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Research Article

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Use of Modified Fiber with Monomer 2-Hydroxy Propyl Methacrylate to Remove Lead Ions from Wastewater

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ABSTRACT

The present study aims to modify the adsorption properties of polyethylene terephthalate (PET) by grafting monomer 2-hydroxypropyl methacrylate for treatment of lead from wastewater. The produced copolymer was divided into three groups of 0 to 20, 20 to 40 and above 40% in terms of graft percentage. In order to achieve optimal conditions for adsorption, the best pH, the best contact time with absorbent (stylish time), the best absorbent to solution ratio, the best graft percentage and the best concentration of the solution for lead were respectively obtained as follows: 6, 30 minutes, 2.5 g / l, over 40% and 120 milligrams per liter. Using the obtained conditions at temperatures of 288, 298 and 313 degrees Kelvin, the most suitable isotherm for adsorption was determined from Langmuir, Freundlich, Temkin, Dubinin-Radushkevich equations. Data fitting with the adsorption isotherms of Langmuir and Freundlich showed the highest correlation. To examine the adsorption capacity of the filter prepared in natural conditions, the wastewater of Esfahan Steel Company was used after pH was adjusted and 50 mg /l of lead was added. 50% of the lead added to the wastewater was treated by filtering.

Keywords: *Lead, Polyethylene terephthalate, wastewater, Adsorption properties, Adsorption isotherm.*

INTRODUCTION

The water scarcity crisis is one of the challenges the world is facing now. According to the prediction of the International Water Management Institute for 2025, countries in North Africa and the Middle East, including Iran, Pakistan, India and the northern part of China are facing severe water shortage [1].

The use of wastewater as a supplier of inexpensive nutrients in agricultural lands has always been considered by researchers and experts in agriculture and environment [2]. However, in effluent from chemical plants of heavy metals, it is observed that copper, zinc, lead, chromium mercury and nickel are the most abundant heavy metals found in these wastewaters [3].

Due to carcinogenicity and mutation, cadmium and lead are of the most important heavy metals considered as serious threat for living organisms even in low concentrations for living organisms [4]. Lead enters into the human body and is absorbed in different ways, including adsorption by plants of soils contaminated with lead-containing wastewater, the use of urban and industrial effluent containing lead compounds in irrigation of farms, as well as absorption by parts of plants exposed to the air contaminated with lead particles [5,6]. Lead is stored in three parts of blood, soft tissues and bones, and even in low levels is very dangerous for children under six yearsold and pregnant women. Lead also causes reduction of IQ in children [7]. The lead absorbed in the nervous system and the kidneys produces a lot of poison [7,8]. Indication of acute and chronic poisoning, disruption of calcium and vitamin D metabolism and the incidence of cancers as well as anemia are important complications of lead-containing products [9]. Therefore, in order to prevent accumulation of heavy metals in soil and its entry into the food chain, the effluent must be refined before use.

Different methods have been used to remove heavy metals from industrial sewage. Adsorption is one of the most common methods for separating heavy ions from industrial sewage due to the efficiency and ease of use [10]. Ion adsorption on chelating solid polymeric materials is one of the adsorption-based treatment methods. Because of efficiency and ease of use, the sorption method is one of the most widely used methods [10]. Fibers are one of these synthetic adsorbents. Studies have shown that research on absorbent fibers of ionic compounds have begun since the 80's[11,12,13,14]. Various chemical substances have been produced and used to purify heavy metals. [13]have reported treatment of heavy metals containing effluent through the modification of polyacrylonitrile fibers structure by hydrazine and carboxylic agent groups. The maximum adsorbent capacity for absorbing copper, cadmium, zinc, cobalt, lead, chromium, nickel and mercury were respectively reported as 1.33, 1.30, 1.03, 1.2, 0.98, 0.96, 0.95 and 0.63 mg / g. [16] used a polyamidoamine grafted with 2- benzoyl thiourea to purify cobalt, copper, mercury, nickel, lead and zinc ions.[17] grafted a mixture of two monomers methyl methacrylate and acrylic acid with PET polymer and used it to remove cadmium. They recognized Freundlich adsorption isotherm as the best isotherm to absorb in order to explain the adsorption behavior of cadmium by the filters. [18] Studied the absorption properties of ions on modified acrylic acid-fibers by ethanolamine. They converted polyacrylonitrile (PAN) fibers to modified polyacrylonitrile mono ethanol amine (PAN-MEA) by reaction with ethanolamine. The modification of PAN fibers was carried out by adding nitrile groups to hydroxyl using ethanolamine solution with different concentrations at a temperature of 91 ° C. Then, the modified fibers were converted to PAN-MEA Micro Nano fiber, which was used as a chelating material in a series of absorption tests for the separation of copper, lead and nickel ions. The results showed that the strength of Nano-filter was more than that of the conventional fiber due to the increase of its specific surface area for the ions mentioned. [18] Used PET polymer modified with monomer 2-hydroxypropyl methacrylate to remove color. [21] Used the PET modified with acrylamide and acrylic acid mixture to absorb lead from natural environments as well as blood plasma. Abdel-Razik and Kenawy (2012) have used PET grafted with diaminomaleo di nitrile for wastewater treatment of heavy metals. They used the produced filter to absorb lead, cadmium, zinc, iron, copper, nickel, cobalt and mercury ions, and recognized it suitable for the purification of nickel, cobalt and zinc. [20] Used polyethylene terephthalate grafted with monomer 2-hydroxypropyl methacrylate for the treatment of cadmium.

