration or desorption studies

Regeneration of most adsorbent is a momentous process in wastewater treatment by adsorption. Less attention has been paid to the recycling of used adsorbents and the recovery of heavy metals from eluents [57]. The primary objective of media regeneration is to restore the adsorption capacity of the exhausted adsorbent. Recovery of valuable components present in the adsorbed phase is the secondary objective of media regeneration. In that case, the selected media for heavy metal retention should have high desorption efficiency and allow the use of low-cost eluents for desorption. Besides, the replacement and disposal costs of the media should also be lower. Several adsorbents media, their regeneration efficiency, recovery of metals from solutions used are illustrated in Table 5 below.

Table 5: Media regeneration results from previous studies

Adsorbent	Adsorbates	Eluent used	Desorption Efficiency (%)	Metal recovery	Remarks	Reference
Maghemite	Cr(VI)	0.01MNaOH $NaHCO_3$ Na_2CO_3 Na_3PO_4	87.7 73.5 69.6 82.9	-	NaOH, Na_2CO_3& Na_3PO_4 were used as eluents. NaOH was most effective. Disposal of metal free adsorbents was not considered.	[58]
Iron(III)oxide or Iron(III)Hydroxide Nanoparticles	Cr(VI)	NaOH and $BaCl_2$	95-97%	99.9-100%	BariumChloride formed precipitates of Barium chromate.Recovery was possible with minute amount of NaOH.	[59]

2.8.4 Leachability and toxicity of media

The maximum contaminant levels of chromium have been adopted by different environmental regulatory bodies such as USEPA, EU, WHO. The selected adsorbent media for chromium retention should be non-hazardous. In most cases, an adsorbent with better retention usually does not leach the retained heavy metals, making media regeneration and recovery of metals more arduous. Few researchers in the field of adsorption conducted leachability tests on their studies to determine if media can be appropriately used (Table 6). A few, accomplished their tests by batch and column leaching mode as illustrated by [52 and 61] in Table 6 below. Some investigations on Arsenic leachability of water treatment adsorbents were done by [52]. Moreover, surface complexation modelling and Extended X-ray Adsorption Fine Structure (EXAFS) Spectroscopy are other techniques that can be used for assessment of media leachability.

Table 6: Media leachability and toxicity results from previous studies

Media	Metal ions	Mode of test	Observations	Reference
GFH, GFO, Tio_2, Activated alumina, and Modified activated alumina	As	Batch test using TCLP and WET methods	TiO_2 and GFO were non-hazardous as As concentration were lower than the limit. Concentration of As for GFH exceeded the WET limits thus hazardous.	[52]
Clay bricks made of sewage sludge	As, Ba, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Se, Sn, V, Zn, Br^-, Cl^-, F^-, SO^{2-}_4	Netherlands Tank Leaching Test	Sewage sludge bricks had no potential of leachability according to the standards NEN 7345, ESAPSS-01-702 and ESA PSS-01-729	[60]
Granular Red mud	As,Ag,Zn,Ni, Hg,Pb, Cd,Cr,Ba	Column	The concentration of all toxic metal ions were lower than the maximum permissible levels	[61]

2.8.5 The competition of chromium removal with other common ions

Common ions coexisting with Cr (VI) in wastewater such as sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), Copper (Cu^{2+}), and Nickel (Ni^{2+}) were investigated by [58]. Authors ignored the competitive influence of anions such as NO^{-3} and Cl^- on chromate ions because anions are regarded as inert biologically and poor ligands with weaker adsorption mechanism. Both aforementioned cations had an insignificant influence on competition of active sites with chromate anions, thus selective adsorption of Cr (VI) was accomplished and the possibility of recycling Cr (VI) back to industries was high. Other researchers investigated the competitive sorption of Cr (III) and Cr (VI) with the presence and absence of Cu^{2+} using Kaolin [62].In absence of Cu^{2+}, it was found out that the sorption capacities of trivalent chromium were less than of hexavalent chromium. The reason behind this might be the presence of active sites on kaolin which could be surface complexation done by the occupying Cu^{2+}

[63].

3. Conclusion

This review paper investigated the main characteristics considered during the selection of media for adsorption of chromium from wastewater. The review also investigated the physiochemical process parameters influencing the performance of various reactive media on adsorption of chromium from wastewater. Most of the adsorbents have proven a great potential in the removal of chromium from effluents. Though the process parameters were investigated using various reactive media, the influence of practical issues such as mechanical strength of media, wear resistance on the adsorption capacity of media were not thoroughly investigated. Sodium hydroxide (NaOH) was the most effective eluent used for regeneration of numerous adsorbents.

