ORIGINAL RESEARCH PAPER

Optimization of copper adsorption process from aqueous solution by Descurainia sophia plant stem using Taguchi method

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Received: 2019-11-14 Accepted: 2020-01-08 Published: 2020-02-01

ABSTRACT

The aim of this project is production of Descurainia Sophia adsorbent in nano dimensions using a super-grinding disk mill. The top-down method was used in the process of nanogel preparation. After complete drying of the stems, the stems were reduced to smaller sizes by an electric mill, and by using the available sieve to standard number 60, adsorbent granulation was performed. The adsorbent was used to remove copper from aqueous solution. The tests and their optimization results were based on the design of experiments in three levels of variables using the Taguchi method. According to the experiment results, pH, contact time, and adsorption mass are the main factors and the most influential effect on the removal of copper from the aqueous solution is the pH parameter, which has a lower p-value. As the pH increases from 5 to 9, the efficiency of copper metal removal increases. The concentration of hydrogen ions is the most important parameter affecting the adsorption process. The effect of temperature on adsorption efficiency has been investigated in the range of 20-50°C. Finally, the highest efficiency of copper cation removal was at 30°C and 8.89%. The results showed that the pH of the solution had the most effect on the copper removal efficiency and in the playing environment, the effect of copper removal was more than the acid and neutral conditions of the solution. Also, the adsorbent mass and contact time have the most effect on copper removal after the pH parameter in the Taguchi method.

Keywords: Nanogel, Descurainia sophia Plant Stem, Copper, Design of Experiments (DOE), Taguchi Method

How to cite this article

Yadolahi K, Ghadi A, Alavi SA. Optimization of copper adsorption process from aqueous solution by Descurainia sophia plant stem using Taguchi method. J. Water Environ. Nanotechnol., 2020; 5(1): 68-80.

DOI: 10.22090/jwent.2020.01.006

INTRODUCTION

In the last few years, sustained development and attention to the next generation has led researchers to work on methods that help reduce environmental degradation and reduce the spread of pollution, but the more industries become larger, the pollution-induced from their activity will become larger as well and they threaten the environment[1]. Natural adsorbents, due to the ability to recover and return to the ecosystem cycle, have become much more convenient and beneficial. Among the natural adsorbers used by the researchers, it is possible to use chitosan[2]

carbon derived from the tamarind core[3] and bran ash which is activated by bentonite[4] and a vertebrate species[5], the use of pine tree raw wood and improved wood with acid[6] and are among the adsorbents that have been evaluated by various researchers. Excessive amounts of copper in the body also cause a lot of harm, resulting in a headache, decreased blood sugar, increased heart rate, and nausea. The excess copper in the brain and the liver is deposited, it damages the kidneys and prevents the production of urine. Copper poisoning leads to anemia and loss of hair in women. The high amount of copper interferes with

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the zinc element that is needed to make digestive enzymes. Copper poisoning is associated with overactive children and learning disabilities such as reading and writing disorders, attention deficit disorder, and ear infections. Other symptoms of copper poisoning associated with psychology include symptoms of autism (such as depression, hallucinations, insomnia, paranoia, personality changes, insanity) and schizophrenia symptoms (such as high irritability, lack of awareness and understanding of the senses and time)[7, 8]. In this research, nano-stems of Descurainia Sophia as an effective and inexpensive adsorbent for the removal of copper from aqueous solutions have been used. The tests and their optimization results were based on the design of experiments in three levels of variables using Taguchi methods. The term adsorption refers to the fact that the concentration of surface adsorption molecules at the solid contact surface is higher than the gas or solution phase and is due to the adsorbent mass of atoms or molecules on the surface of the solid. Various physical and chemical forces are involved in this process, the amount of which depends on the nature of the absorbing material and the adsorbent, so the material can be separated from a mixture.

Adsorbents size is between 92 mm to 56 micrometers. The optimal adsorbent should not cause much pressure difference and should be removed from the substrate along with the materials and should be easily stored in laboratory containers.

MATERIALS AND METHODS

Materials

To prepare a copper solution at different concentrations, a solution of 1000 mg / l was prepared by using copper nitrate (Cu(NO₃)₂.3H₂O), then various concentrations were diluted using this initial solution. Hydrochloric acid (HCl) and soda (NaOH) was used to adjust the pH of the solution.

