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RESEARCH ARTICLE

Chemical Synthesis for Mesoporous Silica (MCM-41) and Evaluating Its Efficiency in Removal of Heavy Metals Ions

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ABSTRACT

The pollution of water sources due to harmful chemicals, especially heavy metal ions such as Ni^{++} and Co^{++}, remains a global challenge. To address this issue, various studies have focused on developing new treatment methods. Nanotechnology provides innovative techniques for efficiently removing heavy metals and other pollutants from water and wastewater. It is crucial to eliminate these hazardous heavy metals to protect both human health and the environment. Mesoporous silica (MCM-41) is a type of silica nanoparticles with pores ranging from 2 to 50 nm in diameter, and a total diameter below 1 μm. It is gaining attention as a promising adsorbent due to its large surface area, high pore volume, thermal and mechanical stability, and organized pore structure. The synthesis of mesoporous silica (MCM-41) using tetraethyl orthosilicate (TEOS) as a source was successful, and the material was characterized using FTIR, FESEM, XRD, and TGA techniques. The removal abilities of the synthesized silica for Ni^{++} and Co^{++} ions from water samples were tested under various conditions, including pH, initial concentration, contact time, and mass. The results showed that Ni^{++} ions were removed with an effectiveness of 96% and Co^{++} ions with an efficiency of 97.8%. The most effective removal rates were observed at a pH of 9 and a contact time of 180 minutes at temperatures of 25°C, 35°C, and 45°C. The adsorption data was analyzed using the Freundlich, Langmuir, and Temkin isotherm models.

Keywords: Efficiency removal, Freundlich, Langmuir and temkin isotherm models, Mesoporous silica (MCM-41), Ni^{++} and Co^{++} ions, Wastewater

Introduction

Heavy metal (HM) pollution has long been a significant source of environmental deterioration.[1] Nickel and cobalt ions, which are hazardous heavy metal ions, are currently causing significant ecological challenge due to the harmful effects of these elements as toxic pollutants for organisms.[2] Water contamination, notably the pollution of heavy metals within water, has become known as a worldwide environmental concern. Heavy metals, as significant contaminants in wastewater, do not undergo biodegradation and build up in the environment.[3,4] Consequently, removing heavy metals from water is essential to alleviate their harmful effects on the ecosystem.[5] Wastewater pollutants, primarily due to human activity, negatively impact organisms, including plants and animals. Tanning, battery manufacture, pesticides, mining, refineries, paints, and dyes are the primary contributors to water pollution by nickel and cobalt ions.[6] High amounts of harmful and hazardous pollutants in industrial effluent have been a growing concern.[7] The water has seen an alarming increase in toxic substances due to natural phenomena such as spring waters, volcanic eruptions, erosion, and bacterial activity. So, applying several techniques to remove heavy metals from water is essential, such as ion exchange, membrane separation,[8] phytoextraction,[9]

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flocculation,[10] oxidation-reduction,[11] electrochemical treatment,[12] and reverse osmosis.[13] However, these techniques have multiple disadvantages, such as ineffective removal, limited effectiveness, delicate operational requirements, and expensive disposal. To overcome these limitations, researchers have developed various approaches aimed at producing more cost-effective aerated effluents. Adsorption is typically regarded as a favored technique for eliminating heavy metals, owing to its benefits of diverse adsorbents, high efficacy, straightforward operation, favourable reversibility, and low expense. Adsorption can be classified into two categories: physical adsorption and chemical adsorption (chemisorption). Physical adsorption occurs when van der Waals forces, not specific to the substance, cause the adsorbate concentration to rise at the interface. On the other hand, chemical reactions between the adsorbate and the adsorbent cause chemical adsorption, resulting in the formation of covalent or ionic bonds. Physical adsorption has little specificity or reversibility, and the heat effect is small, measured in (kJ/mol). In contrast, chemisorption is selective and typically irreversible, with a heat range of tens to hundreds of (kJ/mol).[14,15] Researchers are now investigating the synthesis and design of an appropriate adsorbent with a high capacity for pollutant adsorption. Mesoporous silica is an example of a silica nanoparticle with unique properties, including a substantial surface area, a high volume of pores, a constant and adjustable pore size, a relatively low density, and a non-hazardous composition.[15,16] Many studies have used MCM-41 to remove pollutants from wastewater.[17,18]

The present study aims to synthesize mesoporous silica (MCM-41) and test its capacity to remove $Ni{+}{+}$ and $Co{+}{+}$ ions from aqueous solutions directly. The study also identified the ideal variables (pH, contact time, initial concentration, and amount of adsorbent) for removal. The adsorption data was evaluated using isotherm models.

Materials and methods

The reagents utilized in the preparation are of high purity and purchased from tetraethyl orthosilicate ($C_8H_{20}O_4Si$) (TEOS) 99% from A Johnson Matthey, Germany; cetyltrimethylammonium bromide $C_{16}H_{33}N\ (CH_3)_3Br$ (CTAB) 99% from AVONCHEM, UK; nickel nitrate $Ni(NO_3)_2.6H_2O$ from BDH, UK; cobalt nitrate $Co(NO_3)_2.6H_2O$ from G.P.R., UK; zinc nitrate $Zn(NO_3)_2.6H_2O$ from Scharlau; ethanol (C_2H_5OH) 99.9% from BDH, Netherlands; and ammonia (NH_3) 25% from BAKER ANALYZED.