Polyethylene terephthalate or PET is one of the most commonly used fibers used as a polymer base for the adsorption of heavy metals. In this research, the production of polymeric filter of polyethylene terephthalate grafted with monomer 2-hydroxypropylmethacrylate and its use in the treatment of lead from effluent was investigated in order to use the produced polymer to treat lead.

METHOD OF TESTING

In the present study, PET artificial fibers with a score of dtex=167 and filaments = 44 made in the Textile Faculty of Amir Kabir University of Technology were used as the base and in order to increase its cationic absorption capacity, monomer 2-hydroxypropyl methacrylate (with active agent of alcoholic OH of the second type) was grafted to it according to the method proposed by [21, 22].

The produced copolymer was classified and divided into three groups of 0-20%, 20 to 40%, and above 40% in grafting percentage as calculated by the following formula.

$$\text{Graft percentage} = \frac{\text{Secondary weight} - \text{Primary weight}}{\text{Primary weight}} \times 100$$

In order to equalize the ionic strength of the solution with natural sewage, all experiments were carried out in the solution of calcium chloride (0.01 molar). To begin the experiment, 0.05 grams of the fiber with the highest graft percentage were added to the Arlene containing 20 cubic centimeter of a lead solution (50 mg / l) from the source of lead nitrate and the mixture obtained at the temperature of 25 ± 2 ° and velocity of 150 rpm became stylish and step-by-step tests were done to determine the optimal absorption conditions. In order to compare the results and determine the best absorption conditions, the absorbed amount per unit weight of the adsorbent (q) was calculated according to the following formula.

$$q= (C_0-C)\times(V/m)$$

In the above formula, q represents the amount of metal adsorbed on the adsorbent in metal milligram in adsorbent gram, C0 and C, respectively, represent the concentration of metal in the solution before and after contact with the adsorbent in milligrams per liter, m represents the adsorbent weight in gram and V represents the volume of solution in liters.

Lead solutions of 25, 50, 75 and 100 mg / L of were used to fit adsorption isotherms on adsorption data. The pH of these solutions was set to be 6.20 cubic centimeters. Each of the above solutions was added to Arlene containing 0.05 grams of fiber with a graft percentage of over 40%. The Arlene became stylish for about 30 minutes for lead at temperatures of 15, 25 and 40 degrees Celsius with velocity of 150 rounds. The mixtures were then passed through the filter paper and the lead concentration was measured.

In order to determine the most suitable isotherm of adsorption, the results obtained at this stage were fitted using the Langmuir, Freundlich, Temkin, Dubinin-Radushkevich equations and based on the highest value of correlation coefficient of data (R2), the most suitable isotherm for lead was determined in every tested temperature.

Analysis of the filter power in natural wastewater

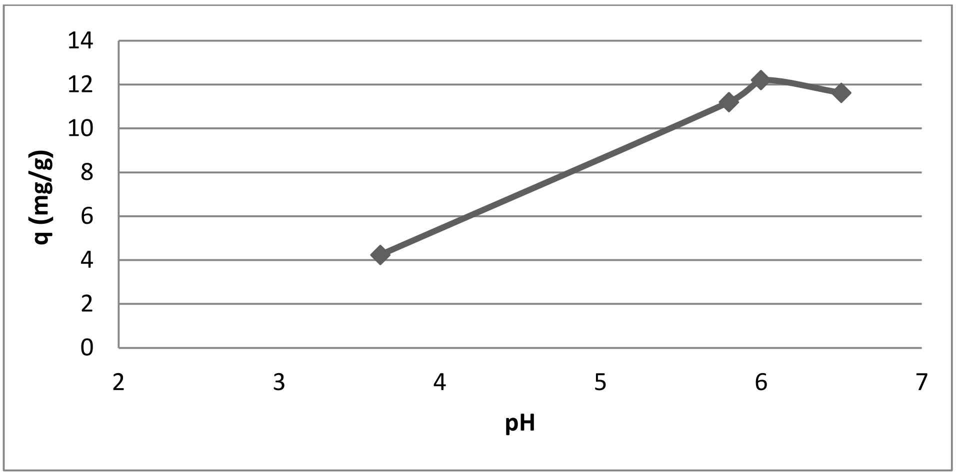
The effluent of Esfahan Steel Company was used to study the adsorption properties of the filter prepared in natural conditions. A sample of the wastewater belonging to the long furnace of Esfahan Steel Company was tested. In the sample, the amount of electrical conductivity, pH and lead were measured. Due to the high pH of the effluent, the pH of the wastewater was adjusted to optimum levels for the adsorption of lead (pH = 6) using nitric acid. Then, the concentration of lead in the used wastewater was measured by atomic absorption device. Due to the low amount of heavy elements in them, enough amount of lead nitrate was artificially added to the effluent to provide a concentration of 50 mg per liter of lead. Other conditions were adjusted according to optimal absorption conditions. It should be noted that a sample was tested as a witness and without adding filter. After completion of the test, all samples were passed through a filter paper and the concentration of lead was measured in the solution using an atomic absorption device and the filtering ability was determined for separating lead from the effluent. For this purpose, using SPSS software, the numbers obtained at this stage were compared with values calculated in laboratory conditions.