Procedure

Adsorption experiments using a mixer were performed discontinuously. The required concentrations of copper solutions were obtained by diluting the solution. The total volume of the solutions used was 100 milliliters (50 ppm copper concentration) and after each experiment, the solution was filtered off and the adsorbent was removed and the sample was prepared for analysis. All concentrations of copper-soluble are considered to be 50 ppm.

Statistical design of the experiment using the Taguchi method

In late 1940, Dr. Taguchi introduced new statistical concepts and later proved that these concepts are valuable tools in the field of control and quality improvement. Since then, many Japanese industrialists have used this method to improve the process of quality and products. The increasing quality of vehicles constructed by Japan is heavily linked to the widespread use of this method. In this research, the primitive and practical concepts of the Taguchi method are presented with examples of various practical applications. Taguchi's method is completely different from the typical and commonly used methods of engineering. Taguchi's methodology emphasizes designing quality when designing products and processes, while commonly used methods are based on inspection and quality control during or after the production process. Taguchi has used quite commonly used statistical tools in his quality improvement methods. But he has simplified these methods by identifying a set of powerful strategies for designing tests and analyzing results. Taguchi's method has been very effective in improving the quality of Japan's products. Recently, Western industrialized nations have used Taguchi as a simple and effective way to improve products and improve the quality of their manufacturing processes. The Taguchi test design method has a wide range of applications in various industries. However, this method is usually applicable to "outsource" quality control. The Taguchi method creates two new and powerful elements: the first is that it is a systematic way to develop a product or to examine complex issues. Secondly, this method provides a tool for the cost-effective inspection of usable final options. Although the Taguchi method develops concepts of optimization through experimental design, his philosophy with considering the quality of the value and the procedure of new experiments were brand new. The power and generality of this method are more proper than the method itself[9, 10]. Statistical design of the experiments and analysis of data was done using Minitab statistical software (version 17). For this design, three main factors of pH (A), contact time (B), and adsorbent mass (C) were evaluated at three levels. The interaction of AB, AC, and BC parameters is not being considered and only the effect of the main parameters is being considered. In general, the range and amount of each of the variables used in this study for the removal of copper ion from aqueous solution with the aid of a nano gel adsorbent of the flixweed (*Descurainia Sophia*) plant stem are shown in Table (1).

In the next step in Taguchi optimization, the effect of E_i (i = A, B, and C) has been calculated. For the E_i analysis, the average response (% of copper removal efficiency) for all levels of the factors (surface effect) must be calculated. Then the effect of the factor, which is a criterion for analyzing the impact of each of the factors on the response, can be obtained from the difference of the lowest average from the highest of it for each factor[15]. For example, to obtain the effect of Factor A, the removal of copper by a nanofibre is as follows:

Step 1: Calculate the <u>mean</u> of responses at all three levels of factor A (A_1). In the same way, we can calculate the mean of responses for factor A at two other levels.

Step 2: The difference between the highest response means from its lowest for factor A.

$$\overline{E_A} = \left(\overline{A_I}\right)_{max} - \left(\overline{A_I}\right)_{min} \tag{1}$$

Furthermore, the effect of other factors can also be calculated in the same way. Table (2) shows the effect of factors on copper removal. Based on these tables, the factor A, the pH of the solution, has the most effect on the copper removal efficiency. After that, the amount of adsorbent mass and contact time are respectively in second and third place of the effectiveness.

Equipment

Due to the health, environmental, and safety constraints, the necessary equipment, especially nanoscale particles, preparing and milling adsorbents after reaching the 60 to 50 mesh was entrusted to Nano Novin Polymer company. The package containing 100 grams of 60 to 50 mesh was shipped to the company's address, and after being converted to a nanogel, the structured and turned into a nanogel product was received. In this study, the Scanning Electron Microscope (SEM) device was used to identify the adsorbent level. Before taking the SEM photographs from these two specimens, their surface was fitted with a gold plated sputter to guide these improved materials, which ultimately resulted in a higher-quality image and a thickness of 30 nm coated materials. The identification of functional groups was also done by Fourier transform infrared (FTIR). To

 $Table \ 1. \ The \ amplitude \ and \ level \ of \ studied \ variables \ of \ copper \ adsorption \ using \ the \ nano-gel \ of \ the \ Descurainia \ sophia \ plant \ stem.$

Symbol	Factor	Level1	Level2	Level3
A	рН	5	7	9
В	Contact time (min)	70	100	130
С	Adsorbent mass amount (g)	4	6	8

Table 2. Variables and results from Taguchi experimental design for removing copper using Descurainia sophia nanogel.