Characterization of MCM-41

We carried out a detailed structural characterization of the generated obtained MCM-41. The powder X-ray diffraction (XRD) patterns were obtained using a Bruker D8 Advance diffractometer with CuKα radiation at 40 kV and 40 mA. The TGA analysis was carried out in flowing nitrogen using a Mettler-Toledo instrument (USA). Fourier transform infrared spectroscopy was monitored using a Bruker spectrometer. Field emission scanning electron microscopy (FE-SEM) was obtained using the Imaging-EDS-Mapping-Line-EBSD Instrument (Germany).

Synthesis of (MCM-41)

50 g or 53.6 ml of tetraethyl orthosilicate (TEOS) were put in a one-litre polyethene bottle that contained 417.5 g or 417.5 ml of high-purity deionized water with a resistivity of about 18.2 megaohms per centimetre, 268.5 g or 367.8 ml of ammonia (25 weight per cent), and 10.5 grams of cetyltrimethylammonium bromide (CTAB). The mixture was stirred for 30 minutes and heated at 80 °C for 96 hours. The product was obtained by cooling, filtering, washing with cold ethanol, drying, and calcination at 550°C (Baum).[19] Fig. 1 shows the Mesoporous silica (MCM-41) preparation process.

Batch adsorption studies

The capacity of mesoporous silica (MCM-41) to remove nickel and cobalt heavy metal ions from aqueous solutions was investigated using batch adsorption tests in a shaker. The ideal adsorption conditions should be determined. These experiments looked at the prepared (MCM-41) susceptibility to Ni^{++} and Co^{++} ions from aqueous solutions under various conditions, such as pH ranging from 3 to 9, contact time ranging from 15 to 180 minutes, initial concentrations of Ni^{++} and Co^{++} ions (10 to 100 mg/L), and adsorbent dose on nickel and cobalt adsorption efficiency (5 to 60 mg in 10 ml). In each experiment, 10 mg of mesoporous silica (MCM-41) was combined with 10 ml of solutions containing various amounts of Ni^{++} and Co^{++} ions. In each experiment, 100 mg of mesoporous silica (MCM-41) was mixed with 10 ml of solutions containing multiple quantities of Ni^{++} and Co^{++} ions. The samples were centrifuged at 5,000 rpm for 10 minutes to remove any remaining suspended material after being shaken in a water bath at 100 rpm to ensure the adsorbent and adsorbate made significant contact with one another. A final atomic absorption device was used to calculate the concentration of the sample's nickel and cobalt $Ni{+}{+}$ and

