EFFICIENCY ASSESSMENT OF ARABIC GUM FOR HEAVY METAL REMOVAL FROM POLLUTED WASTEWATER

Halah M. Shalikh **Majid R. Majeed**
Researcher **Assist. Prof.**
Dept. Biot., Coll. Sci., University of Baghdad, Iraq
halashalikh@gmail.com msalewandy@yahoo.com

ABSTRACT

The aim of this study is to use the natural adsorbents which consist of gum arabic as absorbents for plant products to remove heavy metals from industrial wastewater and standard aqueous solutions with a prepackaged bed column (PBC) technique based on a Box-Wilson design . The gum arabic was modified into carbonated gum by oven maville at 300°C. The influence of were studied: pH value, contact time, and removal efficiency estimation using a packed layer column which gives the best heavy metal removal performance. The study showed the removal efficiency tests of charred gum arabic absorbers that the best removal from industrial wastewater were: 80%, 68.75% and 90.7% for lead (Pb), cobalt (Co) and cadmium (Cd) respectively, at pH 5-6.5 and contact time. 0.25 - 4.30 hours. While from the standard aqueous solutions, they were: 82.5%, 71.4% and 91% for Pb, Co and Cd respectively, at pH 5 - 6.5 and contact time 0.25 - 4.30 hours. In addition, other pollutants of charred gum arabic such as total dissolved solids (TDS) and electrical conductivity (E.C) have been reduced in industrial wastewater. The carburizing degumming efficiency showed significant differences between removal of heavy metals at ($p \leq 0.05$).

Keywords: carbonized, industrial wastewater, adsorption, Co, Pb, Cd.

تقييم كفاءة الصمغ العربي في إزالة المعادن الثقيلة من مياه الصرف الملوثة

هالة محمد شالخ **ماجد رشيد مجيد**
باحث **أستاذ مساعد**
قسم التقنيات الاحيائية – كلية العلوم – جامعة بغداد

المستخلص

الهدف من هذه الدراسة هو استخدام الممتزات الطبيعية، والتي تتكون من الصمغ العربي كمواد ماصة للمنتجات النباتية لإزالة المعادن الثقيلة من مياه الصرف الصناعي والمحاليل المائية القياسية باستخدام تقنية عمود السرير المعبأ (PBC) Box–Wilson. تم تعديل الصمغ العربي إلى صمغ مكربن بواسطة فرن مانفيل عند 300 درجة مئوية على أساس تصميم تمت دراسة تأثير كل من قيمة الرقم الهيدروجيني ووقت التلامس وتقدير كفاءة الإزالة باستخدام عمود طبقة معبأة يعطي أفضل أداء لإزالة المعادن الثقيلة. أظهرت الدراسة اختبارات كفاءة الإزالة لممتصات الصمغ العربي المتفحم أن أفضل إزالة من مياه الصرف الصناعي كانت: 80٪، 68.75٪ و90.7٪ للرصاص (الرصاص)، الكوبالت والكادميوم على التوالي عند الأس الهيدروجيني 5–6.5 ووقت الاتصال. 0.25–4.30 ساعة. بينما كانت من المحاليل المائية المعيارية: 82.5٪، 71.4٪ و91٪ للرصاص، بالإضافة إلى ذلك، تم تقليل الملوثات الأخرى للصمغ العربي المتفحم مثل المواد الصلبة الذائبة الكلية الكهربائي (E.C) في مياه الصرف الصناعي. أظهرت كفاءة إزالة الصمغ الكربنة اختلافات معنوية بين إزالة المعادن الثقيلة ($p \leq 0.05$).

الكلمات المفتاحية: الصمغ العربي المتفحّم، مياه الصرف الصناعي، الامتزاز، رصاص، كوبلت، كادميوم.