	Variable by encoding surfaces	Copper removal results (%)			
Number	PH	Contact time (min)	The amount of adsorbent mass (g)	Experimental results of the first experiment	Experimental results of the second experiment
1	1	1	1	36.21	32.34
2	1	2	2	53.78	52.23
3	1	3	3	64.35	67.34
4	2	1	2	62.21	64.43
5	2	2	3	73.21	75.54
6	2	3	1	58.12	59.13
7	3	1	3	71.2	74.71
8	3	2	1	66.4	62.31
9	3	3	2	88.56	86.11

prepare the sample for testing, mix 1 milligram of adsorbent with 1000 milligrams of KBr uniformly, then press them on a plate that is transparent under the pressure of 2200 kg/cm² for 5 minutes. After this operation, the sample is ready for the FTIR test. The range of scans for specimens was between 4000-500cm⁻¹.

Adsorbent Used for Adsorption in This Research

The first adsorbent material used in this research is *Descurainia Sophia*. *Descurainia Sophia* is a one-year-old or two-year-old Brassicaceae plant. *Descurainia Sophia* grows in the plains and mountains, and the height of the stem reaches one meter. The bottom of the plant is fluffy, while its top is not. The seed of the plant, which is the same *Descurainia Sophia*, is tiny and slightly long and usually has two colors; one of them is red, with a slightly bitter taste and the other is dark red.

Preparation of a Descurainia sophia Adsorbent in Nano Dimensions Using a Disk Grinding Mill

To prepare the nanogel, the top-down method was used. In preparation of adsorbent nanogel, two milling and crushing steps were necessary, to prepare the adsorbent, first, the obtained stems were washed to remove any dust and contaminants. After complete drying of the stems, the stems were reduced to smaller sizes by an electric mill, and by using the available sieve to standard number 60, adsorbent grading was performed. To increase the absorbance, the adsorbent was placed in a mesh size range of 60 in 1 mol Hydrochloric acid for 1 hour on a stirrer at 150 rpm to activate the active adsorption sites. In the next step, 100 g of adsorbent was prepared and was transferred to a super mill. The second stage was the use of the Japanese Super Disk Milling, which was considered as a sensitive phase, due to the high pressure that converted the size of the mesh to nano dimensions for the disc mill, the feeding to the mill was slowly performed, and most of the feed input in this mill was introduced with DM (double distillation) water so that hard solids and dirt contained in the adsorbent that was left in the adsorbent cavity after the washing step, not damaging the rotating discs. The distance between the two discs in this device is very close, and the two disks are in the opposite direction and roughly at 1500 rpm, so any irregularity at rotation and very hard objects could damage the discs. All mills from the first stage of the mill should be to the point that passed through the mesh 60. Considering the

loss in the second stage of the mill due to the lack of feed, about 400 grams of nanoparticles were produced that were enough to complete all the experiments. For copper adsorption experiments, a nanogel was used which, because of the water content for this type of adsorbent, the percentage of water should be determined for this state, therefore the experiments related to water percentages were performed, and a certain amount of gram of nanogel was poured into the hourglass and placed in the oven at a temperature of 70 ° C for 12 hours. The amount of water used in the nanogel was 90% which is the same as the percentage of added water in the Nano Novin Polymer company.

RESULTS AND DISCUSSION

SEM analysis

An electron microscope was used to investigate the shape and size, as well as the uniformity of the surface and appearance of the adsorbent and the adsorbent particles (Fig. 1). However, in the case of the nanogels, because of their lack of solidification, a transmission electron microscope was used.

Since the structure of the plants is legged and should have the necessary strength, therefore, in the creation of plants for firmness and strength, a substance called lignin is placed, the role of lignin, as seen in Fig. 2. is a framework for the main body. This prevents the plant from bending and softening during growth and afterward, and causes the plant to always be raised. Lignin, as the hardest element in the plant, prevents the adsorbing material from reaching adsorbed areas. In the present work, after converting the adsorbent into the form of a nanogel, one of the barriers preventing the adsorption of the adsorbent material was removed.