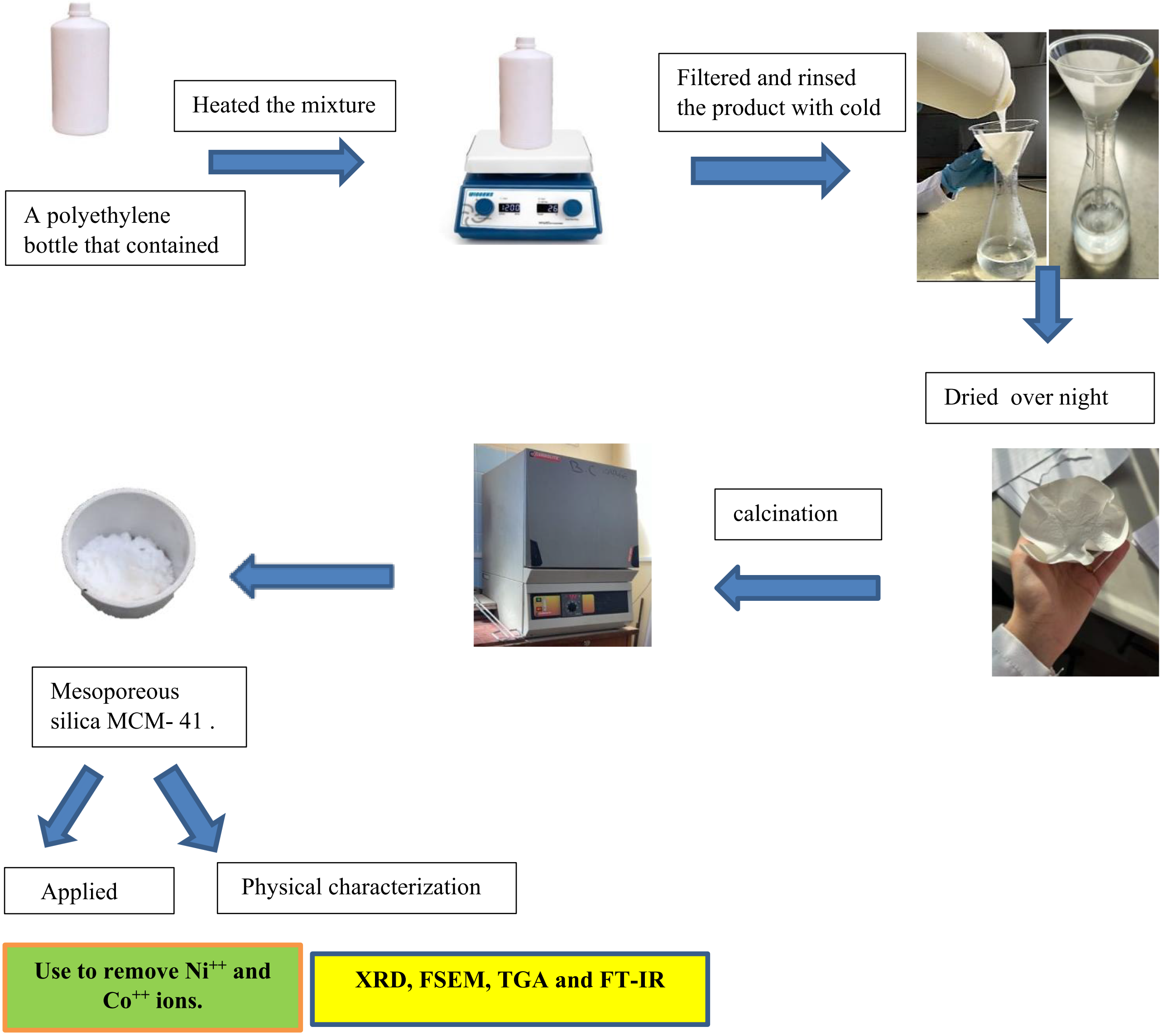

Fig. 1. Mesoporous silica (MCM-41) preparation process.

Co^{++} ions. At temperatures of 25 °C, 35 °C, and 45 °C, all experiments were carried out. Eqs. (1) and (2) were used to calculate the adsorption capacity (qe) percentages and removal efficiency (%R) for Ni^{++} and Co^{++} ions, respectively.

$$.\%R = \frac{(Co - Ce)}{Co} \times 100 \tag{1}$$

$$qe = \frac{(Co - Ce) \times V}{m} \tag{2}$$

Where,

Co: represents the initial metals ion concentrations (milligram per litter)

Ce: the concentration of metals ion at equilibrium (milligram per litter).

V: volume of solution (litter)

m: the mass of adsorbent (gram)

Results and discussion

Characterization of mesoporous silica (MCM-41)

Fourier transforms infrared spectroscopy

The FTIR spectra of mesoporous silica (MCM-41), Fig. 2, show strong peaks in the ranges of 1400–1700 cm^{-1} and 800–1000 cm^{-1}. The spectrum of MCM-41 has a significant peak at around 1000 cm^{-1}, which shows the presence of Si-O stretching vibrations often observed in silicates and MCM-41.[20]

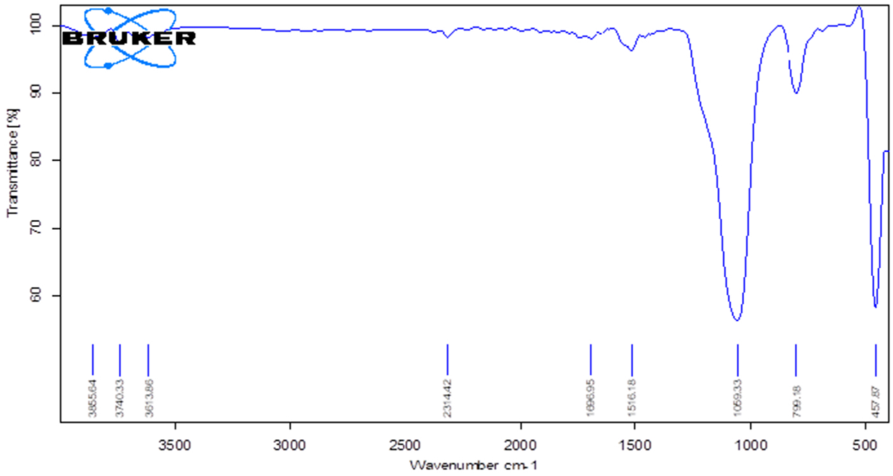

Fig. 2. FTIR spectra of mesoporous silica.

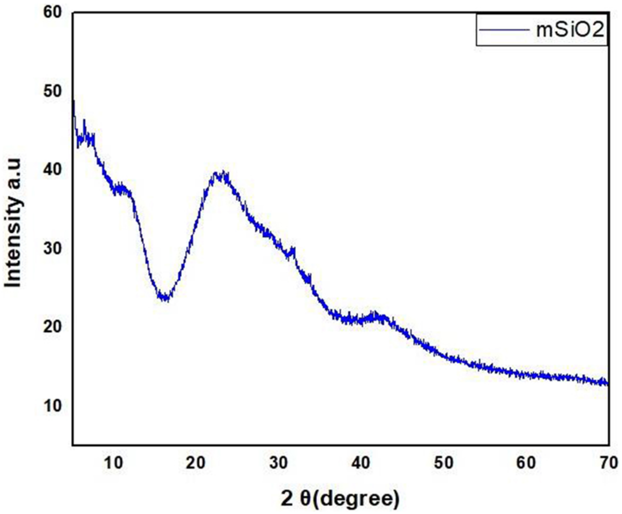

Fig. 3. X-ray diffraction of (MCM-41).

