

## SUSTAINABLE REMEDIATION OF COBALT ION FROM WASTER USING CELLULOSE ETHER-ESTER DERIVATIVES

Syed Muhammad Zafar Iqbal Shah<sup>1</sup>

<sup>1</sup>Faculty of Sciences, Superior University Lahore, Lahore 54000, Pakistan

<sup>1</sup>[zafarshah971@gmail.com](mailto:zafarshah971@gmail.com)

Muhammad Umar<sup>2</sup>

<sup>2</sup>Departed of Chemistry, University of Education Lahore, Jauharabad Campus

<sup>2</sup>[muhammadumar.chemist@gmail.com](mailto:muhammadumar.chemist@gmail.com)

Muhammad Arshad<sup>3</sup>,

<sup>3</sup>Department of Chemistry, Government College University Faisalabad, Faisalabad, Pakistan

<sup>3</sup>[arshadawan15@gmail.com](mailto:arshadawan15@gmail.com)

Muhammad Ashraf Shaheen<sup>\*4</sup>

<sup>\*4</sup>faculty of sciences, superior university lahore, lahore 54000, pakistan

<sup>4</sup>[ashraf.shaheen.sgd@superior.edu.pk](mailto:ashraf.shaheen.sgd@superior.edu.pk)

### Author Details

#### Keywords:

Hydroxypropylcellulose, Cobalt, Adipic acid, Esterification, pH

Received on 15 December, 2025

Accepted on 15 February, 2025

Published on 28 February 2026

Corresponding E-mails & Authors\*:

Muhammad Ashraf Shaheen

[ashraf.shaheen.sgd@superior.edu.pk](mailto:ashraf.shaheen.sgd@superior.edu.pk)

### Abstract

The current research is focused on the development of a new and chemically modified-natural materials in uptake of a toxic heavy metal, i.e., cobalt ions in aqueous environment. Hydroxypropylcellulose (HPC) was chemically modified to adipate followed by its conversion to the sodic form (HEC-Adip-Na). Experiments with batch series of experiments were conducted to investigate the influence of the dosage of sorbent (10- 100 mg), pH (1-7), Co<sup>2+</sup> concentration (20-160 mg/L), contact time (1-120 min), and temperature (298-338 K) on sorption capacity of sodic form of HEC. The maximum Co(II) removal from the ground water by HEC-Adip-Na

was appeared at pH 6, sorbent dose 50 mg, metal ions concentration 80 mg/L, contact time 30 min, and temperature 298 K.

## INTRODUCTION

The excessive rate of urbanization, industrialization, and human activities generate a high population of the pollutants such as heavy metals to the water bodies [1]. The lethal effects of heavy metals are experienced in all the living organisms even at their minute concentrations [2]. Some of natural and anthropogenic pathways of  $\text{Co}^{2+}$  to the environment include volcanic eruption, mining, burning of fossil fuels, refining of crude petroleum, manufacturing of batteries, paint, pigment and dye manufacturing industries, and printing and photographic industries. However, consumption of  $\text{Co}^{2+}$  containing foods would increase  $\text{Co}^{2+}$  concentration on the living tissues beyond their acceptable threshold that would cause disorders in body organs [3].  $\text{Co}^{2+}$  toxicity to humans has some of the most attractive and negative health effects, which include pulmonary edema, renal dysfunction, kidney malfunction, bone demineralization, lung insufficiency, renal disturbance, hypertension and cancer [4]. Therefore, there is an urgent need to eliminate  $\text{Co}^{2+}$  in wastewater in order to ensure its suitability to human consumption.

Some of the traditional, physical, and chemical procedures such as coagulation, membrane filtration, chemical and electrochemical precipitation, solvent extraction, reverse osmosis and nanofiltration, adsorption and ion exchange have been employed in the past to treat the contaminated waters [5]. Of these approaches, physical methods and a significant number of chemical methods are not effective and selective. Its elimination of heavy metal ions, followed by an ion-exchange is increasingly gaining scientific interest today since it is a highly efficient and selective process [6-15]. The ease of biomaterials,

their wealth, and their environmental friendliness were the eye catching components to the researchers in removing  $\text{Co}^{2+}$  in aqueous environment. However, such bio-sorbents possess low sorption and is not selective. These biomaterials can be chemically modified to enhance their functionality and selectivity towards removal of  $\text{Co}^{2+}$  in polluted water because of the introduction of functionalities. In the past 20 years, numerous modification techniques have been implemented with regard to the production of low-cost and more effective sorbents. One of the typical modification strategies is the use of succinic anhydride as the esterifying agent to do the esterification. The uptakes of metal ions with these esterified polysaccharides have been given more attention due to the fact that sodium salts are non-toxic and environmentally friendly. In addition to this, these sodic types possess clear functional groups and natural cross-linking in their backbone polymers renders them insoluble in water hence simplifies their applications in wastewater treatment processes. Out of the naturally available polysaccharides, polysaccharides derived using mucilage of the plant seeds i.e. mucilage of plant seeds were observed to be highly effective and of great choice in  $\text{Co}^{2+}$  uptake following their esterification [16-26].