For the nano-structuring of the adsorbent, some of it became in the form of a nanogel. In this form, the particles were completely uniform and the particle size was much smaller and the cavities disappeared, Fig. 3. shows uniformity in reaching the nanogel receptor

Figs. 4 (a-b) represent the adsorbent form with mesh 60 (before the conversion to the nanogel), which are taken with different magnifications. as it is shown in the figures, there is high porosity in the adsorbent, the pore size reaches a few microns, this is one of the most important positive-adsorbing parameters. In addition to the fact that the plant stem has a lot of cavities, the walls of the cavities themselves are very porous, as shown in Fig. 1c. It can be seen from Fig. 4a that fibers

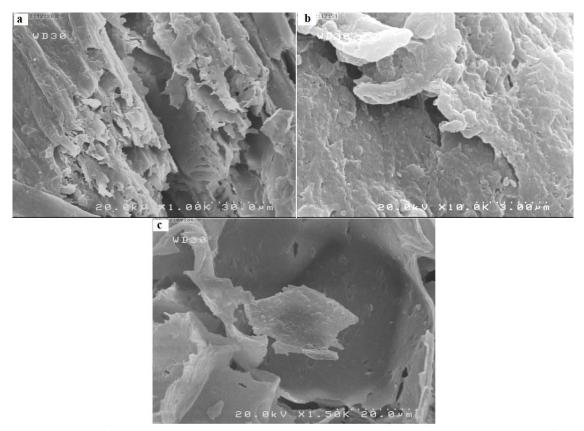


Fig. 1. The image of the electron microscope, The adsorbent sample used with a magnification of 1000 times (a), the image of the electron microscope, The adsorbent sample used with a magnification of 10,000 times (b) and adsorbent electron microscope image, with a magnification of $1.5 \, \mathrm{k}$ (c).

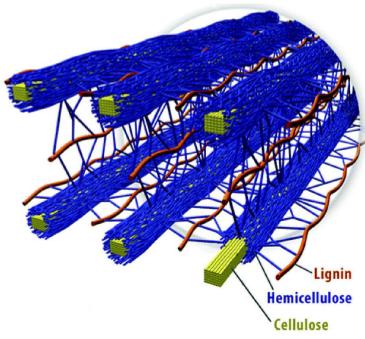


Fig. 2. The lignin model and the cellular cell that is hard to reach cellulose[20].

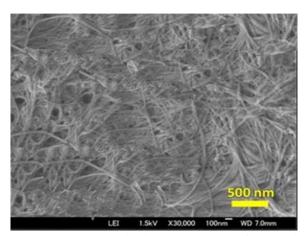


Fig. 3. Transmission Electron Microscope (TEM) image related to the nanostructure of nanogel adsorbent with a magnification of 30K.

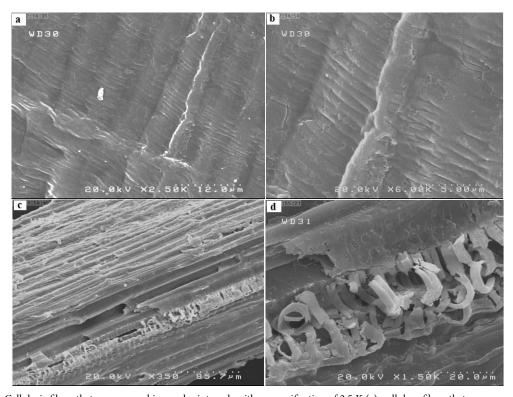


Fig. 4. Cellulosic fibers that are arranged in regular intervals with a magnification of 2.5 K (a), cellulose fibers that are arranged in a regular manner, like woven fabric, with a magnification of 6K (b), an image of an adsorbent electron microscope before gelting, after being added to the chlorine admixture of 1 mol and with a residual time of 1 h with a magnetic stirrer at 150 rpm, with a magnification of 350 times (c), an image of an adsorbent electron microscope before gelting, after being attached to the 1 molar additive with 1 mol of chloride and 1 hour with a magnetic stirrer at 150 rpm, with a magnification of K 1.5 (d).

and cellulosic fibers are tangled together and woven in *Descurainia Sophia*, which is the same lignin, and hardens the adsorbing stress to the internal holes. Fig. 4b shows the cellulosic fibers that are arranged regularly, like woven fabric, with a magnification of 6000 times. After the

adsorption of the acid before the gelation process, as shown in Fig. 4c and Fig. 4d, some adsorbent lignin was lost and this factor was also affected by better adsorption. With nano-structuring of the adsorbent, easy adsorbent and adsorbent access were possible.