Received:8/3/2021, Accepted:9/5/2021

INTRODUCTION

The sources of wastewater are many, some of them are domestic and some are industrial and agricultural. For example, it may be difficult to treat industrial wastewater, while household wastewater is relatively easy to treat (although household waste is increasingly difficult to treat). The reason is the increase in the quantities of medicines and personal care products that are discarded in domestic wastewater (20). There are industries that pose a threat, especially to health and the environment, such as industries that use heavy metals, such as the manufacture of electric batteries, the manufacture of electrical and electronic devices and the leather industry, as these industries emit various pollutants in large quantities such as toxic dyes or heavy metals that pose a danger when they enter the food chain and accumulate in Tissue organisms through the processes of biological concentration and their effects on human health (24). The treatment plant utilizes a series of stages to treat and clean water that could be safely released into a lake, river, or waterway. This treatment usually consists of three main steps, (3). In these stages, different techniques are employed to take off heavy metals from polluted water, for instance; Ion exchange, chemical precipitation, Reverse Osmosis (RO) and membrane separation (23).

All of these technologies are fairly expensive and not effective enough to allow recovery of the highly dilute heavy metals that are founded in the effluents and are not appropriate for small industries [8]. In the obscurity of chemical, physical or costly treatment methods for wastewater, other approaches, such as the use of successful biological systems will be needed with an adsorption process to remove toxic metals from wastewater (1) . As plant waste materials available in large quantities in many operations at no cost as successful alternative absorbents (7), such as fruit peels, peanut skin, tree bark and plant gum, they can be used as raw materials or as modified materials that reduce various heavy metal ions from polluted water (6). Heavy metals are the elements that have more than five times the specific gravity than that water. (23) The toxicity of heavy metals are affected by several factors such as chemicals firm and its presence in the ecosystem. (24) Heavy toxic elements are faound in water and concentrated as result of human activities. (25) This research aims to use charred gum arabic as a natural absorbent to eliminate heavy metals from industrial wastewater using fixed filter technology.

MATERIALS AND METHODS

Samples of industrial waste water were taken from the main basin of the treatment unit in General State Battery manufacturing Company (Babel Factories), in Baghdad. Three waste water samples, (each sample of 5 Liters), were collected using pre-sterilized glass bottles for the period lied between 4th and 20th of September 2019 during the treatment unit operation. Each sample measured for determination of the highest ratio of heavy metals (Pb, Co and Cd), A measured by a device atomic absorbyion Total dissolved solids (TDS) A measured by TDS meter, pH, and electrical conductivity (E.C) A measured by E.C meter, and then chooses the sample that containing the highest proportion of heavy metals and pollutants for study.

Preparation of standard solutions

Heavy metals standard solutions (single ion system): The following equation was used to present heavy metal standard solutions based on the atomic and molecular weight of the element (22).

Cobalt standard solution

The 50 mg/l Cobalt adsorbate standard solution was made by dissolving 0.2 mg of Co(NO3)2 in 1000 ml de-ionized distilled water (DDW). The solution was passed through a 0.45m membrane filter to block unsolvable particles from passing through and was used as the standard solution for experimental tests. Efficiency of Removal ER % = $\frac{Co-Cf}{Co} \times \mathbf{100}$ This is a difference in Alti, which were taken to heavily heavily heavily in heavy metals, which are mainly different in their salts

Lead standard solution

The adsorbate standard solution of 50 mg/l of Lead was obtained by adding 0.09 mg of Pb (CH3COO) 2.3H2O in 1000 ml of DDW. The whole solution was then passed through a 0.45m filter membrane and used as the standard solution for the experimental studies.

Cadmium standard solution

The 50 mg/l Cadmium adsorbate standard solution was made by dissolving 0.08 mg of CdCl2 in 1000 ml of DDW. The mixture was passed via a 0.45m filter membrane and used as the experimental standard solution.

