Pomegranate Peels as Biosorbent Material to Remove Heavy Metal Ions from Industerial Wastewater

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Abstract

Pomegranate peels were used to remove zinc, chromium and nickel from industrial wastewater. Three forms of these peels (fresh, dried small pieces and powder) were tested under some environmental factors such as pH, temperature and contact time.

The obtained results showed that these peels are capable of removing zinc, chromium and nickel ions at significant capacities. The powder of the peels had the highest capability in bioremoving all zinc, chromium and nickel ions while dried peels had the lowest capacity again for all metals under test. However, the highest capacities were found in a sequence of chromium, nickel and zinc. Furthermore, all these data were significantly ($LSD_{\text{peel forms}}$ = 2.761 mg/l, $LSD_{\text{metal ions}}$ = 1.756 mg/l) varied.

In case of chromium, these figures were 69.7 ± 0.9 mg/l, 58.0 ± 2.4 mg/l and 49.7 ± 0.5 mg/l for powder, fresh and dried peels respectively. Regarding nickel ions, the data were 58.7 ± 1.1 mg/l for peel powder, 50.7 ± 2.0 mg/l for fresh peel and 42.0 ± 1.2 mg/l for dry peel. While for zinc ions, the biosorption capacity was 48.4 ± 2.2 mg/l, 39.4 ± 0.8 mg/l and 32.0 ± 1.6 mg/l for powder, fresh and dry peels respectively.

However, some examined factors were found to have significant impacts upon bioremoval capacity of pomegranate peels such as pH, temperature, and contact time where best biosorption capacities were found at pH 4, with temperature 50 Cº and contact time of 1 hour.

Regarding pH, the highest bioremoval ability was found at pH 4 for all heavy metals, but with the sequence of Cr, Ni, and Zn and the data were 68.1 ± 1.5 mg/l, 56.0 ± 0.5 mg/l and 47.88 ± 1.21 mg/l respectively. Similar pattern of bioremoval capacity was detected for temperature which was 50 Cº giving capacities of 72.0 ± 0.0 mg Cr/l, 60.0 ± 1.84 mg Ni/l and 54.0 ± 1.72 mg Zn/l. In case of contact time, these capacities were again similar to those of pH and temperature and found to be 76.0 ± 3.0 mg/l , 64.0 ± 1.82 mg/l and 60.0 ± 2.0 mg/l for Cr, Ni, and Zn respectively but at 1 hour contact time.

Keywords: pomegranate peels, biosorption, zinc, chromium, nickel, industrial wastewater

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استخدام قشور الرمان كمواد مازة لإزالة أيونات العناصر الثقيلة من مياه الفضلة الصناعية

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الخلاصة:

لقد استخدمت قشور الرمان في إزالة ايونات عناصر الخارصين ، الكروم و النيكل من مياه الفضلة الصناعية واختبرت ثلاث إشكال (القشور الطرية ، الجافة ، مسحوق القشور) تحت ظروف بعض العوامل مثل الدالة الحامضية ، درجة الحرارة و زمن التلامس.

تشير النتائج الى قدرة قشور الرمان على امتزاز ايونات هذه العناصر من مياه الفضلة الصناعية عند مستويات معنوية وان أفضل قدرة وجدت في حالة مسحوق القشور ثم القشور الطرية بينما كانت القشور الجافة اقل كفاءة. من جهة ثانية ، وجد أن أعلى التراكيز كانت لايون الكروم ثم النيكل و الخارصين. أن الفرق بين تراكيز العناصر الممتزة كانت واضحة ومعنوية بدلالة الفرق المعنوي الأصغر سواءً لأشكال القشور أو العناصر الممتزة (ف م أ للقشور= 2.761 ملغم/ لتر وللعناصر = 1.756 ملغم / لتر).