RESULTS

1. Determination of the best absorption conditions of the filter produced in laboratory conditions

1-1 The most appropriate pH

Graph1 displays the amount of lead absorbed by adsorbent at différent pHs.

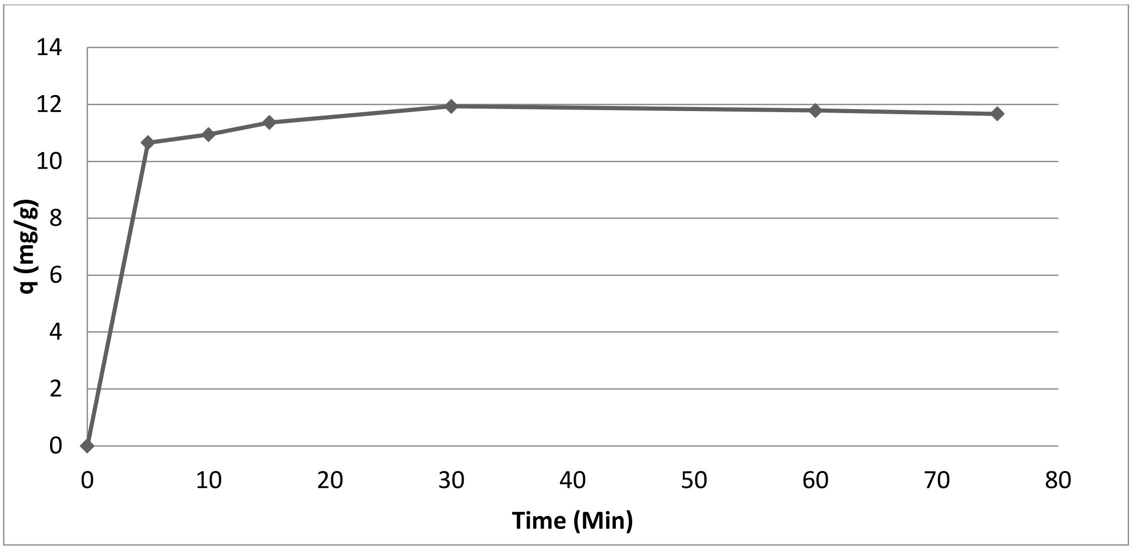


Graph1. Effect of pH on lead absorption by adsorbent

According to the graph, it is concluded that as pH increased, the amount of lead absorption per unit weight of the absorbent increased with a steady slope. It should be noted that at pH higher than 6.5, the concentration of lead in the solution was reduced without adding the fiber, which is probably due to the lead deposition at pH higher than 6.5 in the solution. Since the highest level of adsorption per unit weight of the adsorbent is obtained at a pH 6, then it was selected as the best pH and considered for continued testing. Researchers have reported various pHs for absorption of heavy elements by filters used. For example, [2] reported pH 3 to be the most suitable value for chromium absorption. Because at this pH, the amine and hydroxyl groups available on the protonated fiber surface are positively charged and can absorb the anionic chromate HCrO4 present in the solution. Also, [21] reported that as pH decreased, absorption of chromate increased and the highest adsorption rate occurred at the lowest pH that is 2. However, Ahmad Panahi et al. found that pH 8 is suitable for absorbing lead by PET grafted to acrylic acid and acrylamide. [15] Realized that the optimal pH 6.5 is the best for cadmium adsorption by PET modified with two-monomer mixture of acrylic acid and methyl methacrylate. [21] Investigated the effect of pH changes between 2 and 8 on the absorption of heavy elements and realized that pH 8 is the best for lead adsorption. They also concluded that at the pH close to 8%, almost 100% of lead is in the form of Pb (OH) +, and its adsorption by the fiber is reduced slightly.

2.1The best solution and absorbent contact time (stylish time).

The effect of contact time on the amount of cadmium adsorption is shown in Graph. 2.