Adsorbent preparation

Arabic gum collected from the local market and then prepared as carbonized adsorbent (charcoal). The samples of raw Arabic gum (500gm) were carbonized at 300C for 3h. in muffle furnace in order to carbonize Arabic gum (fig.1). The resulting samples (450 gm) was stored in plastic container and kept air tight to evade absorption of moisture from the atmosphere . These prepped adsorbents (carbonized Arabic gum) were used in experiment (14).

Figure 1. Arabic gum, (A) Raw gum, (B) Carbonized gum

Parameters affecting adsorption process and experimental design

The pH value and contact time (the period of survival of the wastewater with Arabic gum column) (fluidized bed reactor) (retenation time) (semi-continious) were the central examined parameters which may affect toxic metals adsorption. The research methodology followed the Box Wilson method, with waste water pH ranging from 5-8 and contact time ranging from 0.25 to 5 hours (3).

Experimental studies of adsorption

The adsorption steps were carried out in a clear glass column with an internal diameter of 2.0 cm and a height of 30 cm, figure 2. The adsorbents (Arabic gum carbonized) were limited in the column by a fine Teflon (PTFE) filter (No.1) at the lower end of the column and a glass bed layer at the top of the column (Fig.2).

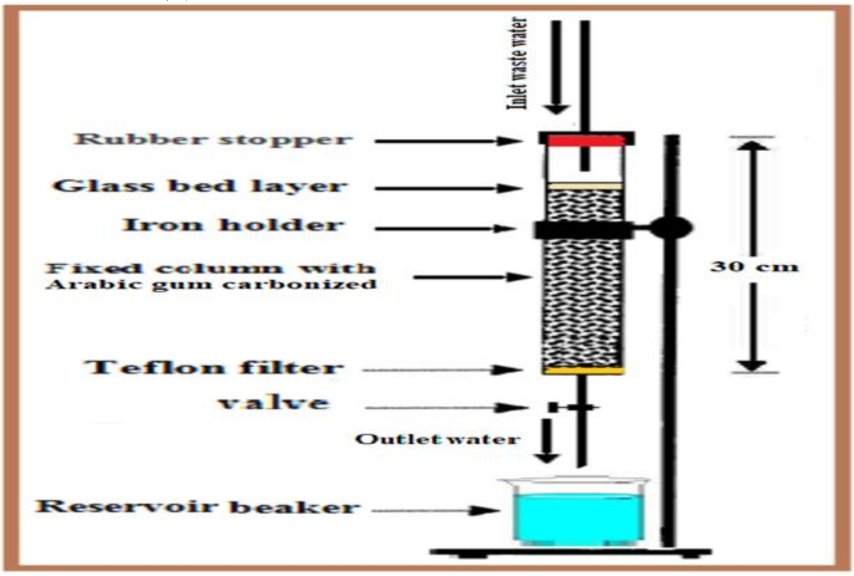

Figure 2. Schematic of experimental column

Before the adsorption trials, the column was overwhelmed with de-ionized vapor. It was filled with prepared Arabic gum carbonized samples and industrial waste water or regular solution samples in order to assess and estimate the efficiency of the adsorbent for treatment of industrial waste water using the Box-Wilson design (pH values and Contact time) [10]. All waste water samples were taken after treatment with adsorbents and analyzed for estimating certain variables such as Ph, EC, and TDS that were isolated using standard methods (2) and toxic metals (Co, pb, and Cd) content using atomic absorption spectroscopy in the research lab

Calculations of removal efficiency

The efficiency of the adsorption process was calculated using the equations below (Efficiency of removal) (11)

Efficiency of Removal ER % = $\frac{Co-Cf}{Co} \times$ **100** Where:

Co = the initial metal concentration (mg/l)

Cf = the final concentration (mg/l)

Statistical Analysis

All data were statistically investigated by ANOVA test.