في حالة ايونات الكروم كانت قيم الامتزاز 69.7 ± 0.9 ملغم/ لتر ، 58.0 ± 2.4 ملغم / لتر لمسحوق القشور ، القشور الطرية و الجافة على التوالي. لايونات النيكل ، فان هذه القيم كانت 58.7 ± 1.1 ملغم / لتر لمسحوق القشور ، 50.7 ± 2.0 ملغم/ لتر للقشور الطرية و 42.0 ± 1.2 ملغم / لتر للجافة. في حالة عنصر الخارصين كانت قيم الامتزاز 48.4 ± 2.2 ، 39.4 ± 0.8 و 32.0 ± 1.6 ملغم / لتر للمسحوق والقشور الطرية و الجافة على التوالي.

بالمقابل ، فان بعض العوامل التي تم تقييم تأثيراتها وجدت ذات تأثيرات معنوية على قابلية هذه المازات على امتزاز ايونات العناصر الثقيلة تحت الدراسة وفي ذات الوقت وجدت أن أفضل قيمة دالة حامضية كانت 4 وأفضل درجة حرارة هي 50 م ° وزمن تلامس لمدة ساعة واحدة فقط حيث سجلت قدرة امتزاز بلغت 68.1 ± 1.5 ملغم/ لتر لايون الكروم و 56.0 ± 0.5 ملغم / لتر لايون النيكل عند درجة حامضية 4 وذات الترتيب من طاقة الامتزاز سجلت عند درجة حرارة 50 م ° حيث كانت 72.0 ± 0.0 ملغم كروم/ لتر ، 60.0 ± 1.84 ملغم نيكل / لتر و 54.0 ± 1.72 ملغم خارصين / لتر . كذلك الحال لزمن التلامس حيث وجدت طاقة امتزاز 76.0 ± 30 ، 64.0 ± 1.82 و 60.0 ± 2.0 ملغم / لتر للكروم ، النيكل و الخارصين على التوالي.

كلمات مفتاحية: قشور الرمان، الامتزاز، الزنك، الكروم، النيكل، مياه الفضلة الصناعية.

1. Introduction

Plant material wastes and peels have been used intensively in bioremoving various heavy metal ions from industrial wastewater [1-3] . However, industrial waste-water may vary significantly according to type of products and kind of processing and the environmental effects of such industrial discharges would not rely only on collective characteristics such as BOD and total suspended solids (TSS), but also on their content of specific inorganic and organic substances [4,5].

The contamination of water by various heavy metal ions would result in considerable environmental problems as these ions being contain toxic impacts upon both public health and environment. The main sources of such water contamination with different heavy metals are industrial waste water [4].

However, decontamination of heavy metal ions of industrial waste water was received considerable attention by using various techniques such as activated carbon adsorption [1], chemical precipitation [6], reverse osmosis [7] , electro-dialysis [8] and ion exchange [9].
Recently much attention has been spent on successfully using biological materials and wastes for the removal of heavy metals from

industrial waste water such as microbial biomass [10-13] and biological wastes [14-17]. These biosorbent materials are characterized being less expensive, high bio-removal capacity, metal selective, non sludge generation, possible ion recovery [2,18] and environmentally sound methodology [19].

The technique of plant residues heavy metal ions adsorption was world widely used for waste water treatment [20] such as peat and nut shells, coconut shells, rice husk, tea waste, peanut hulls, almond shells, peach stones, citrus peels, and many others [14-17,21].

It is well known that these biosorbent materials contain mainly polysaccharides, proteins, and lipids, functional groups that act to bind metal ions such as carboxyl, hydroxyl, sulphate, phosphate, and amino groups [22]. Any given group of biosorption of a specific ions would depend upon several variables such as the accessibility of sites, a number of sites of biosorbent material, the chemical state of the site (availability) and affinity between site and metal [18] .

2. Material and Methods

Samples of industrial wastewater were collected, at a volume of 500 ml wastewater samples collected in plastic containers at three random periods between 8th to 29th June 2011, from both pretreatment units of electroplating section in the State Electrical Manufacturing Company in Al-Waziriya area / Iraq-Baghdad. Each sample was divided into two sub-samples, the first had been subjected to chemical & physical analysis while the second was used for bioremoval test of zinc, chromium and nickel ions.