FTIR analysis to investigate species in an adsorbent chemical structure

The adsorbent structure produced through the FTIR spectrum was studied. The FTIR spectrometer provides important information about the types and foundations of the biocompatible polymer structure and the types of composites. The results of the spectroscopy are shown in Figs. 5 (a-c), all spectra were investigated in the range of 500 to 4000 cm⁻¹. From the FTIR analysis, materials can be

identified and categorized. Examples of adsorbents performed by FTIR analysis include *Descurainia Sophia* without acid upgrades (before the gelation process and meshed with sieve 60 mesh) (sample 1), *Descurainia Sophia* with acid upgrades (before the gelation process and meshed with sieve 60 mesh and pickled) (sample 2) and adsorbent after adsorption of copper from aqueous solution (sample 3). As it is known, by adsorbent acidification, a negative charge was induced on the adsorbent, which

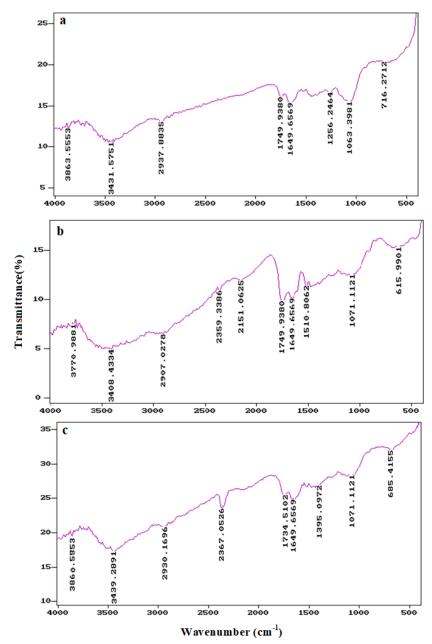


Fig. 5. The FTIR spectrum of the second form of adsorbent without enhancement with acid (a), adsorbent FTIR spectrum after immersion in chlorometric acid 1 molar (b), the adsorbent FTIR spectrum upgraded after copper adsorption from aqueous solution (c).

caused the metal cation to be well adsorbed by the adsorbent, thereby increasing the adsorption rate. For adsorbent without enhancement, Fig. 5a, the peak of 716 cm⁻¹ represents the C-H group attached to the benzene ring. The 1063.3 cm⁻¹ peak is related to the twitch of the carbon-carbon double bond in the aromatic ring. C = C, which is more precisely related to 2-methoxy-2-phenyl ethanol shows the peak at 1256 cm⁻¹ which is related to the internal CH or silica compounds, and the peak at 1649.6 cm⁻¹ is related to the water-adsorbed group. The band in 1749.9cm⁻¹ refers to the carbon-oxygen bond in the carbonyl group C = O[11], although it should be noted that in the range of 3,300 to 3,400 cm⁻¹, this group also generates peak but not so recognizable. The peak at 2937.8 cm⁻¹ is related to carbon group 4 that has been linked to chlorine or bromine halogens. The peak at 3431.5cm⁻¹ is related to the O-H bond of adsorbed water on the adsorbent. The band in 3863.5cm⁻¹ is related to the external C-H bond. In Fig. 5b, the peak at 616 cm⁻¹ is related to the presence of magnesium and aluminum hydroxide, which is probably due to the presence of magnesium hydroxide and aluminum in the chloride-containing acid used to promote. The peak at 1071cm⁻¹ associated with the COlinkage in the structure Polysaccharide, 1510cm 1 is related to the C-C bond in the aromatic ring, 1649cm⁻¹ is related to the adsorbed water group, 1749cm⁻¹ is related to the carbon-oxygen bond in the carbonyl group, 2151cm-1 is related to the carbonyl bond that adsorbed on the hydroxyl[12], 2907cm⁻¹ is related to the CH bond of dimethylsilyl group, 3408/4cm⁻¹ is related to the chloride bond in CHCl₃, which is due to adsorption of glucose in chloride[13], 3770cm⁻¹ is related to hydroxyl bond in AlOH structure and or oxygen-hydrogen bond is related to humidity. In Fig. 5c. 685.4 cm⁻¹ is related to the external C-H gradient, 1071 cm⁻¹ is related to the C-O bond in the polysaccharide structure, 1395 cm⁻¹ is related to the O-H bond, 1649 cm⁻¹ is related to the adsorbed water group, 1734 cm⁻¹ is related to the carbon-oxygen bond in the carbonyl group[14], 2367 cm⁻¹ is related to C≡N bond, 2930 cm⁻¹ is related to the external C-H bond, 3439 cm⁻¹ 1 is related to the external O-H bond, 3770 cm⁻¹ is related to hydroxyl in the structure of AlOH or oxygen-hydrogen bonding is related to humidity. According to Figs. 5 b and c, it can be concluded that the adsorbent structure of the adsorption process has not changed much. Therefore, adsorption of copper by adsorbent can be considered as physical

adsorption.