RESULTS AND DISCUSSION

Physiochemical analysis of industrial waste water: Table 1 displays the values of temperature, pH, EC, TDS, cadmium, lead and cobalt ions concentrations of investigated industrial waste water samples from treatment unit of General State Battery manufacturing Company before treatment. The results observed for temperature, pH, EC and TDS were: 14 C, 9.1, 80000 µS/cm, 14000 mg/L respectively. as for the heavy metal contents of these samples, the results showed that the level of Cd, Pb and Co were 1.5, 5, 0.8 ppm (mg/l) respectively. according to the data, it seems obvious that all variables are very high comparing to the standard limitations that internationally and locally permitted values and this could" be due to the additive chemicals participated and the "type of treatment that" anticipated.

Table 1. Physiochemical and pollutant values of industrial waste water before treatment

Physical and chemical measurements	Unit	Physical and chemical properties before treatment
Temp	℃	14
PH	---	9.1
E.C.	µS/cm	80000
T.D.S	Mg/L	14000
Cd	PPm	1.5
Pb	PPm	5
Co	PPm	0.8

Experimental studies of adsorption

Removing of heavy metals from industrial waste water by carbonized Arabic gum: The research investigations of adsorption for heavy metals removal from wastewaters by carbonized gum that were carried out by different experimental column are shown in Table 2. And (Fig. 3). The findings showed that gum carbonized has the potential to eliminate and reduce the amount of heavy metals in wastewaters. Table 2 displays the important differences in adsorbent percentage removal for removing heavy metals as calculated by a one-way Anova (Post hoc) test with the F and *p* value at the level of likelihood $p \leq 0.05$.

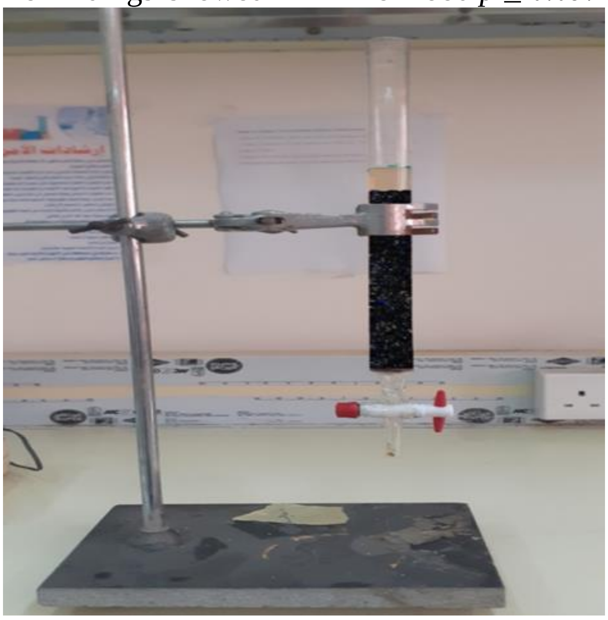

Figure 3. Column filled with prepared carbonized Arabic gum samples and waste water

The results of adsorption process by carbonized gum showed higher adsorption capacities for heavy metals of industrial waste water at pH 6.5 and contact time 0.25 hr. for pb that was 1ppm after treatment, and for Co was 0.25 ppm at pH 5.4 and contact time 4.30 hr., while was 0.14 ppm for Cd ions at pH 5 and 8 with contact time 2.62 hr.(table 2). In same time, the removal efficiency giving ion concentrations at 1ppm, 0.14 ppm and 0.25 ppm were 80%, 68.75% and 90.7% respectively. otherwise, the lowest adsorption efficiency was documented in case of pb that was about 2.5 ppm after treatment (Table 2) with pH 5.4 and contact time 0.94 hr. and for Co was 0. 5 ppm at pH 7.5 and contact time 0.94 hr., while was 1.4 ppm for Cd ions at pH 5.4 and 8 with contact time 0.94 hr. also. Moreover, the removal efficiency for these same values were 50%, 37. 50% and 56.6% respectively. The pH of the adsorption system is an important controlling parameter in toxic elements adsorption protocol (5). This parameter is specifically related to the rivalry of hydrogen ions with metal ions at active sites on the adsorbent surface [16]. Generally, optimum pH for heavy metals adsorption " between 5 and 6 in case of using plant wastes" and plant products (25). as such these adsorbents were created to be different in the adsorption of heavy metal ions such as pb ions, Co ions and Cd ions that gave highest efficiency of heavy metals removal was found in the case of Cd ions, while the lowest in case of Co ions (Tables 2).