3. Biosorption capacity of Pomegranate peels

3.1. Chemical analysis of industrial wastewater

Samples of industrial wastewater were collected, 4 times at weekly rate, form pretreatment tank from State Electrical Manufacturing Company. Some factors such as pH and temperature were recorded *in situ* while the others such as heavy metal content were laboratory assessed.

3.2. Metal biosorption tests

Pomegranate peels were collected from different local markets, washed thoroughly by de-ionized distilled water (DDW) and used subsequently in the following examinations:

3.2.1. Various pomegranate peel forms

Three forms of pomegranate peels were used. The first form represents fresh pieces, the second was as dried pieces and finely these dried peels were powdered and sieved through 2mm stainless steel sieve. These peel forms, however were tested for the bioremoval of zinc, chromium and nickel ions from aqueous synthetic solutions under various factors such as pH, temperature, and contacting time.

The examining Synthetic aqueous metal solution was prepared by taking 20 ml of metal solution (100 mg/l) of zinc, chromium or nickel ions and placed into 50 ml volumetric flasks and pH was adjusted to 5. These heavy metal solutions were received about 0.05 g pomegranate peels as fresh, dried and powder. This experiment was carried out in three replicated test in addition of control (metal ion solution free from peels). All samples were left for almost one hour at 40 C°. Each sample after that, was passed through 0.45μm filter paper [23] and metal ion concentration was determined by using Flame Atomic Absorption Spectroscopy (FAAS) [24].

3.2.2. Factors controlling metal bioremoval

The experiment carried above, was retested for the examination of probable impacts of different levels of pH, and temperature. The ranges of 1 to 6 and from 10 to 60 were applied for pH and temperature (C°) respectively for all examined heavy metals.

4. Results and Discussion

All obtained data were subjected to various biometrical analysis such as analysis of variance with least significant difference.

Chemical analysis of industrial wastewater

The mean values of temperature, pH, Zn, Cr, and Ni of industrial wastewater are shown in (table 1). The temperature values were ranged from 31.0±0.0 of 1st week sample (8/6/2011) to 31.76±0.05 C° of 4th week sample (29/6/2011). For pH data, the highest value (7.67±0.094) was found in water sample of 3rd week (22/6/2011) while the lowest value (7.17±0.047) was recorded in sample of 4th week. Regarding heavy metals content, the highest content was found in case of zinc ion that lied from 418.7±0.942 mg/l in sample of 4th week to 612.0±2.16 mg/l in 1st week sample, followed by chromium ion content which was almost similar levels ranging from 44.0±0.0 mg/l (4th week sample) to 49.33±0.942 mg/l (2nd week sample). In case of nickel ions, again recorded values were almost similar to each other and varied from 8.06±0.055 mg/l (4th week sample) to 12.0±0.0 mg/l (1st week sample).

Table 1- Mean value ± standard deviation of several water variables

Variables	Mean value ± SD of some industrial wastewater components			
	1st week 8/6/2011	2nd week 15/6/2011	3rd week 22/6/2011	4th week 29/6/2011
Temp. C°	31.0±0.0	31.13±0.05	31.33±0.12	31.76±0.05
pH	7.33±0.05	7.37±0.09	7.67±0.094	7.17±0.047
Zn (mg/l)	612.0±2.16	524.7±2.494	418.7±0.942	535.3±1.7
Cr (mg/l)	46.67±1.89	49.33±0.942	45.67±1.247	44.0±0.0
Ni (mg/l)	12.0±0.0	8.96±0.073	9.0±0.0	8.06±0.055

Biosorption capacity of pomegranate peels

Various peel forms

Mean bioremoval capacities of pomegranate peels examined at different forms is given in table 2 and presented in Fig. (1).