4. Recommendations

- There is paucity of information on the effect of leachability of chromium adsorbents; such a knowledge gap should be closed by conducting media leaching test during characterisation of adsorbents.
- More studies on methods of handling and disposal of chromium exhausted adsorbents should be done.
- No author, have conducted some studies on the adsorptive influence of practical features of chromium adsorbents like mechanical strength of media. Such a gap should be closed.
- Restoration of exhausted adsorbents in filtration systems involves backwashing process. Such a process generates abrasion of media resulting in loss of media wear resistance. In this review, no one investigated about such an issue, therefore adsorbents abrasive resistance should always be done during characterisation of adsorbents.
- There is no standardisation of some important adsorbent characterisation test such as of compressive strength, abrasion. Such paramount tests should be standardised.
- Investigations on the influence of Cation Exchange Capacity (CEC) of adsorbents should also be conducted, as there is a gap on such investigation for adsorption of chromium.

Acknowledgments

The authors of this paper would like to thank the Botswana International University of Science and Technology library service staff for the assistance they provided during the write-up of this article.

5. Abbreviations

Table 7

Ac	Activated carbon
Ag	Silver
As	Arsenic
BOS	Botswana Standards
Ba	Barium
$BaCl_2$	Barium Chloride
Br	Bromine
Ca^{2+}	calcium ion
Cd (II)	Cadmium
Cl^-	Chlorine ion
CO	Carbon monoxide
COD	Chemical Oxygen Demand
Cr (III)	Trivalent chromium
Cr (VI)	Hexavalent chromium
Cu	Copper
Cu^{2+}	Copper ion
EU	European Union
EXAFS	Extended X-ray Adsorption Fine Structure
FAO	Food and Agriculture Organisation
GFH	Granular Ferric Hydroxide
GFO	Granular Ferric oxide
Hg	Mercury
M	Molars
MCL	Maximum Contaminated Level
Mg^{2+}	Magnesium ion
Mo	Molybdenum
Na^+	Sodium ion
Na_2CO_3	Sodium carbonate
$NaHCO_3$	Sodium bicarbonate
Na_3PO_4	Trisodium Phosphate
NaOH	Sodium Hydroxide
Ni	Nickel
Ni^{2+}	Nickel ion
Pb	Lead
Sb	Antimony
Se	Selenium
Sn	Tin
SO^{2-}_4	Sulphate ion
TCLP	Toxicity Characteristics Leaching Procedure
TiO_2	Tatinum Oxide
USEPA	United States Environmental Protection Agency
V	Vanadium
WET	Waste Extraction Test
WHO	World Health Organization
Zn (II)	Zinc

References

[1]. V.D Rao, M.V.S Rao, and M.P.S.M. Krishna, “Removal of Chromium (VI) from aqueous solutions using chemically activated Syzygium cumini leaves carbon Powder as an adsorbent,’’ Journal of Applied Chemistry,vol.10,no.8,pp.20–27, 2017

[2]. H.W Hsu, S.C Bondy, and M, Kitazawa, “Environmental and dietary exposure to copper and its cellular mechanisms linking to Alzheimer’s disease,’’ Toxicological Sciences, vol.2, no.163, pp.338–345, 2018

[3]. L. Mezzaroba, D.F Alfieri, A.N.C. Simão, and E.M.V .Reiche, “The role of zinc, copper, manganese, and iron in neurodegenerative diseases,’’NeuroToxicology. Elsevier, vol.74, pp.230–241, 2019

[4]. M.A. Zoroddu, J. Aaseth, G. Crisponi, S. Medici, M .Peana, and V.M. Nurchi, “The essential metals for humans: a brief overview, ’Journal of Inorganic Biochemistry, vol.195pp.120–129, 2019

[5]. Z.L. Harris, Y. Takahashi, H. Miyajima, M. Serizawa, R.T.A. Macgillivray, and J.D. Gitlin, “Aceruloplasminemia: Molecular characterization of this disorder of iron metabolism,’’ Vol.92, no.7, pp.2539–2543, 1995

[6]. R.K. Singh, S. Kumar, S. Kumar, and A. Kumar, “Development of parthenium based activated carbon and its utilization for adsorptive removal of p-cresol from aqueous solution,’’ Journal of Hazardous Materials, vol.155, pp.523–535, 2008

[7]. U. Farooq, J.A. Kozinski, M.A Khan, and M. Athar, “Biosorption of heavy metal ions using wheat based biosorbents - A review of the recent literature,’’ Bioresource Technology. Elsevier Ltd, vol.101, pp.5043–5053, 2010