Table 2. Removal efficiency of carbonized gum adsorbent for heavy metals removal in industrial wastewater

Exp.No.	Variables		Concentration(ppm)			Concentration (%)		
	pH	T(hr)	Pb (5 ppm)	Co (0.8 ppm)	Cd (1.5 ppm)	Pb	Co	Cd
1.	5.439	0.946	2.5	0.3	1.4	50	62.5	56.6
2.	5.439	4.304	1.7	0.25	0.17	66	68.75	88.7
3.	7.561	4.304	1.2	0.4	0.15	76	50	90
4.	7.561	0.946	1.2	0.5	0.19	76	37.5	87.4
5.	5	2.625	1.8	0.4	0.14	64	50	90.7
6.	8	2.625	1.2	0.3	0.14	76	62.9	90.7
7.	6.5	0.25	1	0.4	0.16	80	50	89.4
8.	6.5	5	2	0.3	0.15	60	62.5	90
9.	6.5	2.625	2	0.3	0.15	60	62.5	90
10.	6.5	2.625	2	0.3	0.15	60	62.5	90
11.	6.5	2.625	2	0.3	0.15	60	62.5	90
12.	6.5	2.625	2	0.3	0.15	60	62.5	90
13.	6.5	2.625	2	0.3	0.15	60	62.5	90

In this study, Anova test was used to detect the critical effects of parameters on the adsorption process and heavy metals removal. The significance value in all ANOVA statistical analyses is $p \leq 0.05$, implying that the measure is statistically meaningful (21). as shown in (Table 3), F-value was 66.353 and *p*- value was 0.000 at the level of probability ($p \leq 0.05$). These data indicate to exist a significant effect of pH values and contact times on adsorption process and removing of heavy metals. Also, these data refers to exist significant differences among heavy metals removal depending on type of metal.

Table 3. ANOVA statistical tests for removing of heavy metals from industrial wastewater

Heavy metal	Mean	Standard Deviation	F-value	P-value
Pb	1.62222	0.50194	66.353	0.000
Co	0.35	0.07905		
Cd	0.15444	0.01666		

P≤0.05

On the other hand, Table (4) shows Physiochemical values of industrial waste water after treatment by carbonized Arabic gum. All values variables (pH, E.C. and T.D.S.) were reduced to the lowest values that were 7.8, 1100 and 554 for pH, E.C. and T.D.S. respectively. These values were chosen based on the best values in table 2 and 3 at pH value 8 and contact time 2.62 hr.

Table 4. Physiochemical values of industrial waste water after treatment

Physical and chemical measurements	Unit	Physical and chemical properties before treatment
PH	---	7.8
E.C.	µS/cm	1100
T.D.S	mg/L	554