It seems clearly that pomegranate peel forms had significant ability for bio-removing heavy metals ions from aqueous heavy metal solutions. However, the form of powdered peels gave values of bioremoved heavy metal concentrations higher than those of both fresh and dried peel pieces (LSD = 2.761) for all examined heavy metals. Furthermore, highest metal concentration (69.7 ± 0.9 mg/l) was recorded in case of chromium, followed by nickel (58.7 ± 1.1 mg/l), while the lowest metal concentration (48.4 ± 2.2 mg/l) was found in case of zinc (Fig .1). In case of fresh and dried peels, similar sequences were shown. These values of biosorbed heavy metal ion concentrations were significantly differed from each other (LSD = 1.756 mg/l).

Table 2- Mean zinc, chromium and nickel concentrations (mg/l) biosorbed by various pomegranate peel forms

Pomegranate peel form	Mean metal biosorbed concentration (mg/l) ±SD		
	Zinc	Chromium	Nickel
Peel dried pieces	32.0 ± 1.6	49.7 ± 0.5	42.0 ± 1.2
Peel fresh pieces	39.4 ±0.8	58.0 ± 2.4	50.7 ± 2.0
Peel Powder	48.4 ± 2.2	69.7 ± 0.9	58.7 ± 1.1

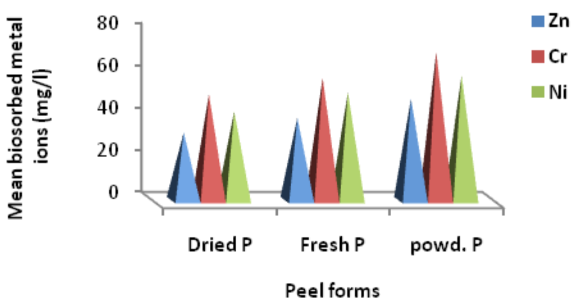

Figure 1- Mean metal ions (mg/l) biosorbed by different pomegranate peel forms

Highest capacity of pomegranate peels may be due to the surface area of peel particles [18] and other environmental factors such as pH and temperature that may affect the biosorption mechanism.

Factors affecting biosorption

pH

It is well shown that increased pH values (Table 3) had significant effects ($P \geq 0.001$) upon biosorbed metal ions of all heavy metals under test. Also, these heavy metals had varied significantly (Table 4) from each other, but highest biosorption concentrations were recorded for Cr ion, followed by Ni ions while the Zn ions had the lowest bioremoved concentrations (Fig 2). However, it seems obviously that pH 4 was the best value for giving optimum bioremoval capacity for all heavy metals under test (Fig 2).

Table 3- Mean metal concentration (mg/l) of zinc, chromium and nickel biosorbed by pomegranate peels at different pH levels

pH level	Mean metal biosorbed concentration (mg/l) ±SD		
	Zinc	**Chromium**	**Nickel**
1	28.0 ± 1.22	26.7 ± 2.29	41.0 ± 0.0
2	31.3 ± 1.25	33.0 ± 1.63	44.0 ± 1.04
3	46.04 ± 1.07	39.6 ± 1.01	53.55 ± 1.74
4	47.88 ± 1.21	68.1 ± 1.5	56.0 ± 0.5
5	43.0 ± 1.44	51.0 ± 0.79	51.8 ± 1.82
6	40.0 ± 0.0	49.0 ± 2.0	49.9 ± 1.35
LSD	3.344 mg/l		

Various studies have examined the possible impact of pH upon heavy metal biosorption of different biosorbent materials and reported similar findings. Recent study [25] showed that highest lead bioremoved by okra wastes were achieved at pH range of 4.5 – 5.5. Cd ions bioremoved by corn, durian, pummel and banana was found to be high at pH 5 [26]. Optimum pH value for copper biosorption by marine algae was within a range of 4 – 6 [27]. A study [28] had shown that highest lead bioremoved by maize leaf occurred at pH 3 .

Table 4- Analysis of variance of mean Zn, Cr, and Ni concentration biosorbed by pomegranate peels at six pH levels

Source of variance	df	SS	MS	Probability
Replications	2	0.744	0.372	N.S.
Treatment	17	5618.63	330.508	0.001
Metal (M)	2	930.97	465.485	
pH (P)	5	3734.86	813.074	
M X P	10	952.8	95.28	
Error	34	382.923	11.262	
Total	53			

The pH of aqueous solution plays a significant role in the biosorption process [29]. This is partially due to the fact that H^+ ions are strongly competing adsorbents. The pH affects the specification of metal ions and the ionization of surface functional groups [30].