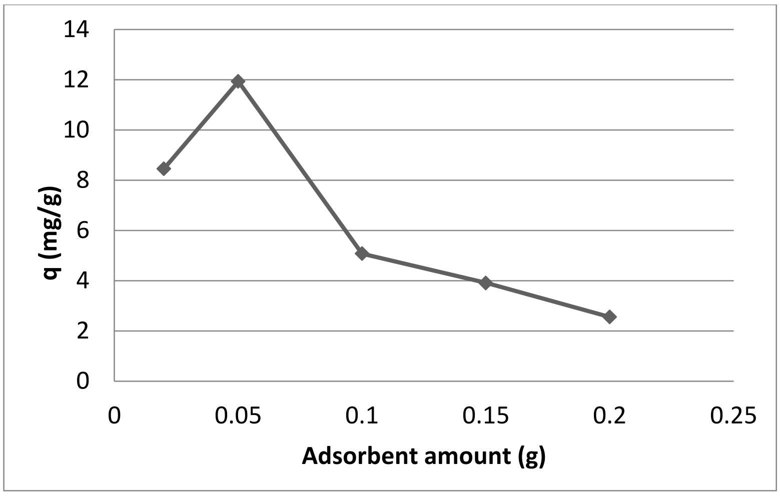


Graph2. The effect of contact time on the amount of lead absorption

According to the graph, as the contact time increased, ions were initially absorbed at a high rate and within the first 10 minutes of the experiment, nearly 80% of the ions in the adsorption medium were filtered and then the absorption rate decreased. This can, as [2] has said, result in the gradual decline of access to charged points by ions. In other words, ion access to the surface of the fiber is easy at first and the ion is gradually getting harder. Determination of the optimal adsorption time depends on the absorbent properties and possible reactions between the adsorbent and the absorbing surface. In the present study, this time was 30 minutes for lead. In general, polymeric adsorbents reach a balance at a much shorter time. For example, Arsalan found that 60 minutes is the best absorption time and stated that more than 80% of absorption occurs in the first 15 minutes of the reaction. [15] Reported that 20 minutes is the best time for the adsorption of cadmium. After this time, the amount of adsorption decreases very slightly due to desorption reactions. Moreover, [23] identified 60 minutes as the best time for absorption of chrome; whereas, [24] reported 48 hours as the adequate time to absorb lead by zeolite and bentonite.

3-1The best amount of adsorbent

The effect of the adsorbent amount on the adsorption rate is shown in Graph. 3.

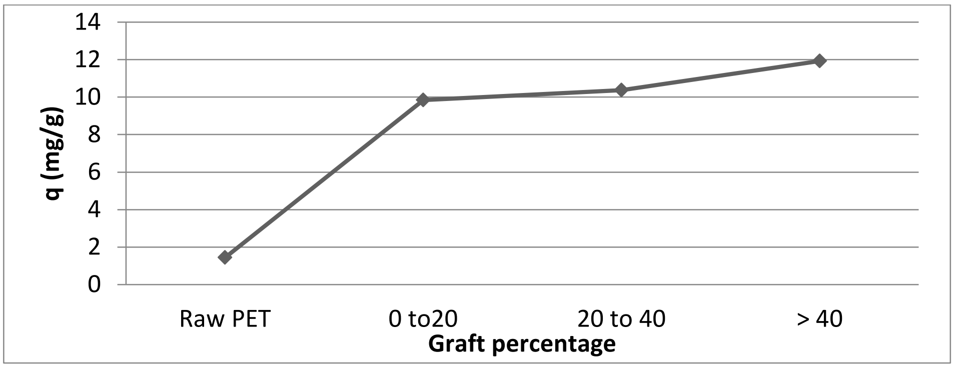


Graph (3) Effect of adsorbent amount on the rate of lead absorption

According to the above graph, it can be seen as the amount of adsorbent increased, the rate of adsorption per unit weight of the adsorbent decreased. The graph consists of two parts. The first part is related to the increase of adsorbent from 0.05 to 0.1 per unit weight of the adsorbent where the slope of the curve is high so that the amount of adsorption per unit weight of the adsorbent decreased from 11.9 to 5 mg / g. Then, the graph was declined with a smaller slope in such a way that as a result of an increase in the amount of adsorbent from 0.1 to 0.2 mg, the absorption rate reaches from 5 to 2.5 mg per gram of absorbent. Since the highest rate of adsorption per unit weight of the absorbent was obtained with 0.05 grams of fiber, this rate was considered as the optimum weight of the fiber; this rate was used in further experiments. As the amount of adsorbent increased, the rate of pure adsorption increased; while, the rate of adsorption per unit weight of the adsorbent decreased. Most researchers have reported that increased absorption rate per units of absorbent weight is due to the increased amount of adsorbent. For example, [15] have mentioned accessible exchange points as the reason for the increased absorption. [2] And [25] have also reported similar results. In the present study, despite the increase in the amount of adsorbent, the amount of adsorbed metal per unit weight of adsorbent decreased. This is apparently contrary to the results obtained by other researchers. The reason for this was investigated and it was found that a low concentration of the initial amount of the metal could be the cause of this difference, because when 0.05 grams of adsorbent was added, more than 50% of the lead in the solution was adsorbed. Hence, in order to keep the absorption rate constant per unit weight of the adsorbent, by doubling the amount of adsorbent, the absorbed metal must also be doubled. This amount is more than whole of the element available in the solution and not practically possible.