In this case, the HEC has been changed into HEC-adipate (HEC-Adip) and then to sodium salt of HEC-Adip-Na.  $\text{Co}^{2+}$  uptake using this HEC-Adip-Na has since been applied in distilled water (DW). The effect of different operating conditions on sorption including the dosage of sorbents, pH, starting concentration of metal ions and temperature has been assessed.

## 2. Materials and methods

### 2.1. Materials

HEC (Natrosol, HE10K, Belgium) was acquired from local market. Analytical grade reagents and chemicals were used. Adipic anhydride was supplied by Alfa Aesar, Kandel Germany. Sigma-Aldrich, USA provided N,N-Dimethylacetamide (DMAc), 4-dimethylaminopyridine (DMAP),  $\text{CoCl}_2 \cdot 2\text{H}_2\text{O}$ ,  $\text{NaHCO}_3$ , HCl, NaOH, NaCl, ethanol, methanol, and n-hexane. The groundwater of high-hardness (HW) at the various locations of the district of Sargodha were taken in Pakistan. Glassware that was employed in the study was washed and rinsed with acid ( $\text{HNO}_3$ ) and dried in vacuum oven.

### 2.2. Synthesis of adsorbent

HEC-Adip-Na was prepared by the reaction of HEC with adipic anhydride as an ester through a method which had been reported [8] with minor modification.

### 2.3. Batch sorption experimentation

Experiments of sorption were conducted to determine the influence of different operational parameters. The sorbent dosage (10-100 mg) effect, pH (1-7) effect,  $\text{Co}^{2+}$  initial concentration (20-160 mg/L) effect, contact (10-90 min) effect and temperature (298-338K) effect on the sorption capacity of the sorbent were studied in order to optimize the best conditions under which the sorbent could extract the most  $\text{Co}^{2+}$  DW. The volume of a sample used in all these experiments was 100 mL. To this end,  $\text{CoCl}_2 \cdot 2\text{H}_2\text{O}$  was dissolved in DW to get the stock solution (1000 mg/L, 1000 mL). DW was used to dilute this stock solution to desired concentration to carry out batch sorption experiments. The pH of the solutions was adjusted using the 0.1 M NaOH and 0.1 M. The solutions of  $\text{Co}^{2+}$  ions (100 mL) were pipetted into Erlenmeyer flasks (250 mL) and they were spotted with an adequate amount of sorbent. Glass stoppers were used to close flasks and

solutions shaken with shaking thermostat machine an appropriate time at 150 rpm. Following filtration, FAAS was used to identify the concentration of  $\text{Co}^{2+}$  in the supernatant layer through the application of equations (1) and (2) so as to establish the quantity of  $\text{Co}^{2+}$  that was removed by the sorbent ( $q_e$  in mg/g).

$$q_e = \frac{C_i - C_e}{m} \times V \quad (1)$$

$$\text{Percentage metal uptake} = \frac{C_i - C_e}{C_i} \times 100 \quad (2)$$

The results were presented by all the experiments in triplicates and mean values.

### 3. Results and discussion

#### 3.1. Effect of pH

The ion exchange affinity of any sorbent is conditional on the level of ionization and surface charge of the sorbent that in turn depends on the level of pH of metal ion-solution. Fig. 1 indicates how the pH influences the sorption capacity of the sorbent. It was noted that under acidic pH condition,  $\text{Co}^{2+}$  was sorbed by HEC-Adip-Na in small quantity since it was protonated resulting in the surface of the sorbent being positively charged which does not favor the sorption of  $\text{Co}^{2+}$ . When the pH is higher than  $\text{pH}_{\text{ZPC}}$  (4.6), the sorbent surface becomes negatively charged and hence positively charged  $\text{Co}^{2+}$  is absorbed. Peak sorption was observed at pH 6. Moreover, the pH of  $\text{Co}^{2+}$  solution was raised beyond 6 after which  $\text{Co}^{2+}$  was precipitated and partially hydrolyzed to  $\text{Co}(\text{OH})_2$ . Consequently, the amount of  $\text{Co}^{2+}$  ions in the solution was reduced and the sorption performance was inhibited [27,28]. As such, pH = 6 was regarded to be an optimum pH in which to perform all other sorption experiments.