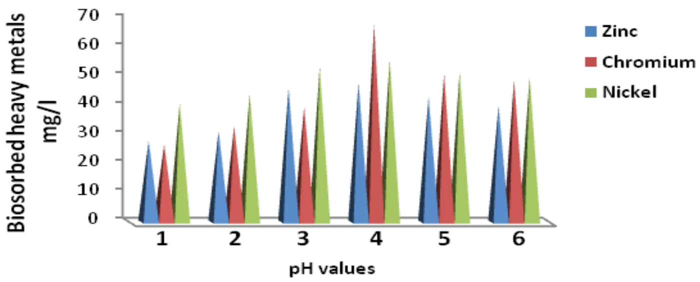

Figure 2- Mean absorbed metal concentration (mg/l) by pomegranate peels form solution of zinc, chromium and nickel different levels of solution pH.

Temperature

Table (5) shows mean biosorbed metal concentration (mg/l) by pomegranate peels from solution of zinc, chromium and nickel at different temperatures. Apparently, increased temperature had significant impacts on bioremoved metal ions (LSD = 3.003 mg/l) of these heavy metals resulting in increased biosorption capacity but up to 50

Table 5- Mean biosorbed metal concentration (mg/l) by pomegranate peels from solution of zinc, chromium and nickel at different temperatures

Temperature C°	**Mean metal biosorbed concentration (mg/l) ±SD**		
	Zinc	Chromium	Nickel
10	26.0 ± 1.02	22.0 ± 1.6	19.0 ± 1.45
20	34.0 ± 1.33	34.0 ± 1.44	27.0 ± 1.05
30	43.0 ± 1.5	61.0 ± 2.0	40.0 ± 1.12
40	51.0 ± 0.98	71.0 ± 1.26	58.0 ± 1.52
50	54.0 ± 1.72	72.0 ± 0.0	60.0 ± 1.84
60	50.0 ± 0.0	68.0 ± 1.2	57.0 ± 1.31

The highest capacities were found in case of chromium that ranged from 22.0 ± 1.6 mg/l to 72.0 ± 0.0 mg/l, and varied from 19.0 ± 1.45 mg/l to 60.0 ± 1.84mg/l and from 26.0 ± 1.02 mg/l to 54.0 ± 1.72 mg/l for Ni and Zn respectively (Fig 3).

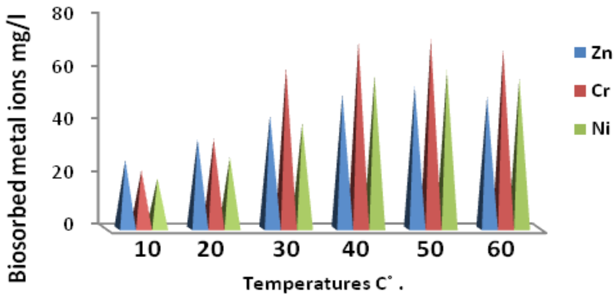

Figure 3- Mean metal ions (mg/l) biosorbed by pomegranate peels at different temperatures.

Analysis of variance (Table 6) shows significant differences (P ≥ 0.001) firstly between increased temperatures and secondly between heavy metal ions biosorbed by pomegranate peels

Table 6- Analysis of variance of mean Zn, Cr, and Ni concentration biosorbed by pomegranate peels at six temperature values

Source of variance	**df**	**SS**	**MS**	**Probability**
Replications	2	9.13	4.565	N.S.
Treatment	17	1714724.0	866.118	0.001
Metal (M)	2	1521.0	760.5	
Temp (T)	5	12226.0	2445.2	
M X T	10	977.0	97.70	
Error	34	102.87	3.026	
Total	53			

The current results are similar to those of various studies that examined different biological materials [2,16, 31]. Recent study [24] has reported that highest Cr bioremoved by tassel powder was at 45 C° while for Cd bioremoval, it was 25 C°. These contracting values may be related to several variables such as biosorbent species, quantity, and other environmental factors.