[8]. S. Babel, and T.Kurniawan, “Low-cost adsorbents for heavy metals uptake from contaminated water: A review,’’ Journal of Hazardous Materials, vol.97, pp.219–243, 2003

[9]. C.R Ramakrishnaiah ,and B .Prathima, “Hexavalent Chromium Removal by Chemical Precipitation Method: A Comparative Study,’’ International Journal of Environment Research and Development, vol.1, pp.41–49, 2016

[10]. P.D .Johnson, P .Girinathannair, K.N .Ohlinger, S. Ritchie, L .Teuber ,and J. Kirby, ‘’Enhanced Removal of Heavy Metals in Primary Treatment Using Coagulation and Flocculation, ’Water Environment Research, vol.80, pp.472–479, 2008

[11]. B. S. Thaçi, and S.T. Gashi “Reverse osmosis removal of heavy metals from wastewater effluents using biowaste materials pretreatment,’’ Polish Journal of Environmental Studies, vol.28, pp.337–341, 2019

[12]. K.C. Khulbe and Matsuura “Removal of heavy metals and pollutants by membrane adsorption techniques,’’ Applied Water Science. Springer Berlin Heidelberg, vol.8, pp.1–30, 2018

[13]. A.P. Lim and A.Z. Aris, “A review on economically adsorbents on heavy metals removal in water and wastewater,’’ Reviews in Environmental Science and Biotechnology, vol.13, pp.163–181, 2014

[14]. M.M. Marchioretto, H. Bruning, and W. Rulkens, “Heavy metals precipitation in sewage sludge,’’ Separation Science and Technology,vol.40,pp.3393–3405, 2005

[15]. M.Chiban,“Application of low-cost adsorbents for arsenic removal:A review,’’ Journal of Environmental Chemistry and Ecotoxicology,vol.4,pp.91–102,2012

[16]. C.B. Crawford and, B.Quinn, “The interactions of microplastics and chemical pollutants,’’Microplastic Pollutants, pp.131–157, 2017

[17]. S.M. Ali, A.R. Khalid, and R.M. Majid “The removal of Zinc, Chromium, and Nickel from industrial wastewater using Corn cobs,’’vol.55, pp.123–131, 2014

[18]. V.H. Waghmare, U.E. Chaudhari, “Removal of hexavalent chromium from aqueous solutions by adsorption on Commiphora myrrha bark,’’ Rasayan Journal of Chemistry,vol.7,pp.16–19,2014

[19]. M. F. El- Shahat and A. M. A .Shehata,“Adsorption of lead, cadmium and zinc ions from industrial wastewater by using raw clay and broken clay-brick waste,’’ Asian Journal of Chemistry, vol.25, pp.4284–4288, 2013

[20]. N .Amin, S .Kaneco, T .Katagawa, A .Begum, H .Katsuma, T .Suzuki and K .Ohta,“Removal of arsenic in aqueous solutions by adsorption onto waste rice husk,’’ Industrial and Engineering Chemistry Research,vol.45,pp.8105–8110,2006

[21]. A. Papandreou, C.J. Stournaras,D. Panias,“Copper and cadmium adsorption on pellets made from fired coal fly ash,’’ Journal of Hazardous Materials vol.148,pp.538–547,2007

[22]. L.Dupont, and E.Guillon, “Removal of hexavalent chromium with a lignocellulosic substrate extracted from wheat bran,’’ Environ. Sci. Technol, vol.37, pp.4235–4241, 2003

[23]. K.K. Singh, H.S. Hasan, M .Talat, V. K .Singh and S.K. Gangwar,“Removal of Cr (VI) from aqueous solutions using wheat bran,’’ Chem. Eng. J,vol.151,pp.113–121,2009

[24]. J.P. Vareda, A.J.M. Valente and L. Durães, “Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review,’’Journal of Environmental Management. Elsevier, vol. 246, pp. 101–118, 2019

[25]. G .Blázquez, F .Hernáinz, M .Calero, M. A. Martín-Lara and G .Tenorio, “The effect of pH on the biosorption of Cr (III) and Cr (VI) with olive stone,’’ Chemical Engineering Journal,vol.148 pp.473–479,2009

[26]. B.Singha and S.K. Das, “Biosorption of Cr (VI) ions from aqueous solutions: Kinetics, equilibrium, thermodynamics and desorption studies,’’ Colloids and Surfaces B: Biointerfaces. Elsevier B.V, vol. 84, pp.221–232, 2011

