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Removal of cobalt from contaminated water using magnetic iron oxide nanoparticles

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ABSTRACT: In the present study, the removal of heavy metals (in the case of cobalt removal) from contaminated water using Fe3O4 magnetic nanoparticles and the effects of pH factors, time, cobalt concentration and temperature on cobalt removal were investigated and to describe the data obtained Langmuir and Freundlich equilibrium isotherms have been used for absorption experiments. The experiments were designed with the Taguchi method in the Coalition software, which uses a partial factorial method. Nanoparticles are synthesized by co-operation in the laboratory, and then experiments are performed on four levels of each factor on a simulated solution containing cobalt, and the results are analyzed with the aid of the Coalytic software using the Taguchi standard analysis method. The highest cobalt adsorption rate is 81%, pH is equal to 9, 15 minutes, initial concentration of cobalt is 7 mg / l, and 60 ° C. Also, according to the analysis, the optimum conditions in pH state are 9, the remaining 10 minutes, the initial concentration of cobalt is 25 mg / L, and 20 ° C. The rate of yield in cobalt adsorption is expected to be 383/86 percent. At the end, the result of the experiment under optimal conditions on real industrial waste water contains 36 mg / l of cobalt 60 with an absorption rate of 6.7%, which is 17.1%, due to changes in experimental and actual conditions. The data obtained from adsorption isotherms are consistent with the two models and are more fitted to the Freundlich model.

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1. INTRODUCTION

Iran is among the developing countries. Therefore, the use of heavy metals has reached a high level with the development of industries such as the nuclear industry, dyeing, mining, etc., day by day. If untreated industrial wastewater is abandoned in nature, it will seriously threaten the environment and human health. Heavy metals, unlike organic matter and most other pollutants, do not decompose and, most often, form stable compounds in the environment. Therefore, it is very necessary to find a simple and inexpensive method with an acceptable yield for the treatment of such wastewater. Conventional methods such as chemical deposition, ion exchange, membrane technology, coagulation and flocculation, electrochemical purification, and surface absorption are used to remove heavy metals, but they are not normally economically feasible, and in very low concentrations of metals, they do not show a decrease in metal concentration. Among the conventional methods for the removal of heavy metals, the absorption method has been more prominent in recent years due to its simplicity, relatively low cost, and efficiency in the removal of heavy metal ions. The absorption method can be used by using different materials such as activated carbon, magnetic nanoparticles, modified nanoparticles, modified silica nanoparticles, metal oxide nanoparticles, carbon nanotubes, etc. Extensive laboratory studies have shown that iron nanoparticles can be used to remove the color from organic solutions and organic pollutants from contaminated wastewater. Magnetic iron nanoparticles have also been used to remove heavy metals of copper, cadmium, lead, arsenic, and chromium.

In the present study, the amount of cobalt adsorption by iron oxide magnetic nanoparticles is investigated, as well as the effect of four factors of time, pH, contaminant concentration, and temperature on adsorption. Then, using the Taguchi method in Qualick software, a partial factorial method is designed to test the optimal mode. Finally, the data from the absorption experiments are used to describe the Freundlich and Langmuir equilibrium isotherms.

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1. 2. MATERIALS AND METHODS

2.1. Procedure and design of the test

In the present study, an experiment was first performed on a laboratory sample and at the end, after obtaining the optimal state, the experiment was conducted on industrial wastewater. The experiments were done using the Taguchi method with a co-optic soft technology, using a partial factorial method. The factors considered to be relevant to their effect on the absorption of cobalt and different levels of variables are shown in «Table 1». To obtain more accurate results, each test was performed 3 times. The number of absorption tests at each stage, including three repetitions, is 48.

Table 1. Investigating factors for the absorption of cobalt and their effect on the absorption

Level 4	Level 3	Level 1	Level 1	Variables
9	7	5	3	pH
30	15	10	5	Retention time (min)
60	50	40	25	Temperature (°C)
20	15	7	3	Pollutant concentration (mg/l)

Table 2. Percentage of the contribution of each factor to the absorption of cobalt.

Factor	Percentage of the contribution of each factor to absorption
pH	71.58
Retention time	7.812
Initial concentration of cobalt	7.75
Temperature	7.99
Error	4.87

Table 3. Optimal absorption conditions.

Factor	Optimum level	The optimal value of each factor
pH	4	9
Retention time (min)	2	10
Initial concentration of cobalt (mg/L)	1	25
Temperature (°C)	4	20

2.2 . Synthesis of Fe_3O_4 nanoparticles

Different methods such as microemulsion, polypropylene, and chemical coexistence exist for the synthesis of Fe3O4 nanoparticles. Among the aforementioned methods, the use of chemical co-modality is more common in terms of simplicity, cheaper equipment, and high production potential. In this study, chemical co-modality was used to synthesize Fe_3O_4.