Reviewing the results of Taguchi experiment design

The results of designing the copper adsorption experiment using the *Descurainia Sophia* nanogel are as below:

In these experiments, the removal of copper from aqueous solution using the *Descurainia Sophia* plant nanogel and the effect of three variables of pH, contact time, and adsorbent mass using the Taguchi method, 9 batch adsorption tests were performed based on L9 array design with two repetitions. The percent of efficiency Deletion (% R) was selected as the test response. In all experiments, 100 ml of an aqueous solution of copper was used. In Table (3), the experimental design of these experiments and the response obtained from each experiment (Taguchi L9 array) for copper are presented.

In the future study, the more efficient the removal (%) is, the more ideal the process will be. According to these forms and information are given in Table (4), it can be concluded that the combination of A3, B3, and C3 has the greatest effect on increasing the removal efficiency of copper from aqueous solution by the adsorbent.

According to the results obtained from the diagrams of the main factors for copper removal from aqueous solution, the optimal conditions were predicted as follows:

Statistical Analysis of Variance of Taguchi Method

In addition to analyzing the effect of factors, statistical analysis (ANOVA) shows which factor has a meaningful significance. Variance analysis

Table 3.The Effects of Factors and Their Rankings for Copper Removal.

Level		Factor			
Levei	A	В	С		
1	51.04	56.85	52.42		
2	65.44	63.91	67.89		
3	74.88	70.60	71.06		
E_{i}	23.84	13.75	18.64		
Effectiveness Rank	1	3	2		

Table 4. Optimal levels of the studied factors to achieve maximum copper removal efficiency.

Controllable Factors	Level	Surface value for copper
pН	3	9
Contact Time (min)	3	130
Adsorbent Mass (g)	3	8

is a method used for the average comparison of two or more groups[16]. The results of ANOVA analysis for adsorbing of copper are presented in Table (5) and the effects of the three main factors in the design are presented briefly. Also, because with 9 experiments, the effect of the interaction of factors cannot be investigated, the effect of interactions between AB, AC, and BC has been discarded. Based on the design of ANOVA, the more the P-value of the investigated factor is smaller (close to zero), the more effective it is. In the same condition (P-number is equal), the sum of squares (SS) will be decisive, so the larger the SS number, the more effective it will be. As you can see, the results of ANOVA analysis for adsorbing copper from aqueous solution by the Descurainia Sophia plant nanogel are consistent with the results of the analysis of the effect of the factor considered in the previous section.

The last step in the Taguchi statistical analysis is predicting the response of the optimal situation. After determining the optimal combination of factors and their levels by analyzing ANOVA and analyzing the effect of the agent, we can predict the optimal response from the following relationship[17, 18]:

$$R_{pred} = \overline{R} + (\overline{A}_3 - \overline{R}) + (\overline{B}_3 - \overline{R}) + (\overline{C}_3 - \overline{R})$$
 (2)

In equation (2), R_{perd} is the predicted removal efficiency in the optimal relationship, and \overline{R} is the average of the responses in 18 experiments, which is 63.788 for copper adsorption. The predicted answer by the software is 88/964 to adsorb copper. A confirmation experiment for optimal conditions was repeated for both adsorbents and the removal efficiency for copper was 87/87. The error percentage of the repeated experiment is calculated as:

$$\%Error = \left| \frac{R_{exp} - R_{pred}}{R_{exp}} \right| \times 100 \tag{3}$$

Where $R_{_{\text{exp}}}$ is the removal efficiency obtained from the confirmation experiment and $R_{_{\text{perd}}}$ is the

optimum adsorption capacity predicted by the Taguchi method. The repetition of the experiment had an error of about 1.25 for copper, indicating its repeatability.

As described above, three factors, pH, contact time (min), and adsorbent mass (g) were considered as the main factors for copper removal by the adsorbent.