[27]. Y. Ku and I.L. Jung, “Photocatalytic reduction of Cr (VI) in aqueous solutions by UV irradiation kara with the presence of titanium dioxide,’’ Water Research, vol.35, pp.135–142, 2001

[28]. F .Fu and Q. Wang “Removal of heavy metal ions from wastewaters: A review, “Journal of Environmental Management. Elsevier Ltd, vol.92, pp.407–418, 2011

[29]. S.K .Gunatilake,“Methods of Removing Heavy Metals from Industrial Wastewater,” vol.1, pp.12–18, 2015

[30]. E.A. López-Maldonado, O.Mercedes, B. José Luis Jurado and T. Adrián Ochoa, “Coagulation-flocculation mechanisms in wastewater treatment plants through zeta potential measurements,” Journal of Hazardous Materials. Elsevier B.V, vol.279, pp.1–10, 2014

[31]. L. Benefield , J. Judkins and B. Weand, “Process Chemistry for Water and Wastewater Treatment,” Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1982

[32]. T. Tripathy and B.R. De, “Flocculation: A New Way to Treat the Waste Water,” JPS10art9, vol.10, pp.93–127, 2006

[33]. O.S. Amuda, I.A. Amoo, K.O. Ipinmoroti and O.O. Ajayi, “Coagulation/flocculation process in the removal of trace metals present in industrial wastewater,” Journal of Applied Sciences and Environmental Management,vol.10, pp. 1–4,2006

[34]. T. Guo , J. Englehardt and T. Wu , “Review of cost versus scale: Water and wastewater treatment and reuse processes,” Water Science and Technology, vol.69,pp.223–234,2014

[35]. T.C. Jorgensen, “Removal of ammonia from wastewater by ion exchange in the presence of organic compounds,”M.Sc. thesis, Department of Chemical and Process Engineering, University of Canterbury, Christchurch, New Zealand’, Graduate Theses and Dissertations,2002

[36]. K. Trivunac and S. Stevanovic,“Removal of heavy metal ions from water by complexation-assisted ultrafiltration,”Chemosphere,vol.64,pp.486–491,2006

[37]. C.N. Joshi, “Heavy metals, conventional methods for heavy metal removal, biosorption and the development of low-cost adsorbent,” European Journal of Pharmaceutical and Medical Research, vol. 4,pp.388–393, 2017

[38]. J.D. Englehardt, T. Wu and G .Tchobanoglous, “Urban net-zero water treatment and mineralization: Experiments, modeling, and design,” Water Research. Elsevier Ltd, vol.47, pp.4680–4691, 2013

[39]. F.N. Robertson, “Arsenic in ground-water under oxidizing conditions, south-west United States,” Environmental Geochemistry and Health, vol.11, pp.171–185, 1989

[40]. M. Kim, H.J. Um, S.B. Bang, S.H. Lee, S.J. Oh, J.H. Han, K.W. Kim, J .Min and Y.H. Kim, “Arsenic removal from Vietnamese groundwater using the arsenic-binding DNA aptamer,” Environ Sci Technol,vol.43,pp.1–13,2009

[41]. P. Côté, S. Siverns and S. Monti , “Comparison of membrane-based solutions for water reclamation and desalination,” Desalination,vol.182,pp.251–257, 2005

[42]. P.Thilagavathy and T .Santhi, “Adsorption of Cr (VI) Onto Low-Cost Adsorbent Developed from Acacia Nilotica Leaf Activated with Phosphoric Acid: Kinetic, Equilibrium Isotherm and Thermodynamic Studies.International Journal of Science and Research,” vol.3, pp.308–314, 2014

[43]. N .Mridul and S.K. Gupta, “Removal of Chromium (VI) from Aqueous Solution by using Mango, Neem and Eucalyptus Tree Parts,”vol.6, pp. 37–41, 2015

[44]. V. Sarin and K.K. Pant, “Removal of chromium from industrial waste by using eucalyptus bark,” Bioresource Technology, vol. 97, pp.15–20, 2006

[45]. G. Gebrehawaria, A. Hussen and V. M. Rao, “Removal of hexavalent chromium from aqueous solutions using barks of Acacia albida and leaves of Euclea schimperi,” International Journal of Environmental Science and Technology, vol.12, pp.1569–1580, 2015

[46]. P.K. Shrivastava and S.K. Gupta, “Removal of Chromium from Waste Water by Adsorption Method Using Agricultural Waste Materials,” International Journal of Chemical Sciences, vol.6, pp.2278–6015,2015