X-ray diffraction

X-ray patterns for the (MCM-41) are displayed in Fig. 3. These patterns yield data on the arrangement of atoms inside the lattice structure. The X-ray diffraction (XRD) pattern of MCM-41 has prominent peaks at around 5 degrees and 23 degrees. In addition, the small-angle X-ray scattering pattern has a prominent peak that corresponds to a d-spacing of 3.5 nm. The result of this study is consistent with previous studies.[20]

Field emission scanning electron microscopy (SEM) analysis

Field emission scanning electron microscopy (FE-SEM) was employed to study the surface morphology of the MCM-41, as shown in Fig. 4. After analyzing the resolution of MCM-41, it is evident that the picture shows an amorphous structure without any observable crystals. The result in this study is consistent with previous studies.[21]

Thermogravimetry differential thermal (TGA) analysis

The TGA-DTA curve for mesoporous silica (MCM-41), Fig. 5, has a notable peak at 90 °C, corresponding to the removal of physically adsorbed water. Subsequently, there is a minor, gradual, and continuous weight loss from this temperature up to 800 °C, attributed to the elimination of surface OH- groups.

Studied adsorption

Effect of pH

The impact of pH on the adsorption of heavy metal ions, such as Ni^{++} and Co^{++} ions, in MCM-41 in an aqueous solution is widely known.[22] The present part studies the impact of changing the pH of the solution from 3 to 9 on removing Ni^{++} and Co^{++} ions, keeping a constant initial concentration of 100 mg/L for both Ni^{++} and Co^{++} ions. The contact time had been set for 3 hours, and the adsorbent dose was 0.01 g. The duration of contact was determined to be 3 hours. Fig. 6 shows the adsorption of Ni^{++} and Co^{++} ions on MCM-41 at 25 °C, 35 °C, and 45 °C. experiment.

The results can be divided into two pH areas. The first pH range is between 3 and 5, during which the removal effectiveness of nickel and cobalt experiences a significant rise as the pH level rises. As an example, the effectiveness of removing Ni^{++} ion significantly increased from 5% to 85%, while the removal efficiency of cobalt rose from 10% to 80% when the pH level increased from 3 to 5. The interaction may be characterized by the charge of the adsorbent surface and the concentration of hydrogen ions in the solution. When the pH level drops below three (pH $<$ 3), the concentration of hydrogen ions

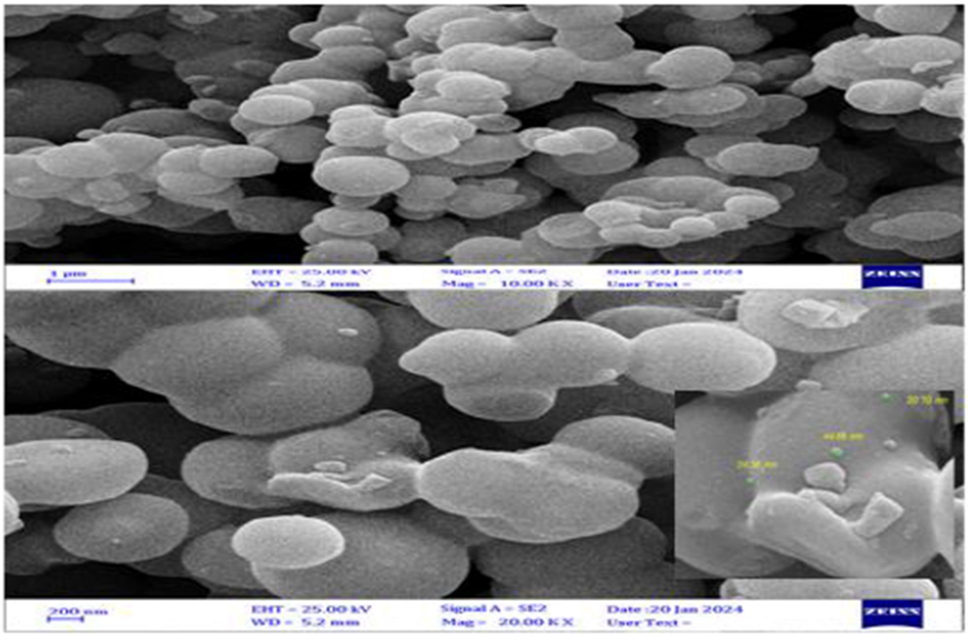

Fig. 4. Field emission scanning electron microscopy (FESEM) images for synthesized (MCM-41). (1 μm and 200 nm).