4.1 The best graft percentage

The effect of grafted monomer on the absorption rate is shown in Graph. 4

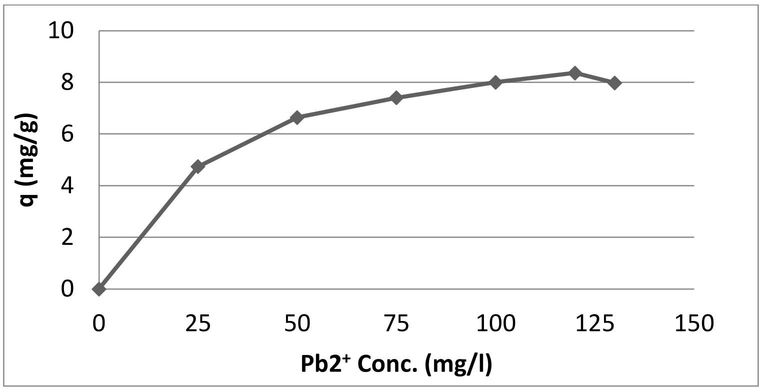


Graph (4) Effect of grafted monomer percentage on lead absorption

According the graph, the monomer-to-fiber grafting (converting the raw fiber to the grafted fiber) has resulted in a sharp increase in the adsorption rate per unit weight of the absorbent so that by converting the raw fiber into fibers with 20-0 graft percentage, the adsorption rate increased to 9.85 mg / g of the absorbent; the initial value was 1.45. Then, as the graft percentage of monomer increased from 0-20 to 40-20% and over 40%, the curve increased with lower slope and the absorption increased from 9.85 to 11.99 mg / g of the absorbent. According to the results, considering that the maximum adsorption per unit weight was obtained with fibers containing more than 40% monomer, the fibers were selected as suitable ones and used to continue the experiments. As the percentage of monomer grafted to the fiber increased, the adsorption rate of heavy metals increased because the monomer mostly means creation of more capacity to adsorb the elements. Other researchers have also reported similar results. Among them, [25] showed that due to the increase of the grafted monomer percentage and the number of agent groups in the produced fiber structure, the adsorption of iron and copper has increased by the filter. [15] have reported that increasing the graft percentage from 17 to 60 and then to 75% leads to the increase of the adsorption rate of10.6, 12.88 and 14.22 mg of cadmium per gram of adsorbent. [2] Has used the fiber of 90 graft percentage as the best percentage of the graft in all experiments. The remarkable point in this section of the experiment is related to the lead adsorption test by washed raw fibers.

5.1 Effect of initial concentration of lead on its adsorption

The effect of initial concentration of lead on its adsorption by adsorbent is shown in Graph 5.



Graph (5) Effect of the initial concentration of lead in the solution on its adsorption by the filter

As the initial concentration of lead increased, the adsorption rate also increased per unit weight of the adsorbent, but the curve slope decreased with the increase of the lead concentration in the solution. In general, the graph (5) can be divided into three parts. The first part is related to the increase of concentration from 0 to 75 mg / l; the maximum slope is seen in this part and the amount of adsorption per unit weight of absorbent increases from zero to 17.47 mg / g. In the continuation, the curve with a lower slope still shows an increasing trend, so that due to increase of initial concentration of lead in the solution from 75 to 120 mg / L, the adsorption increased from 17.47 to 20.74 mg / g of the absorbent. Then, because of increased initial value of lead in the solution, the rate of adsorption decreased from 20.74 to 19.99 mg / g of the absorbent. Therefore, the highest amount of adsorption per unit weight of the adsorbent was obtained with a concentration of 120 mg / L. This amount was determined as the appropriate concentration for adsorption per unit weight of lead adsorbent and was reported as the maximum adsorption per unit weight of the adsorbent. It should be noted that the solution became cloudy at concentrations of 150 mg / l and higher, and the production of sediment was clearly observed. Also, due to the formation of sediment in the presence of CaCl2 0.01 molar at concentrations of 120 and 130 mg / liter of lead, the solution of Ca (NO3) 2 was used instead of CaCl2. By increasing the initial concentration of ion in the solution, the amount of adsorption primarily increased per unit weight and then the adsorption rate became almost constant at high concentrations.

This occurred at low concentrations because of the increased ion adsorption by adsorption points. By increasing the concentration, the adsorption points were coated by ions and finally, at high concentrations, almost all of the adsorption points were occupied. In this case, due to the lack of absorbing points, the increase in initial concentration

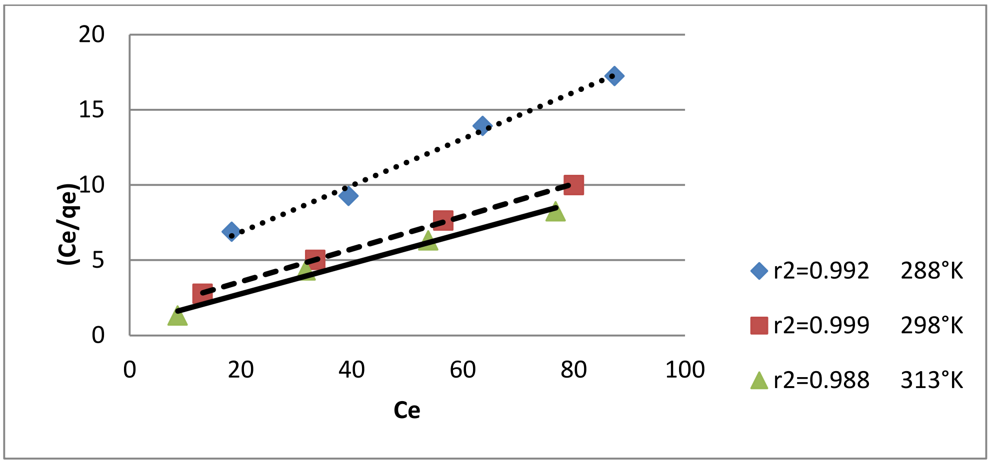
did not have an effect on ion absorption. The best initial concentration was 120 mg / l for the adsorption of cadmium and lead by the fiber used. Overall, in the adsorption systems, the initial concentration of heavy metals in the solution used plays a significant role as the driving force overcoming the resistance caused by the mass transfer between the liquid and solid phase. [2] Reported that as a result of increased initial concentration of chromium in the solution from 25 to 500 mg /l, the adsorption rate per unit weight increased from 2.6 to 88 mg/g via the PET grafted by glycidyl. However, a rapid increase in adsorption amount has been observed only up to 400 mg / L. [15] indicated that with increasing the initial concentration of cadmium in solution from 50 to 140 mg /l, the amount of cadmium adsorption has increased from 2.5 to 17.07 mg/g via the PET grafted to methyl methacrylate and acrylic acid monomer mixture, and then, due to the increase of it by150 mg /l, the amount of adsorption decreased slightly by 16.95.
According to the above, the best conditions for adsorption per unit weight of lead absorbent from the solution were determined by the produced filter as the following:

- pH is 6.
- The contact time between solution and absorbent is 30 minutes.
- Concentration for the adsorbent is 2.5 g /l.
- The high graft percentage is above 40%.
- The concentration of lead in solution is 120 mg /l.

2. The fitting of adsorption isotherms on lead absorption data for the produced filter
To determine the best isotherm, the results obtained from the previous step were fitted using the Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich equations, and the most suitable isotherm for every element at each tested temperature was determined based on the highest correlation coefficient of data (R2) (Table 1and graphs 6 to 9)
Table1. Isotherm parameters for removal of Pb^{2+}

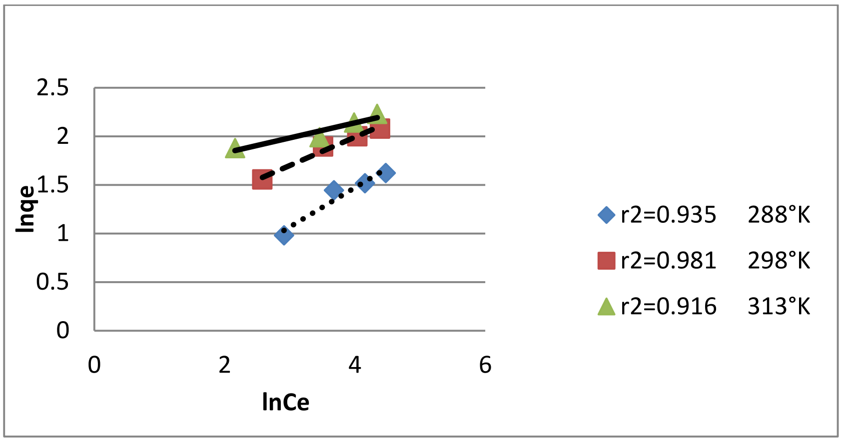
Isotherms	Coefficients	Temperature in ° K		
		288	298	313
Langmuir	q_m mg/g	16.95	21.05	22.13
	K_a l/mg	0.04	0.08	0.13
	r^2	0.992	0.999	0.988
Freundlich	K_f $((mg/g)(l/mg))^{1/n}$	0.86	2.29	4.55
	N	5.47	7.14	9.39
	r^2	0.935	0.981	0.916
Temkin Piaget	a	-1.56	0.18	3.70
	b	1.50	1.80	1.21
	r^2	0.962	0.944	0.891
Dubinin-Radushkevich	q_0 mg/g	5.291	8.655	8.932
	B_0 l/g	0.91	2.37	0.58
	E	23.41	14.51	29.32
	r^2	0.901	0.993	0.757

As shown in the table, in Langmuir isotherm, the adsorption capacity of the metal is increased as temperature increases from 16.95 to 22.13 mg /g. In all of the adsorption isotherm equations, the correlation coefficient has increased due to the increase in temperature from 288 to 298 degree, but due to temperature increase up to 298 degrees, correlation coefficient has decreased. The highest correlation coefficient at temperatures 288, 298 and 313 belongs to Langmuir's equation with values of 992.0, 0.992 and 0.898. In the whole experiment, the highest correlation coefficient belongs to Langmuir's equation at a temperature of 298 ° K. The maximum single-layer adsorption capacity was obtained in Langmuir model at 288, 298 and 313 ° K, respectively as the following: 16.95, 21.05, and 22.13 mg /g. However, in Freundlich's model, the maximum adsorption capacity at the aforementioned temperatures was respectively obtained equal to 47.5, 14.7 and 39.9 mg /g in the absorbent.



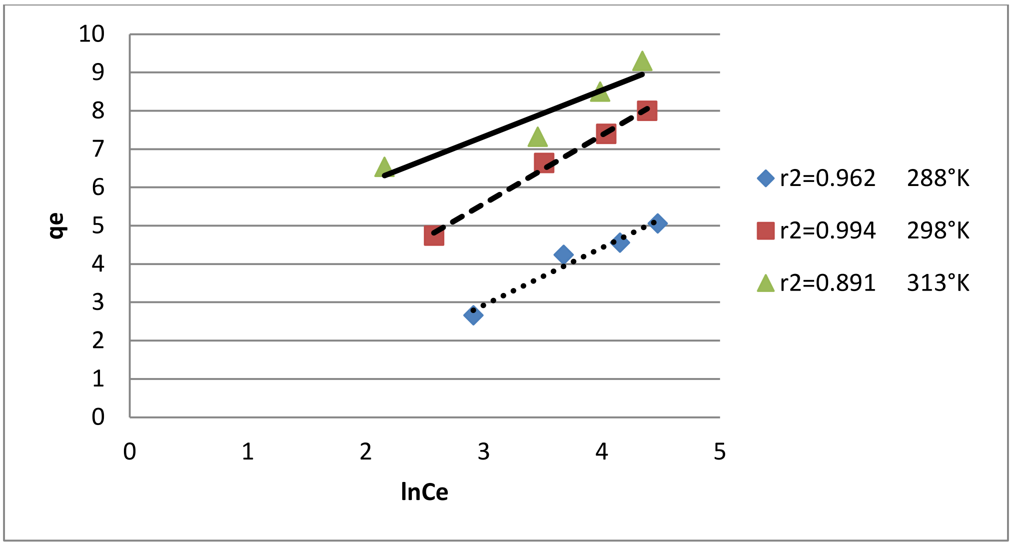
Graph (6) Fitting of data on the linear form of Langmuir's adsorption isotherm for lead at three temperatures