Effect of pH Parameter on Responses

pH solution is one of the most important adsorption action factors. The inherent value of the optimal pH value in the filtration system can have a significant impact both on the design and construction costs of the facility and on the system, and then on the maintenance and operation of the system. As a result of the accurate study of this parameter, it is important to study the optimal point of the purification process or the adsorption process in this study and its efficiency and the effect of deviation from this point, if necessary, in practice or sensitivity analysis of the parameter. As shown in Table 4, the maximum effect on the removal efficiency of copper from aqueous solution by the adsorbent is the pH parameter (with a lower P-value). The concentration of hydrogen ions is one of the most important parameters affecting the adsorption process. In low pH values, the reduction in adsorption rates is due to the increasing and higher mobility of hydrogen ions than metal ions. The higher mobility of hydrogen ions causes these ions to react with reactive adsorbents before metal ions[19]. Also, at low pHs, negative sites of adsorbent surface decreases, and the number of positive sites of the adsorbent surface would be increased. Consequently, the Hg+2 ions and Hg(OH)+ would not be adsorbed by the adsorbent surface[19]. In Fig. 6, 3D, and Cantor graphs of the effect of pH on contact time on the removal efficiency of copper from aqueous solution by Descurainia sophia plant stem nano is shown. As you can see, the copper removal efficiency increases with increasing the pH and time of contact and reaches its maximum value.

Fig. 7. 3D and Cantor graphs of pH interactions

Table 5. Analysis of variance for the process of copper removal using the Descurainia sophia plant nanogel.

Factor	Degree of Freedom	Square Sum	F amount	P amount
A	2	864.80	36.06	0.027
В	2	283.73	11.83	0.048
С	2	596.78	24.88	0.039
Residual Error	2	23.99	-	-
Total	8	1769.30	-	-

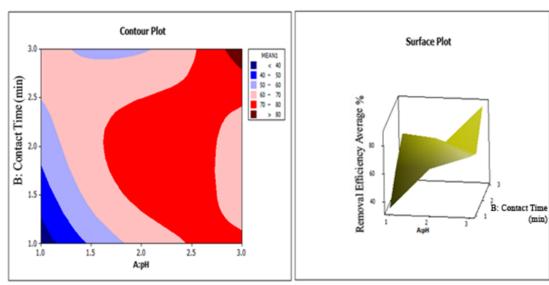


Fig. 6. Diagram effects of main factors of copper adsorption by the adsorbent.

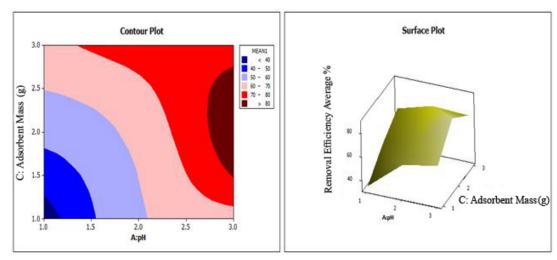


Fig. 7. 3D and Cantor graphs of the effect of pH and adsorbent mass on copper removal by the adsorbent.

and amount of adsorbent material on the removal efficiency of copper for the *Descurainia Sophia* plant nanogel, which, as in the previous state, with increasing the two parameters simultaneously, the efficiency of copper removal from aqueous solution has increased.

The effect of the contact time parameter on responses

Contact time operational parameter is the other variable which its effects on the system responses and its overall effect on the adsorption process and studied adsorbents are one of the goals of this research. The contact time is the other variable

which its effects on the system responses and its overall effect on the adsorption process and studied adsorbents are one of the goals of this research. In any filtration system based on a discontinuous process, the contact time can have a significant effect on the overall system efficiency and therefore the total purge capacity of the system. It can be said that any part of the system's time and its sensitivity to deviation will, directly and indirectly, affect all costs and benefits. It should be noted that the contact time in the adsorption process is an equilibrium parameter. This means, this variable has an optimal and equilibrium point, which at

this point does not have a significant effect on adsorption. As a result, the accurate study of this variable can be very important and necessary. As can be seen in these graphs, with increasing contact time, the removal efficiency of copper increases. In justifying this phenomenon, it can be said that at the beginning of the reaction, with increasing contact time, the adsorbed particles have more chance of penetrating the adsorbent and occupy active adsorbing sites, but when the process reaches the balance, adsorbent would be saturated and increasing the duration of the contact time has no effect on adsorption efficiency. In Fig. 8., the 3D and cantor graphs show the simultaneous effect of adsorbent mass and contact time. It is clear that with increasing the parameters, removal efficiency would also increase.

The effect of the parameter of the amount of adsorbent material on the responses

The operating parameter or the next system variable that has been studied is the amount of adsorbent material in the wastewater samples. The adsorption process takes place on the surfaces and structures of the adsorbent material, so the availability of the adsorbable surface will have a significant effect on the removal efficiency. Like all other operating parameters, this item is also, directly and indirectly, related to processes and costs and other issues related to the purification system. The amount of adsorbent material is perhaps the most important determinant of choice with not choosing that material in an adsorption process-based system because of the cost of procuring and as well as using this substance, if necessary, washed

Table 6. Effect of temperature on the removal efficiency of copper by adsorbent.