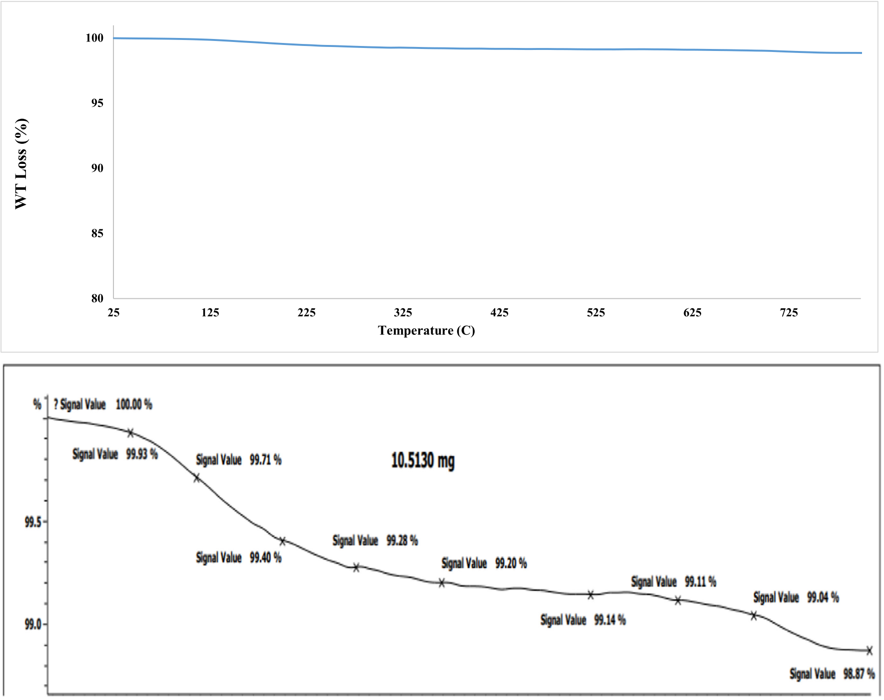

Fig. 5. TGA data for (MCM-41).

(H^+) in the surrounding medium increases. Therefore, the surface of the adsorbent displays a positive charge. Studies were conducted on the competition between H^+ ions and metal ions and the repulsion between metal ions and positively charged adsorbent particles.[23] The observed effect may be related to the concentration of protons at the pH level of 25.

Effect of contact time

The contact time is another major factor that affects the efficient removal of Ni^{++} and Co^{++} ions from aqueous solutions. Therefore, it is critical to optimize the contact time for the highest level of absorption efficiency. Identifying the contact time at which the metal adsorption rate achieves its maximum

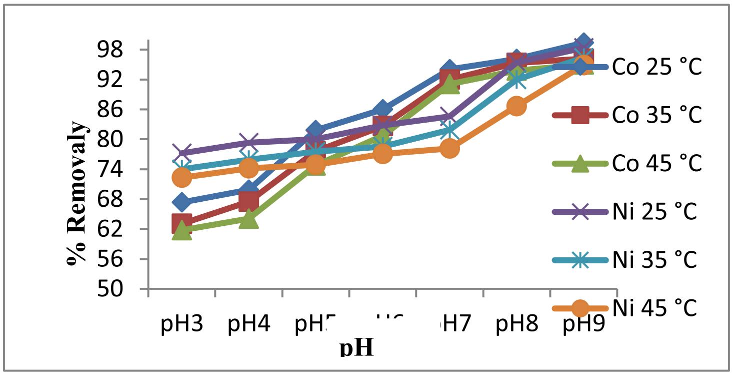

Fig. 6. Effect of pH on % Ni^{++} and Co^{++} ions removal, with a range of pH of the solution (3 to 9), the initial solution concentration of 100 mg/L, 10 mg of adsorbent, and a solution volume of 10 mL, at temperatures of (25 °C, 35 °C, and 45 °C), and an equilibrium time of 3 h.

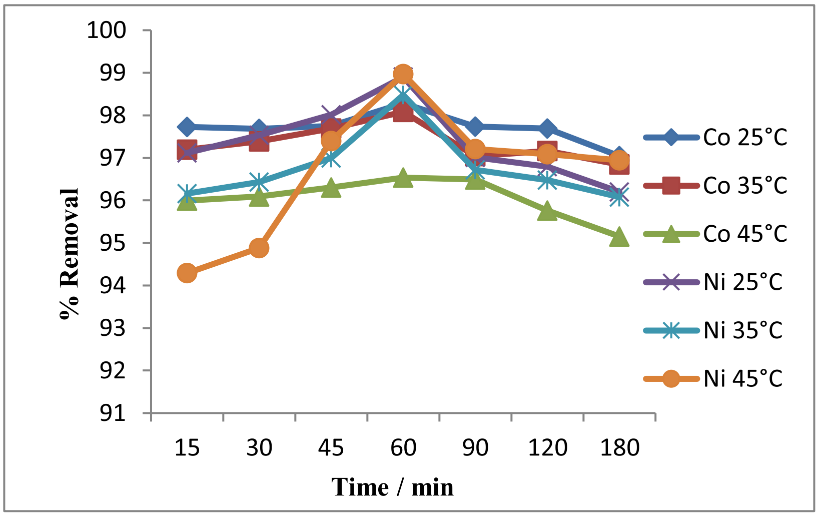

Fig. 7. Effect of contact time on % Ni^{++} and Co^{++} ions removal at pH 9, initial concentration 100 mg/L, 10 mg adsorbent, at temperatures of (25 °C, 35 °C, and 45 °C), and for various time intervals (15, 30, 45, 60, 90, 120, and 180 minutes).

efficiency is essential. The pH values of 6 were previously corrected for Ni^{++} and Co^{++} ions.[20]