However, the adsorbed species might have enough energy from temperature of the system and subsequently be desorbed at even a faster rate than adsorption rate, or may be due to linkage of cells in both higher and lower temperature extremes which may reduce the availability surface area of contact [31].

Contact time

The impacts of various contact times upon all Zn, Cr, and Ni bioremoved by pomegranate peels (Table 7) are quite obvious but nevertheless, one hour contact time seems to be optimum in case of all heavy metal examined in this study. However, highest capacities (20.0 ± 1.3 mg/l to 76.0 ± 3.0 mg/l) were recorded for Cr biosorption, followed by those (10.0 ± 1.88 mg/l to 64.0 ± 1.82 mg/l) of Ni and (12.0 ± 1.34 mg/l to 60.0 ± 2.0 mg/l) Zn (Fig 4).

Table 7- Mean biosorbed metal concentration (mg/l) by pomegranate peels from solution of zinc, chromium and nickel at different contact time

Contact Time	**Mean metal biosorbed concentration (mg/l) ±SD**		
	Zinc	Chromium	Nickel
1 min.	12.0 ± 1.34	20.0 ± 1.3	10.0 ± 1.88
15 min.	28.0 ± 3.0	31.0 ± 1.8	21.0 ± 1.68
30 min.	40.0 ± 2.0	49.0 ± 1.71	31.0 ± 2.0
1 hour	60.0 ± 2.0	76.0 ± 3.0	64.0 ± 1.82
2 hour	60.0 ± 4.0	74.0 ± 1.44	64.0 ± 2.0
24 hour	57.0 ± 1.5	71.0 ± 2.0	62.0 ± 3.0
48 hour	56.0 ± 1.8	71.0 ± 1.64	60.0 ± 2.64
LSD	2.854 mg/l		

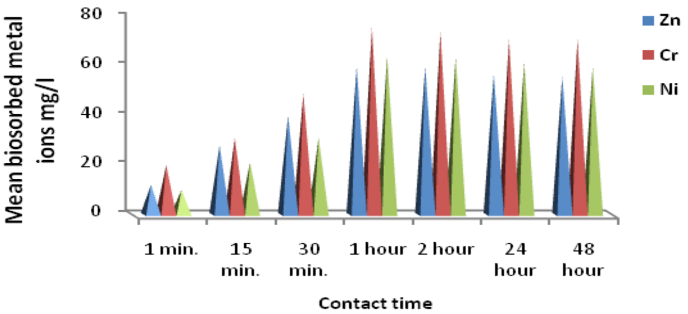

Figure 4- Mean metal ions biosorbed by pomegranate peels at different contact time.

The analysis of variance of contact time effects shows significant differences (P ≥ 0.001) between firstly increased times and secondly between heavy metals biosorbed by pomegranate peels (Table 8).

Table 8- Analysis of variance of mean Zn, Cr, and Ni concentration biosorbed by pomegranate peels with different contact time

Source of variance	**df**	**SS**	**MS**	**Probability**
Replications	2	18.052	9.026	N.S.
Treatment	20	27381.71	1369.086	0.001
Metal (M)	2	1783.139	819.5695	
C. time (T)	6	25191.71	498.618	
M X I	12	406.861	33.905	
Error	40	131.948	3.299	
Total	62			

The obtained results are agreed with other studies [18,32,33,34]. However other work [35], has reported that required contact time for best copper bioremoved by orange peels was less than one hour (40 minutes).