Temperature (°C)	Removal Efficiency (%)
20	87.3
30	89.8
40	90.7
50	92.4

or disposed of it can be economical or completely uneconomic. As a result, this parameter must be carefully studied.

The Effect of Temperature

The effect of temperature on adsorption efficiency was investigated at a temperature range of 20-50°C. For adsorption of copper using Descurainia Sophia plant stem nanogel, pH=9, the contact time of 130 minutes, the adsorbent of 8 g of nano gel (0.8 g solids) in 100 milliliters, the initial copper concentration of 50 ppm was selected. The results are shown in Table (6). As can be seen, with increasing temperature, the removal efficiency also increases. However, this amount is not impressive. To analyze this, it can be said that the temperature increase, increases the adsorption power between the adsorbent and the adsorbed particles in the aqueous solution. In justifying this, it can be said that with increasing temperature, the thickness of the boundary layer is increased around the adsorbent, and therefore, the transfer of the adsorbed component from the solution to the adsorbent active sites is easily accomplished, which results in increased efficiency. The positive effect of temperature on the removal efficiency indicates that the copper adsorption reaction is thermosensitive.

Using the data in Table (7), the thermodynamics of adsorption processes have been discussed and the Gibbs free energy (G Δ), enthalpy (Δ H), and entropy (Δ S) parameters based on the formulas (4), (5) and (6) are calculated.

$$K_{c} = \frac{F_{e}}{1 - F_{e}} \tag{4}$$

$$\log K_{c} = \frac{-\Delta H}{2.303RT} + \frac{\Delta S}{2.303R}$$
 (5)

$$\Delta G = -RT \ln K_c \tag{6}$$

In Equation (4), F_e is a part of a water-soluble substance that adsorbs adsorbent material. The thermodynamics of the copper adsorption process

Table 7. Thermodynamic parameters of copper adsorption on adsorbent.

	ΔH (kj/mol)	ΔS (kj/molK)	T °C	ΔG (kj/mol)	\mathbb{R}^2
			20	-4.696	
Cu(II)	15.08	0.067	30	-5.4797	0.9782
			40	-5.9268	
			50	-6.7081	

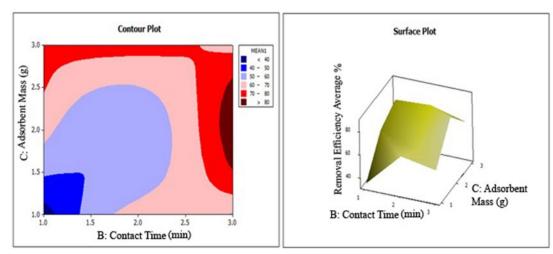


Fig. 8. 3D and Cantor graphs of the Impact of contact time and adsorbent mass on copper removal by adsorb

by the nano-gel of the *Descurainia Sophia* plant stem are shown in Table (7). As can be seen, ΔG is a negative process that indicates the self-sustainability of these processes. Positive ΔH is also indicative of the thermostability of these two processes. Positive ΔS reveals that the solid-liquid phase interface increases accidentally when the ions are stabilized on the adsorbent surface.

CONCLUSIONS

In this study, the adsorbent uptake was used in two physical and chemical methods. The first adsorbent was manufactured using the top-down method from the primary material with mesh 60 in the form of a nanogel. The adsorbent was promoted chemically before being converted into a nanogel, which was then acidified with 1 mol of chloride acid and a magnetic stirrer for 1 hour. For adsorbent nanogel, due to the adsorption reaching to nano dimensions, the mass transfer resistance was lost to reaching adsorbent molecules from the adsorbent surface to active cavities and passageways. Identification of the structure of the Descurainia Sophia plant stem was performed before and after the process of adsorption through the FTIR machine. The results indicated that the adsorbent structure did not change after the adsorption process, which indicates the physical nature of the adsorption process. In the process of copper uptake by nano-stems of the Descurainia Sophia plant, the Taguchi method has the most effect on the removal efficiency of copper pH solution. In the play environment, copper removal is more

than neutral and acidic soluble conditions for the adsorbent. After pH, adsorbent mass and contact time, respectively, had the most effect on copper removal efficiency. By investigating the effect of temperature on the adsorption process and the study of the thermodynamics of the process, it was determined that the process, is a self-adsorption and heat-adsorbing process.

CONFLICT OF INTEREST

There are no conflicts to declare.

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