Ni^{++} and Co^{++} ions removal efficiency reaches its peak after approximately 3 hours, with a recorded value of about 95% for Ni^{++} ion and 98% for Co^{++} ion, as shown in Fig. 7. The results showed a beneficial relationship between contact time and absorption efficiency. This phenomenon can be related to the lengthening of the time of contact, which consequently increases the possibility of a relationship between the particles of the adsorbent surface and the larger ions of the contaminant that are expected to be removed 24. The results obtained in this study are in agreement with previous studies.[24]

Effect of concentration

The ratio of adsorbents to the quantity of pollutant ions greatly influences the adsorption of heavy metals by low-cost adsorbents. Researchers have conducted batch adsorption studies on treated mesoporous silica (MCM-41) to determine the most effective adsorbent. This research aimed to look at the process of adsorption of Ni^{++} and Co^{++} ions under certain conditions at a temperature of 25°C and a pH of 9. The adsorbent concentration varied from 10 mg/L to 100 mg/L, while the concentration of Ni^{++} and Co^{++} ions remained constant at 100 mg/L. Fig. 8 shows the percentage of Ni^{++} and Co^{++} ions adsorption on mesoporous silica (MCM-41) concerning the adsorbent.

The results showed that the removal efficiency for Ni^{++} and Co^{++} ions was 90% and 88% at a concentration of 10 mg/L and increased to about 87% and 84% at 100 mg/L, respectively. The results of this study suggest that the adsorption efficiency correlates closely with the surface area of the adsorbent (the amount of adsorbent in the solution). The phenomenon may be explained by the increased surface area, which leads to more active sites for the binding of metal ions. As a result, this causes an increased removal rate of heavy metal ions from contaminated

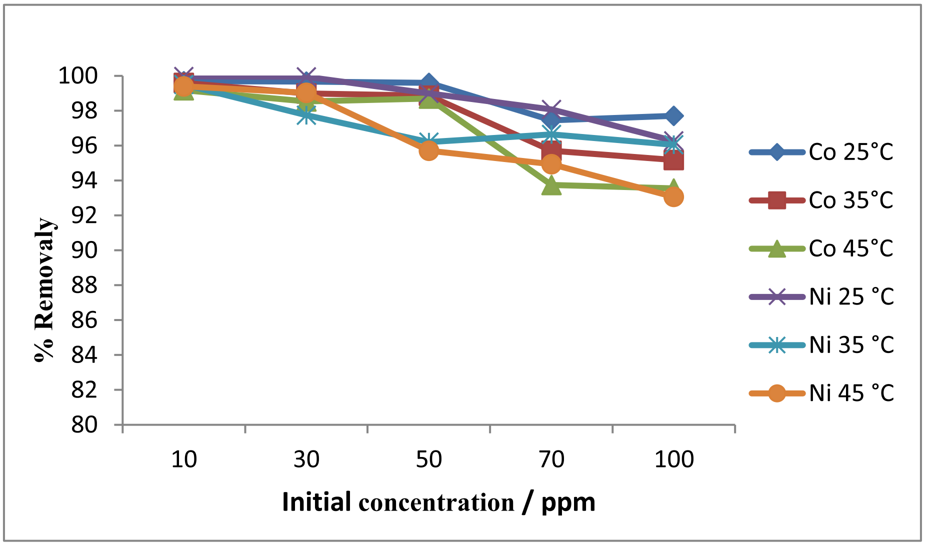

Fig. 8. Effect of initial concentration on % Ni^{++} and Co^{++} ions at pH 9, at (25 °C, 35 °C, and 45 °C), an equilibrium time of 3 h, and sorbent dose 10 mg: 10 ml solution.

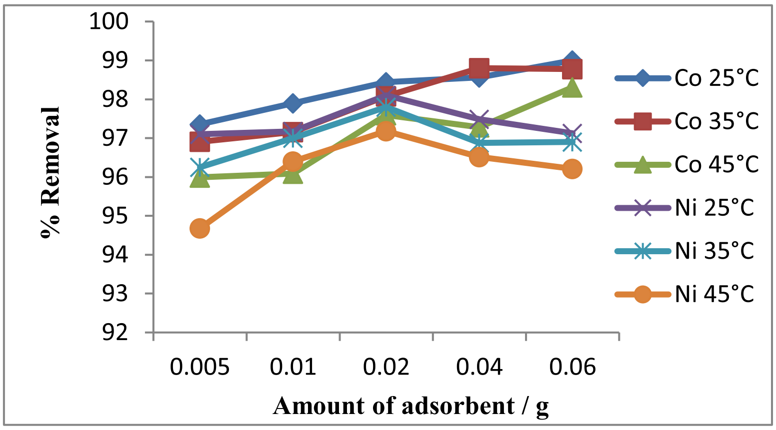

Fig. 9. Effect of adsorbent dose on % Ni^{++} and Co^{++} ions removal with conditions set at pH 9, at temperatures of (25 °C, 35 °C, and 45 °C), an equilibrium time of 3 h, a total volume of 10 ml, and an initial concentration of 100 mg/L at different amounts of ions (5, 10, 20, 40, and 60 mg).

water.[25] The findings obtained in our study agree with previous studies.[26,27]