Removing of heavy metals from standard solutions by carbonized Arabic gum

The results of removing process by carbonized gum showed higher removal for heavy metals of standard solutions at pH 6.5 and contact time 0.25 hr. for pb that was 8.75 ppm after treatment, and for Co was 14.3 ppm at pH 5.4 and contact time 4.30 hr., while was 4.5 ppm for Cd ions at pH 5 and 8 with contact time 2.62 hr. (table 5). In same time, the removal efficiency giving ion concentrations at 8.75 ppm, 14.3 ppm and 4.5 ppm were 82.5%, 71.4% and 91% respectively (Table 5). On the other vein, the lowest adsorption efficiency was registered in case of pb that was about 22.5 ppm after treatment (Table 5) with pH 5.4 and contact time 0.94 hr. and for Co was 26. 5 ppm at pH 7.5 and contact time 0.94 hr., while was 6.25 ppm for Cd ions at pH 7.5 and contact time 0.94 hr. Moreover, the removal efficiency for these same values were 55%, 47% and 87.8% respectively. The pH of the adsorption process is a key controlling parameter in toxic metals adsorption (5). This parameter is immediately linked to the rivalry of hydrogen ions with metal ions at sensitive sites on the adsorbent surface (16). Furthermore, one of the most critical parameters for successful adsorption application is contact time. Conclude, there have been three critical rate steps in the adsorption of materials from solution by plant wastes in a given contact time. The very first step is transport of the adsorbate through such a surface layer to the exterior of the adsorbent (film diffusion); the step two is diffusion of the adsorbate inside the pores of the adsorbent (pore diffusion); and the final step is adsorption of solute on the internal surfaces bounding pore and capillary spaces. Transport of the adsorbate through the surface layer or boundary layer is rate-limiting for most Operational conditions, but if enough turbulence is given, transport of the adsorbate even within porous adsorbents will regulate the rate of uptake (15). The contact time expected by all types of adsorbents for me, according to (13).

Table 5. Removal efficiency of carbonized gum adsorbent for heavy metals removal in industrial wastewater

Exp.No.	Variables		Concentration (ppm)			Concentration (%)		
	pH	T(hr)	Pb (5 ppm)	Co (0.8 ppm)	Cd (1.5 ppm)	Pb	Co	Cd
1	5.439	0.946	22.5	17.8	4.6	55	64.4	90.8
2	5.439	4.304	12.5	14.8	5.5	75	71.4	98
3	7.561	4.304	11.25	21.5	5	77.5	57	90
4	7.561	0.946	11.25	26.5	6.25	70	47	87.5
5	5	2.625	15	21	4.5	77.5	58	91
6	8	2.625	11.25	17.8	4.5	82.5	64.4	91
7	6.5	0.25	8.75	21	5.3	62.5	58	89.4
8	6.5	5	18.75	16	5	62.5	68	90
9	6.5	2.625	18.75	16	5	62.5	68	90
10	6.5	2.625	18.75	16	5	62.5	68	90
11	6.5	2.625	18.75	16	5	62.5	68	90
12	6.5	2.625	18.75	16	5	62.5	68	90
13	6.5	2.625	18.75	16	5	62.5	68	90

Additionally, according to (Table 6), F-value was 38.69 and P- value was 0.000 at the level of probability ($p \leq 0.05$). These data indicate to exist a significant effect of pH values and contact times on adsorption process and removing of heavy metals. Also, these data refer to exist significant differences among heavy metals removal depending on type of metal. Furthermore, a nova test showed significant differences between treatment of industrial waste water and aqueous standard solutions by carbonized gum at the level of probability ($p \leq 0.05$) where the F- value was 20.13 and P- value was 0.000, and found that the removal efficiency and adsorption process are enhanced when heavy metal concentration was increased up to certain values in the solutions. Therefore, the removal efficiency of carbonized gum towards aqueous standard solutions was better than towards industrial waste water, this difference belongs to the heavy metal concentration (9, 17) explained that increasing ~~of~~ metal concentration caused a clear enhancement in the reaction extent of heavy metals adsorption from aqueous solution (Figure 4).