From the current work, it seems clearly that the ability of pomegranate peels was significantly effective for the removal of Cr, Ni, and Zn ions from industrial wastewater as it had been reported for various biosorbent plant materials [3,18,30,36,37] and would successfully be applied for various heavy metals from industrial wastewater since it seems environmentally safe

References:

1. Kobya, M.; Demirbas, E.; Senturk, F. and Ince, M. **2005.** Adsorption of heavy metal ions from aqueous solution by activated carbon prepared from apricot. Bio-resource. *Technol.*, 96, pp: 1512-1518.
2. Reddad, Z.; Gerente, C.; Andres, Y. and Pierre, L.C. **2002.** Adsorption of several metal ions onto a low cost biosorbent: Kinetic and Equilibrium studies. *Environ. Sci. Technol.*, 36(9) , pp: 2067-2073.

3. Khan, N.A., Ibrahim, S. and Subramanian, P.**2004.** Elimination of heavy metals from wastewater using agricultural wastes as adsorbents. *Malaysian Journal of Sci*., 23, pp:43-51.
4. Richman, M.I. **1997.** Water pollution. *Wastewater*, 5(2), pp:24-29.
5. Volesky, B. **2001.** Detoxification of metal-bearing effluents: biosorption for the next century. *Hydrometallurgy*, 59, pp:203-216.
6. Ahalya, N.; Ramachandra, T.V. and Kanamadi, R.D. **2003.** Biosorption of heavy metals. *Res. Journal of Chem. Environ*. 7, pp: 71-79.
7. Volesky, B. **2003.** Sorption and biosorption. Sorbex. Inc. St. Lambert (Montreal) .Quebec, Canada.
8. Xia, Y and Liyuan, C. **2002.** Study of gelatinous supports for immobilizing inactivated cells of *Rhizopus oligosporus* to prepare biosorbent for lead ions. Internat. J*ournal of Environ. Studies*. 5(16) , pp: 33-38.
9. Rengaraj, S.; Kyeong-Ho, M. and Seung, H. **2001.** Removal of chromium from water and wastewater by ion-exchange resins. *Journal of Hazard. Mater*,87, pp:273-287.
10. Gadd, G.M. and White, C. **1993**. Microbial treatment of metal pollution working biotechnology, *Trends Bio technol. Journal* 11, pp:353-359.
11. Cho, D.H. and Kim, E.Y. **2003.** Characterization of Pb^{+2} biosorption from aqueous solution by *Rhodotorula glutinis* bioprocess. *Biosyst. Eng*. 25, pp: 271-277.
12. Vijayaraaghavan, K.J.; Jegan, K.P. and Velan, M. **2005.** Batch and column removal of copper from aqueous solution using a brown marine alga. *Journal of. Chem. Eng*. 106, pp:177-184.
13. Gadd, G.M. and White, C. **1993**. Microbial treatment of metal pollution- a working biotechnology, *Trends Bio technol. Journal of* 11, pp: 353-359.
14. Laszlo, J.A. and Dintzis, F.R. **1994.** Crop resides as ion exchange material. Treatment of soybean hull and sugar beet fiber (pulp) with epichlorochydrin to improve cation-exchange capacity and physical stability. *Journal of Appl. Polymer Sci*. 52(4), pp:531-538.
15. Montanher, S.F.; Oliveira, E.A. and Rollengerg, M.C. **2005.** Removal of metal ions from aqueous solution by sorption onto rice bran. *Journal of Hazard Mater*.117, pp:207-211.
16. Ahalya, N.; Ramachandra, T.V. and Kanamadi, R.D. **2005.** Biosorption of chromium (VI) from aqueous solution by the husk of Bengal gram (*Cicer arientinum*). *Elec. Journal of Bio technol*. 18 (3) , pp: 44-48.
17. Zafar, M.N.; Nadeem, R. and Hanif, M.A. **2007**. Biosorption of nickel from protonated rice bran. *Journal of Hazard Mater*. 143, pp: 478-485.
18. Husoon, Z. A**. 2011.** Biotreatment of some heavy metals in industrial wastewater. Ph.d. thesis, College of Science, University of Baghdad. Iraq.
19. Volesky, B. **2001.** Detoxification of metal-bearing effluents: biosorption for the next century. *Hydrometallurgy,* 59, pp: 203-216.
20. Aaron, W.T. **2001**. Water and human society. *J. Contemporary Water Research and Education*.118: (29).
21. Ahmed , L. A. A. **2010**. Removal of heavy metals from wastewater by Date Palm Tree Wastes. *Eng. Tech. Journal*, 28: (1).
22. Igwe, J. C. and Abia, A.A. **2003.** Maize cob and husk as adsorbents for removal of Cd, Pb, and Zn ions from wastewater. *The physical Sci*. 2, pp:83-94.
23. Ogali, R.E.; Onyewuchi, A. and Vivian , O. **2008.** Removal of some metal ions from aqueous solution using orange mesocarp. *African J. Biotechnol*. 7(17), pp:3073-3076.
24. Saikaew, W. and Kaewsarn, P. **2009.** Pomelo peel: Agricultural waste for biosorption of cadmium ions from aqueous solution. *World Academy of Sci. Eng. Technol*.56, pp:12-13.
25. Hashem, M. **2007.** Adsorption of lead from aqueous solution by okra wastes. *Int. Journal of Phys. Sci*, 2(7), pp:178-184.
26. Eslamzadeh, T.; Nasernejad, B. and Pour, B.B. **2004.** Removal of heavy metals from aqueous solution by carrot residues. *Iranian Journal of Sci. & Technol. Transaction*. 28(A), pp:16-19.
27. Yu, Q. and Kaewsarn, P. **2002.** Biosorption of copper (II) from aqueous solution by