According to the results in Graph 6, the slope of the curve is incremental and has the same value at almost all temperatures. In addition, the slope of the curve decreased as the temperature has increased. The lowest slope is observed at 313 ° K and the highest slope belongs to the temperature of 288 ° K. Also, with increasing the temperature, the correlation coefficient first increases and then decreases. The highest correlation coefficient (0.999) was obtained at a temperature of 298 ° K.



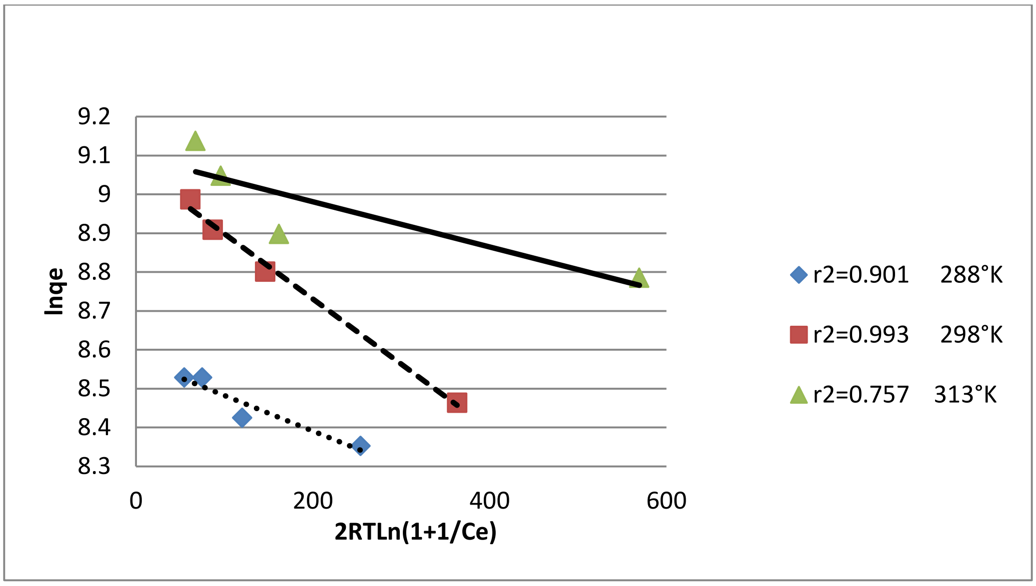
Graph (7) Fitting of data on the linear form of Freundlich’s adsorption isotherm for lead at three temperatures

The graph indicates that the slope of all curves is positive and the graph of 288 degrees has the maximum slope. The curves trend is uniform at all temperatures. As with the previous isotherms, the highest correlation coefficient (0.998) was obtained at a temperature of 298 ° K. At temperature of 288 and 313 ° K, the correlation coefficient of the equation is low and, as shown in the graph, the data is deviated from the linear form of the graph, and this model cannot well describe the adsorption data.



Graph (8) Fitting of data on the linear form of Temkin Piaget's adsorption isotherm for lead at three temperatures

As with previous adsorption isotherms, the highest correlation coefficient (0.995) belongs to the temperature of 298° K and the slope of the all curves is positive. The lowest curve slope was observed at 313 ° K. The correlation coefficient is reduced to below 0.9 at the temperature of 313 ° K. Therefore, it seems that the Piaget's equation is not suitable for describing absorption data.



Graph (9) Fitting of data on the linear form of Dubinin-Radushkevich adsorption isotherm for lead at three temperatures

In the graph, unlike other isotherms, the slope was negative and the highest slope was obtained at 298 ° K. Also, the highest correlation coefficient (0.993) belongs to the temperature of 298 ° K. At temperature of 288 and 313 °K, the deviation of the graph from the linear form indicates the weakness of the model in describing the data. Like the Piaget's Temkin equation, the correlation coefficient has decreased in these two temperatures, and this equation is not suitable for explaining the adsorption properties of lead by the filter produced.