[47]. N.S. Elangovan, V. Lavanya and S. Arunthathi, “Removal of chromium from groundwater using neem leaves as adsorbent,” International Journal of Environmental Research, vol.9, pp. 439–444, 2015

[48]. P. Venkateswarlu, V.R. Myneni, D.S. Rao and M.V. Rao, “Removal of chromium from an aqueous solution using Azadirachta indica (neem) leaf powder as an adsorbent,” International Journal of Physical Sciences,vol.2, pp.188–195,2007

[49]. P.V. Hemalatha and V.V.P. Rao,“Adsorption Batch Studies on Calcined Brick Powder in Removing Chromium and Nickel Ions,” International Journal of Advanced Research in Chemical Science (IJARCS),vol.1,pp.14–21, 2014

[50]. K .Ahmad, I.J .Bhatti , M. Muneer, M. Iqbaland and Z. Iqbal, “Removal of heavy metals (Zn, Cr, Pb, Cd, Cu, and Fe) in aqueous media by calcium carbonate as an adsorbent,”International Journal of Chemical and Biochemical Sciences,vol.2,pp.48–53, 2012

[51]. S .Kara, C. Aydiner, E. Demirbas, M .Kobya and N. Dizge ,“Modeling the effects of adsorbent dose and particle size on the adsorption of reactive textile dyes by fly ash,”Desalination,vol.212pp.282–293,2007

[52]. C .Jing, M .Patel and X .Meng, “Arsenic leachability in water treatment adsorbents,” Environmental Science and Technology, vol.39, pp.5481–5487, 2005

[53]. H.A.M. Bennour, “Influence of pH and Ionic Strength on the Adsorption of Copper and Zinc in Bentonite Clay,” Chemical Science Transactions, vol.1, pp.371–381, 2012

[54]. B. Thallapalli and S.Prasad, “Removal of Chromium from Wastewater Using Low-Cost Removal of Chromium from Wastewater Using Low,” World Journal of Pharmacy and Pharmaceutical Sciences,vol.4,pp. 2164-2173, 2015

[55]. V.E. Pakade, T.D. Ntuli and A.E. Ofomaja,“Biosorption of hexavalent chromium from aqueous solutions by Macadamia nutshell powder,” Applied Water Science. Springer Berlin Heidelberg, vol.7, pp.3015–3030, 2017

[56]. P.S. Kumar, L. Korvinga, J.K. Karel, M.C.M. Loosdrecht, G.J Witkamp, “Effect of pore size distribution and particle size of porous metal oxides on phosphate adsorption capacity and kinetics,” Chemical Engineering Journal. Elsevier, vol. 358, pp. 160–169, 2019

[57]. S. Lata, P.K. Singh and S.R. Samadder, “Regeneration of adsorbents and recovery of heavy metals: a review,” International Journal of Environmental Science and Technology, vol.12, pp.1461–1478, 2015

[58]. J. Hu, G .Chen and I.M.C Lo, “Removal and recovery of Cr (VI) from wastewater by maghemite nanoparticles,” Water Research, vol.39, pp.4528–4536, 2005

[59]. G .Zelmanov and R .Semiat, “Iron Fe (III) oxide/hydroxide nanoparticles-based agglomerates suspension as adsorbents for chromium Cr (VI) removal from water and recovery,”J Sep Purif.Technol, vol. 80, pp.330-337, 2011

[60]. J.A. Cusidó and L.V. Cremades, “Environmental effects of using clay bricks produced with sewage sludge: Leachability and toxicity studies,’’ Waste Management, vol.32, pp.1202–1208, 2012

[61]. Q .Yue, Y. Zhao, Q. Li, W .Li, B. Gao, S.Han, Y . Qi, and H .Yu, “Research on the characteristics of red mud granular adsorbents (RMGA) for phosphate removal, “Journal of Hazardous Materials, vol.176, pp.741–748, 2010

[62]. J .Liu , X .Wu, Y .Hu, C .Dai, Q .Peng and D. Liang,“ Effects of Cu (II) on the Adsorption Behaviors of Cr(III) and Cr(VI) onto Kaolin,” Journal of Chemistry,vol.2016,pp.1-11, 2016

[63]. Y.G. Chen, He, W.M Ye and L.Y. Jia, “Competitive adsorption characteristics of Na(I)/Cr(III) and Cu(II)/Cr(III) on GMZ bentonite in their binary solution,” Journal of Industrial and Engineering Chemistry. The Korean Society of Industrial and Engineering Chemistry, vol.26, pp.335–339, 2015