3. RESULTS AND DISCUSSION

48 encoded samples were analyzed by atomic spectrometry. The effect of each factor on the absorption of cobalt has been studied. To study the adsorbent properties, FTIR, XRD, and SEM analyses were employed.

3.1. The contribution of each factor to the absorption rate

Using Eq. (1) given below and Taguchi's standard analysis, in the co-optic software, the contribution of each factor, as well as the contribution of the error in this research, are calculated, which results are shown in «Table 2».

$$V_m = S_m / f_m \quad (1)$$

3.2. Optimum condition

With the help of the Coalition software, using the Taguchi standard analysis, optimum conditions for the highest cobalt adsorption have been obtained. These conditions can be seen for each factor in «Table 3».

3.3. Examination of adsorption isotherms

In the present study, Freundlich and Langmuir isotherm models have been used to draw up absorption data. The correlation coefficients of the Freundlich and Langmuir models are 0.92 and 0.91, respectively. Investigating the values of the correlation coefficients shows that the experimental data are consistent with both isotherms and it can be concluded that the absorption of cobalt by the adsorbent of magnetic iron oxide nanoparticles is carried out both in a single layer and in layers, but it is more fitted to the Freundlich model.

4. CONCLUSIONS

The presence of various types of environmental pollution has become one of today's problems in human societies. In this regard, the release of heavy metals in nature causes environmental concerns for humans and human societies. In the present study, the removal of heavy metals (in the case of cobalt removal) from contaminated water using Fe3O4 magnetic nanoparticles and the effects of pH factors, time, cobalt concentration, and temperature on cobalt removal were investigated and to describe the data obtained Langmuir and Freundlich equilibrium isotherms have been used for absorption experiments. The experiments were designed with the Taguchi method in the Coalition software, which uses a partial factorial method. Nanoparticles were synthesized by co-operation in the laboratory and then experiments were performed on four levels of each factor on a simulated solution containing cobalt and the results were analyzed using

Taguchi standard analysis using Qoalick software. Finally, in optimal experimental conditions, cobalt was removed from the industrial wastewater.

The findings of this research can be summarized as follows:

1) According to SEM, XRD, and FTIR analyses, the synthesized Fe3O4 nanoparticles have a spherical shape, and their size ranges from 30 to 50 nm. These synthesized nanoparticles are also quite magnetic.

2) The results showed that the pH, cessation time, temperature, and initial concentration of cobalt on the cobalt removal efficiency were effective.

3) According to the average results, the percentage of adsorption of cobalt at pH was 9 with the highest absorbance of 67.575%.

4) According to the results of the time to the equilibrium of the absorption process by the Fe3O4 nanoparticles, it is 10 minutes, at which time the average absorption percentage has the highest value compared to the other three levels of time remaining, which is equal to 54.302%.

5) With an increase in the initial concentration of cobalt to 20 mg / L, the average absorption rate of the other levels of this factor has the highest level of 53.455%.

6) The effect of temperature on inverse adsorption rate and by increasing the temperature up to 50C, the average cobalt absorption is 43.317%. At the same time, at 25 °C, the average absorbs its highest value as compared to other factor levels, which equals 55.224%. The results of the study of the thermodynamic parameters indicate that the ΔG ° is negative at different temperatures, which shows the spontaneous nature of the absorption process. Neutralization of enthalpy changes The adsorption reaction on the adsorbent indicates that the process is thermosensitive and the entropy changes are positive, indicates an increase in dissociation in the solid-soluble surface during absorption, and a slight change in the absorbent and absorbent structural changes, and thus the inviolability of the absorption action.

7) The results showed that pH is 9, the remaining 10 minutes, the initial concentration of cobalt 20 mg / L and 25 °C are optimal conditions. Also, the percentage of adsorption in these conditions was predicted to be 86.383%.

8) The result of the experiment in optimal conditions on real industrial wastewaters containing 36 mg / L of cobalt with an absorption rate of 71.6, which is different from the predicted value and has a difference of 17.11% compared to the laboratory conditions.

9) The study of Freundlich and Langmuir adsorption equilibrium isotherms show that experimental data are consistent with both isotherms and it can be concluded that the absorption of cobalt by the adsorbent of magnetic nanoparticles of iron oxide is done in a single layer as well as in layers, but more fit with the model Freundlich has.

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