As shown in the above table and graphs, the adsorption behavior of lead by the fibers produced at a temperature of 288 °K is well explained by Langmuir's equation with a correlation coefficient of 0.992. Regarding the temperature of 298 °K and high concentrations of lead, surfaces are expected to be more uniformly covered with lead. Thus, the higher correlation coefficient of the adsorption behavior of lead with Langmuir's equation seems to be justified. At temperature of 298 °K, like 288 °K, the highest correlation coefficient (0.3) was obtained for Langmuir's equation. As predicted, the increase in temperature may cause non-homogeneity of lead absorbed on the surfaces. This is evident with a significant increase in the correlation coefficient. However, because of the high concentration of lead, the effect of temperature has not been able to neutralize the effect of the concentration, and hence the absorption is homogeneous. In other words, due to the increase in temperature from 288 to 298 ° K, the correlation coefficient of the Freundlich equation increased significantly from 0.935 to 0.998. At a temperature of 313 °K, as in previous two temperatures, the highest correlation coefficient (0.988) was obtained for Langmuir's equation. In other words, due to the increased temperature from 298 to 313 °K, the correlation coefficient of Langmuir's isotherm has decreases, though still remains the most suitable temperature. Among all the equations, Langmuir has the highest correlation coefficient (0.999) at 298 ° K. The Temkin equation has the second highest coefficient of correlation (0.995) at the same temperature. Regarding the correlation coefficients, Langmuir's equation was found to be more suitable than others for description of lead adsorption on the filter.

3- Maximum adsorbent capacity for metal adsorption

The maximum lead absorption capacity was obtained by adsorbent under optimal conditions and at the highest initial concentration of the element. The capacity value was 22.13 mg/g for the fibers used in this study. The maximum adsorption capacity differs for fibers with different graft percentages and at different conditions. According to [13], the maximum capacity of polyacrylonitrile fibers modified with carboxylic group was respectively obtained as 1.3 and 0.98 mmol /g for the adsorption of cadmium and lead. According to [18], the maximum capacity of the PET grafted to acrylic acid and acrylamide was 0.41 mg / g. for absorption of lead [2] determined the maximum capacity of PET grafted with aminiglycidylmethacrylate groups to be 88 mg /g for adsorbing chromium. [15] Reported that the maximum absorption capacity of cadmium by fiber is equal to 17.77 mg / g.

4. Fitting of adsorption isotherm on lead adsorption data for the produced filter

The metal adsorption has increased by the fiber due to the increased temperature. This increase may occur because of an increase in mobility of ions in the solution, and thus an increase in the possibility of collision between the fibers and the metal. [21] Reported that as the temperature increased from 30 to 50 °C, the amount of adsorption increases per unit weight of the adsorbent. According to them, this is due to increased adsorption capacity because of an increase in the kinetic energy of adsorbent particles. They also reported Freundlich isotherm as the best isotherm for describing the adsorption properties of the filter used. In the present study, Langmuir's equation was found to be the best equation for the adsorption of lead, indicating that the adsorption is single-layer. Additionally, the maximum lead adsorption capacity was 21.31 mg/g at 40 °C according to Langmuir's model. [15] Realized the Freundlich adsorption isotherm as the most appropriate equation to explain the adsorption behavior of cadmium by the fibers used. [26] Identified the Langmuir model as the best equation for absorbing nickel, lead, iron and copper by modified acrylic acid fibers at temperatures of 25, 40 and 55 degrees Celsius.

5. Investigating the adsorption amount of lead from the natural environment

According to the results presented in Table 2, the produced filter is capable to remove 32% of lead added to wastewater and 58% of lead contained in pure laboratory solutions. Regarding the amount of lead adsorption by the fibers produced from the effluent of Esfahan Steel Company and its comparison with the numbers obtained for laboratory conditions, it was found that the produced filter is suitable for adsorption of lead from wastewater under natural conditions. [27] Introduced Bacillus Sp bacteria as a high-performance bio-absorbent for absorbing heavy metals from lead, copper and chromium from industrial effluents. Studies by [28]on the adsorption properties of bentonite for zinc and copper adsorption from aqueous solutions showed that bentonite has a good potential for adsorption and treatment of copper and zinc ions from aqueous solutions.

Table2. Comparison of lead adsorption from Esfahan Steel Company effluent with laboratory environment

Sample No.	Absorption environment	Initial concentration (mg /l)	Secondary concentration (mg /l)	Concentration reduction (mg / l)	Percentage of lead adsorption	Adsorption amount per unit weight of the adsorbent (mg / g)
1	Wastewater with adsorbent	50.0	34/2a*	15.8	31.6	6.32a
2	Laboratory solution	50.0	21/1b	28.9	57.8	11.56b
3	Wastewater without adsorbent	50.0	49/7c	0.3		

CONCLUSION

The amount of lead adsorption per unit weight of the adsorbent increased due to the increase in pH, initial concentration of lead in solution, contact time, grafted monomer percentage and temperature, while it was reduced with increasing the amount of adsorbent. According to the results, the most suitable conditions for adsorption of lead are as follow: pH: 6; time: 120 Min; initial concentration: 120 mg /l; monomer percentage: higher than 40%; absorbent concentration: 2.5 g /l; and temperature: 313 °K. The maximum adsorbent capacity for adsorbing lead in this study was determined according to Langmuir equation that is 22.22 mg /g. The best fitted adsorption isotherms on lead adsorption data were obtained for Langmuir and Freundlich equations, indicating that the adsorption is single-layer. The produced filter treated 32% of the lead added to wastewater. Due to the high rate of adsorption and high amount of lead adsorption from the laboratory solution and the natural wastewater, the produced filter was found to be suitable to treat the lead from wastewater.

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