Table 6. ANOVA statistical tests for removing of heavy metals from standard solutions

Heavy metal	Mean	Standard Deviation	F-value	P-value
Pb	14.4	4.59	38.690	0.000
Co	19.1	3.76		
Cd	5.07	0.56		

$P \leq 0.05$

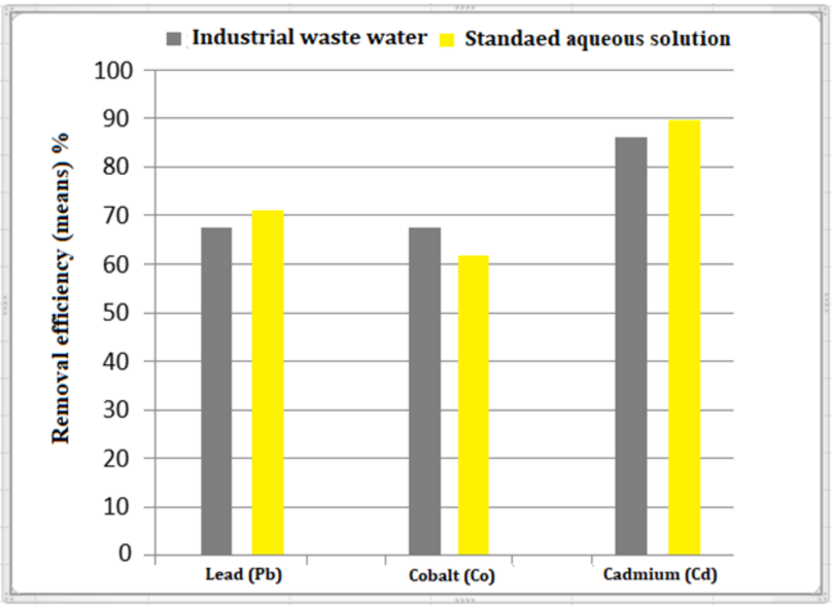

Figure 4. Comparison between the removal efficiency of carbonized gum towards industrial waste water and standard aqueous solutions

We conclude from the results of present study, all "Chemical and physical" values "of industrial waste" water before treating by carbonized Arabic gum such as: pH value, TDS, E.C and heavy metals (pb, Co and Cd) had a higher value than what is permissible internationally and locally. Carbonized Arabic gum (charcoal gum) has a high removal efficiency and adsorption activity for removing and reducing the pollutants from industrial waste water and aqueous standard solutions. In same time, removal efficiency of carbonized Arabic gum showed significant differences and significant effect in removing and adsorption process of heavy metals. Therefore, carbonized Arabic gum could consider successful and suitable natural adsorbent from plant source for waste water treatment.

REFERENCES

1. Al-Pachachi, U. S. 2006. Bioremoval of Zinc by Cell Wall of Bacteria *Bacillus Subtilis*. M.Sc. Thesis. College of Science, Baghdad University, Iraq

2. American Protection Health Agency (APHA). 2005. Standard Methods for Examination of Water and Wastewater. 2[st]. Washington. USA

3. Arivoli, S.; V.Nandhakumar, S. Saravanan, and S. Najarajan, 2009. Adsorption dynamics of copper ion by low cost activated carbon. The Arabian J. Sci. Eng. 34 (1A).

4. Anji, Reddy Mareddy. 2018. Environmental Impact Assessment: Theory and Practice. Elsevier Inc. All rights reserved. Butterworth - Heinemann. Book. pp: 421-490

5. Barrera. H, F. Uren˜a-Nu´n˜ ez, B. Bilyeu, and C. Barrera-Dı´az, 2006. Removal of Chromium and Toxic Ions Presents in Mine Drainage by Ectodermis of Opuntia. J.of Hazard. Mater. 136, pp: 846-853

6. Cobbette, C. S. 2000. Phytochelatins and their roles in heavy metal detoxification. Plant Physiology. 123: 825-832

7. Deans, J. R. and B. G. Dixon, 1992.Uptake of Pb+2 and Cut 2 by novel biopolymers. Water Research. 26 (4): 469-472

8. Demirbas, A. 2008. Heavy metal adsorption onto agro based waste materials: A rev. J. Hazard. Mater. 157: 220-229

9. Dongxiao. Ouyang, Zhuo Yuting, Hu. Liang, Zeng. Qiang, Hu. Yuehua, and He. Zhiguo, 2019. Research on the adsorption behavior of heavy metal ions by porous material prepared with silicate tailings. Minerals Journal. 9, 291.5-16