Dose of Ni^{++} and Co^{++} ions

The initial amount of these ions in the contaminated solution determines the amount of metal ions absorbed from the aqueous solution. Studies are essential for determining the optimal concentration of metal ion solutions while maintaining other parameters constantly. The experiment used mesoporous silica (MCM-41) as an adsorbent to assess the adsorption of Ni^{++} and Co^{++} ions. Initial concentrations of the adsorbent were 100 mg/L, while different amounts of ions (5, 10, 20, 40, and 60 mg) were used. The temperature was maintained at 25°C, 35°C, and 45°C, and the pH ranged from 3 to 9. Fig. 9 displays the results of the experiment. Results suggested that at a dose of 10 mg/L, the removal effectiveness of Ni^{++} and Co^{++} ions is approximately 99%.[28]

At a concentration of 100 mg/L, the removal efficiency for Ni^{++} ion was 95%, and for Co^{++} it was 97%. The results showed a negative relationship between the concentration of polluting ions and the adsorption efficiency. A decrease in the number of active sites on the surface of the adsorbent material is responsible for the reduced ability to bind heavy metal ions in the polluted solution.[29]

Sorption isotherms

To get the equilibrium data, this study involved fitting the experimental adsorption data to the

Table 1. Parameters and equations of the Freundlich, Langmuir, and Temkin linear isotherm model.

Freundlich	Line equation	R^2	1/n	K_F
Ni_(MCM-41) (25°C)	$y = 0.3166x + 1.7966$	$R^2 = 0.9999$	0.3166	62.6037
Ni_(MCM-41) (35°C)	$y = 0.4955x + 1.63$	$R^2 = 0.9806$	0.4955	42.65795
Ni_(MCM-41) (45°C)	$y = 0.4722x + 1.5707$	$R^2 = 0.9928$	0.4722	37.21346
Co_(MCM-41) (25°C)	$y = 0.5166x + 1.7822$	$R^2 = 0.9961$	0.5166	60.56197
Co_(MCM-41) (35°C)	$y = 0.4515x + 1.654$	$R^2 = 0.9896$	0.4515	45.08167
Co_(MCM-41) (45°C)	$y = 0.481x + 1.5631$	$R^2 = 0.9792$	0.481	36.5679
Langmuir	**Line equation**	**R^2**	**q_m, (mg/g)**	**K_L (L/mg)**
Ni_(MCM-41) (25°C)	$y = 0.0003x + 0.0156$	$R^2 = 0.9901$	64.10256	213675.2
Ni_(MCM-41) 35°C)	$y = 0.0044x + 0.0134$	$R^2 = 0.9928$	74.62687	16960.65
Ni_(MCM-41) (45°C)	$y = 0.0052x + 0.0134$	$R^2 = 0.9938$	74.62687	14351.32
Co_(MCM-41) (25°C)	$y = 0.0009x + 0.014$	$R^2 = 0.9932$	71.42857	15.55556
Co_(MCM-41) (35°C)	$y = 0.0035x + 0.0144$	$R^2 = 0.9853$	69.44444	4.114286
Co_(MCM-41) (45°C)	$y = 0.0073x + 0.0125$	$R^2 = 0.994$	80	1.712329
Temkin	**Line equation**	**R^2**	**B_T (J/mol)**	**K_L (L/mg)**
Ni_(MCM-41) (25°C)	$y = 8.6604x + 61.783$	$R^2 = 0.9623$	8.9904	964.9806
Ni_(MCM-41) (35°C)	$y = 18.714x + 63.255$	$R^2 = 0.9729$	18.714	29.32636
Ni_(MCM-41) (45°C)	$y = 35.239x + 33.983$	$R^2 = 0.9656$	35.239	2.623102
Co_(MCM-41) (25°C)	$y = 11.822x + 61.822$	$R^2 = 0.9682$	11.822	186.6813
Co_(MCM-41) (35°C)	$y = 22.076x + 57.876$	$R^2 = 0.977$	22.076	13.75869
Co_(MCM-41) (45°C)	$y = 22.469x + 48.86$	$R^2 = 0.9959$	22.469	8.798239

Langmuir and Freundlich isotherms. Mathematical models known as adsorption isotherms describe the ability of an adsorbate to absorb the adsorbent. The Langmuir model is a fundamental equation of isotherm that posits a surface with a certain number of binding sites, each having equal energy or heat and no lateral interactions. The Langmuir model represents the isotherm of the adsorption data by graphing the ratio of equilibrium concentration to adsorbed quantity (Ce/qe) against the equilibrium concentration (Ce). Plotting the natural logarithm of the amount adsorbed (qe) against the natural logarithm of the equilibrium concentration (Ce) in milligrams per liter (mg/L) represents the isotherm for the Freundlich model. These isotherm models can provide valuable insights into the adsorption process in the studied system and its efficiency level. The Langmuir isotherm describes the adsorption process on the adsorbent surface's randomly distributed sites.[30] The Langmuir constant K_L) L/mg). This constant calculates the heavy metal ions' affinities for the (MCM-41) sites. The KL constant, therefore, reflects the strength of the interaction between the heavy metal ions Ni^{++} and Co^{++} ions and the (MCM-41) sites.[31]

The Temkin isotherm considers the influence of the interactions of the adsorbed compounds. The development of this isotherm model involved considering the adsorption enthalpy values of all molecules present in an aqueous phase. This isotherm theory states that the heat of adsorption for all molecules in the layer will drop linearly with the number of active attachment sites while disregarding the concentration limits at the lower and higher ends.[32] The BT (J/mol) was determined to be 20.98 and 18.789 (J/mol) for Ni^{++} and Co^{++} ions, respectively. Table 1 shows all the results mentioned above.