pre-treated biomass of marine alga *Padina* sp. *Chemosp*., 47, pp:1081-1085.

28. Scheiwer, S. and Patil, S.B. **2008.** Pectin-rich fruit wastes as biosorbents for heavy metal removal: Equilibrium and Kinetics. *Bio. Res. Technol*.99, pp:1896-1903.

29. Vijayaraaghavan, K.J. and Yun, Y.S. **2008.** Bacterial biosorbents and biosorption. *Biotechnol. Adv*. 26, pp: 266-291.

30. Lu, D.; Cao, Q.; Li, X.; Cao, X.; Luo, F. and Shao, W. **2008.** Kinetics and equilibrium of cu (II) adsorption onto chemically modified orange peel cellulose biosorbents. *Hydrometallurgy*. 64, pp:1122-1127.

31. Ozkan, Y. **2003**. Determination of pomological characteristics of Niksar district pomegranate (*Punica granatum*) of the Tokat province. *Acta. Horticulture Journal,* 598, pp:199-203.

32. Cordo, B.; Loderio, P.; Herrero, R. and de Vicente, M.E.S. **2004.** Biosorption of cadmium by *Fucus spiralis*. *Environ. Chem*. 1, pp:180-187

33. Gil, M.; Tomas, F.; Hess, B.; Holcroft, D. and Kader, A. **2000**. Antitoxidant activity of pomegranate juice and its relationship with phenolic composition and processing. *Journal of Agriculture and Food Chemistry*, 48, pp:4581-4589.

34. Najim, T. and Yassin, S. **2009**. Removal of Cr (VI) from aqueous solution using modified pomegranate peel: Equilibrium and kinetic studies. *Electronic Journal of Chemistry*. 6 (S1), pp: S129-S142.

35. Habib, A.; Nazrul, I.; Anarul, I. and Shafiqul Alam, A. M. **2007**. Removal of copper from aqueous solution using orange peel, sawdust and bagasse. *Pak. Journal of Anal. Environ. Chem*.8 (1&2), pp:21-25.

36. Akbarpour, V.; Hemmati, K. and Sharifani, M. **2009**. Physical and chemical properties of pomegranate (*Punica granatum* L.) fruit in maturation stage. *American-Eurasian Journal of Agric & Environ. Sci*. 6 (4), pp:411-416.

37. El-Ashtoukhy, E.; Amin, N. K. and Abdelwahab, O. **2008**. Removal of lead (II) and copper (II) from aqueous solution using pomegranate peel as a new adsorbent. *Desalination*. 223, pp:162-173