10. Ezgi, Oktav Akdemir. 2018. Application of Box Wilson experimental design method for removal of acid red 95 using ultrafiltration membrane. Membrane Water Treatment. 9(5):309-315

11. Fahad, H. G. 1994. A study of Efficiency of Different Microorganisms in Thorium Sorption from Aqueous Solutions.M.Sc. Thesis. College of Science, Baghdad University, lraq

12. Rashid and et al., 2019. Study of toxic heavy metal removal by different chitosan/hyacinths plant composite. Iraqi Journal of Agricultural Sciences, 50(5). https://doi.org/10.36103/ijas.v50i5.809

13. Husoon, Z. A. 2011. Biotreatment of Lead and Copper in Battery Factory Wastewater. Ph.D Dissertation, College of Science, University of Baghdad, Iraq

14. Jorge, Bedia; Peñas-Garzón. Manuel, Gómez-Avilés. Almudena, Juan, J. Rodriguez and Belver. Carolina, 2018. A review on the synthesis and characterization of biomass-derived carbons for adsorption of emerging contaminants from Water. Journal of carbon research, 4(1):63. 7-12

15. Kurniawan, T. A., G. Y. S. W. Chan, H. Lo and S. Babel, 2003. Comparisons of low-cost adsorbents for treating wastewaters laden with heavy metals, Journal Science of the Total Environment, 366. 409– 426. 34

16. Lodeiro, P.; B. Cordero, J.L. Barriada, and R. Herrero, 2006. de Vicente MES. biosorption of cadmium by biomass of brown marine macroalgae. J. of Bioresour Technol.;96,pp:1796–803.

17. Magdalena, Wołowiec : Komorowska-Kaufman Małgorzat,a and Alina Pruss. 2019. Removal of heavy metals and metalloids from water using drinking water treatment residuals as adsorbents: A Review. Minerals Journal., 9, 487. 7-17

18. Sultan, M.S and et al., 2018. Determination of some heavy metals in solid waste from heavy water treatment station in Baghdad. Iraqi Journal of Agricultural Sciences,49(3). https://doi.org/10.36103/ijas.v49i3.122

19._Nisreen J., N., and M. Sirhan, 2021. Comparative study of removal pollutants (heavy metals) by agricultural wastes and other chemical from the aqueous solutions. Iraqi Journal of Agricultural Sciences, 52(2), 392-402. https://doi.org/10.36103/ijas.v52i2.1300

20. Ofomaja, A.E. and Y. Ho, 2007. Effect of pH on cadmium biosorption by coconut copera meal.Journal of Hazardous Material. 139: 356-362

21 .Okoro, I.A.and S.O. Okoro, 2011. Agricultural byproducts as green chemistry absorbents for the removal and recovery of metal ions from wastewater environment. Continental J. Water Air Soil Pollut. 2, 15–22

22. Prescott M, JP. Harley and Klein DA 1996. Microbiology 3rd ed, wMC Brow Publishers, New York, pp: 935

23 Rosangela, A. J.; C. L. Eder, L. P. D. Silvio, C. M Ana, and A. P. Flavio, 2007. Short communication yellow passion-fruit shell as biosorbent to remove Cr and Pb (II) from aqueous solution. Sep. Purif. Technol. 57: 193-198

24 .Runnells, D. D. and T. A. Shepherd, 1992. Metal in water: Determining natural background concentration in mineralized areas. Environ. Sci. Technol. 26: 2316-2323

25. Saikaew, W.; P. Kaewsarn, and W. Saikaew, 2009. Pomelo Peel: Agricultural Waste for Biosorption of Cadmium Ions from Aqueous Solutions. World Academy of Science, Engineering and Technology, 56, pp: 287-291.