Conclusion

In the current study, we synthesized mesoporous silica (MCM-41) by a straightforward procedure. The characterization by FTIR, XRD, FSEM, and TGA analysis enables a greater understanding of the material generated and can be used in future work to optimize the (MCM-41) for pollutant removal. Mesoporous silica (MCM-41) has been employed for the adsorption of Ni^{++} and Co^{++} ions from the aqueous phase. The results were obtained at a temperature of (25°C, 35°C, and 45°C), with a pH ranging from 3 to 9 and an adsorption duration ranging from 15 to 180 minutes. When analyzing the experimental data of the adsorption process under isothermal conditions, it proved that the Freundlich isotherm model supplied a more accurate representation of the adsorption data compared to the Langmuir model. Mesoporous silica (MCM-41) showed a removal efficiency of around 95% for Ni^{++} and Co^{++} ions and approximately 96% and 95.8% at different temperatures. The optimal pH range for this removal process was between 6 and 7. The percentage reduction in Ni^{++} and Co^{++} ions drops from 96.27%, 96.05%, and 95.06% to 97.803%, 95.18%, and 94.55%, respectively, when the initial concentration is raised from 10 mg/L to 100 mg/L. The q_m (mg/g) values for Ni^{++} and Co^{++} ions were found to be 213.34 and 186.132, respectively. The values for the reciprocal of n, denoted as 1/n, for Ni^{++} and Co^{++} ions are 0.447 and 0.396, respectively. This indicates that the adsorptions of Ni^{++} and Co^{++} ions are representative, but the adsorption of Ni^{++} is considerably more intense. All the conclusions obtained indicate the preparation of a high-purity compound that is very efficient in removing Ni^{++} and Co^{++} ions from their aqueous solutions, which suggests the possibility of using this material in water purification.

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Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all figures and tables in the manuscript are ours. Furthermore, figures and images that are not ours have been included with the necessary permission for re-publication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at University of Anbar.

Authors' contribution statement

I. M. F conducted the experimental and original draft preparation, designing, validation, and data acquisition for this manuscript. W. M. S was the supervisor for the research and did the conception, editing, and review of the manuscript.

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التحضير الكيميائي للميزوبوريوس سيليكا (*MCM-41*) وتقييم كفاءتها في إزالة أيونات النيكل والكوبلت من المحاليل المائية

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الملخص

لا تزال مشكلة تلوث مصادر المياه بسبب المواد الكيمياوية الضارة من التحديات المستمرة وخاصة التلوث بايونات المعادن الثقيلة مثل أيونات النيكل والكوبلت مشكلة في جميع أنحاء العالم. ولذلك، ركزت العديد من الدراسات على تطوير خيارات علاجية جديدة. واحدة من هذه هي تقنية النانو. تقدم تقنية النانو تقنيات جديدة لزيادة الكفاءة في إزالة المعادن الثقيلة والملوثات العضوية وغير العضوية من الماء ومياه الصرف الصحي اعتماداً على نوع التلوث، ومن أجل حماية صحة الإنسان والبيئة، لا بد من إزالة هذه المعادن الثقيلة الخطرة من المياه. يشير مصطلح السيليكا متوسطة المسام (MCM-41) إلى جسيمات السيليكا النانوية التي تمتلك مسام يتراوح قطرها من 2 إلى 50 نانومتر، ويبلغ قطرها الإجمالي أقل من 1 ميكرومتر. كان هناك اهتمام كبير باستخدام السيليكا متوسطة المسام (MCM-41) كمادة ماصة في معالجة مياه الصرف الصحي. تحظى السيليكا متوسطة المسام (MCM-41) بالاهتمام باعتبارها مادة مازة واعدة نظرًا لامتلاكها مساحة سطحية كبيرة، وحجم المسام الكبير، وبنية المسام المنظمة، والاستقرار الحراري والميكانيكي، والإمكانات الواسعة للتشغيل لتعزيز قدرتها على الامتزاز. تم تصنيع السيليكا المسامية (MCM-41) بنجاح وتوصيفها باستخدام تقنيات FTIR وFESEM وTGA وXRD. قمنا بعد ذلك بتقييم قدرة السيليكا المُصنّعة على إزالة أيونات النيكل والكوبلت من عينات المياه في ظل ظروف مختلفة، مثل الرقم الهيدروجيني والتركيز الأولي ووقت التلامس وكتلة المادة المازة. بلغت كفاءة إزالة ايونات النيكل و الكوبلت 96% و97.8% على التوالي، مع تحقيق معدلات إزالة مثالية عند درجة حموضة (9-3) ووقت التلامس (15-180) دقيقة عند درجات حرارة (25°C, 35°C 45°C). تم تقييم بيانات الامتزاز باستخدام نماذج فروندليتش ولانجميور وتيمكين.

الكلمات المفتاحية: الإزالة الفعالة، نماذج فروندليتش ولانجميور وتيمكين، السيليكا متوسطة المسام، أيونات النيكل والكوبلت، مياه الصرف الصحي.