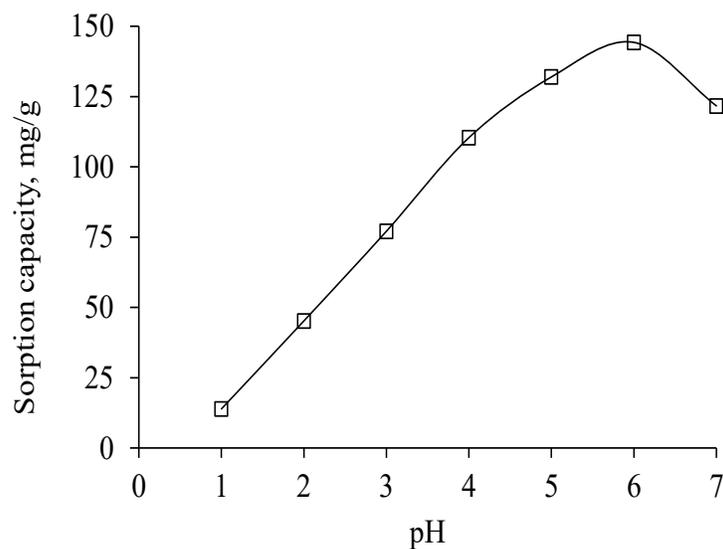


Fig. 1 Effect of pH

### 3.2. Effect of sorbent dosage

The impact of sorbent dosage on sorption capacity of the sorbent was performed to measure the minimum quantity of sorbent (HEC-Adip-Na) that can take out the maximum quantity of sorbate ( $\text{Co}^{2+}$ ) (Fig. 2). A sample volume of 100 mL was used. Sorbent capacity was also noted to go up as sorbent dose was added with highest sorbent dose value of 30 mg. Thus, the number

of 30 mg was selected as a convenient dose of sorbent.

Sorption capacity reduces with increase in sorbent dose beyond 30 mg. This could be explained by the fact that when the dose of sorbents increases, as many active sites as possible are occupied and no additional ions can be sorbed [29] hence the sorption capacity was reduced beyond the optimal point.

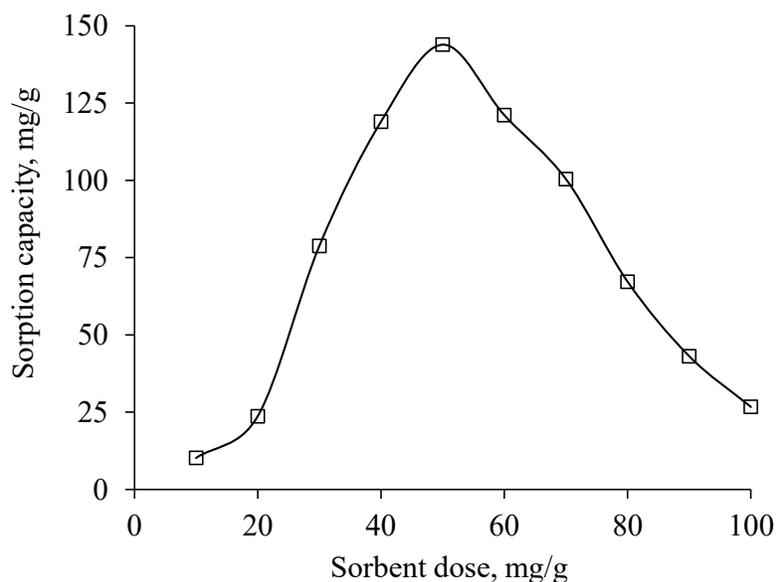


Fig. 2 Effect of sorbent dose

### 3.3. Effect of initial metal ion concentration

The concentration of pre-sorption of the first metal ion on the sorption capacity of the sorbent was assessed and the results were tabulated in Fig. 3. The outcome showed that as the Langmuir isothermal model and pseudo-second-order kinetic model offered the best fit to the experimental data to initial concentration of  $\text{Co}^{2+}$ , sorption capacity also rose up to a constant. The cause may be because as the concentration of the metal ions was more high, the more and more ions were being exchanged with the active sites of the sorbent. Once it was saturated, all the exchangeable ions of sorbent ( $\text{Na}^+$ ) had been replaced by ions of sorbate ( $\text{Co}^{2+}$ ), and no additional metal ions could be bound to any further active sites [30,31]. Therefore, the capacity to sorbent is almost

constant. The 80 mg/L was discovered to be an optimum initial metal ion concentration where HEC-Adip-Na offered optimum sorption capacity.

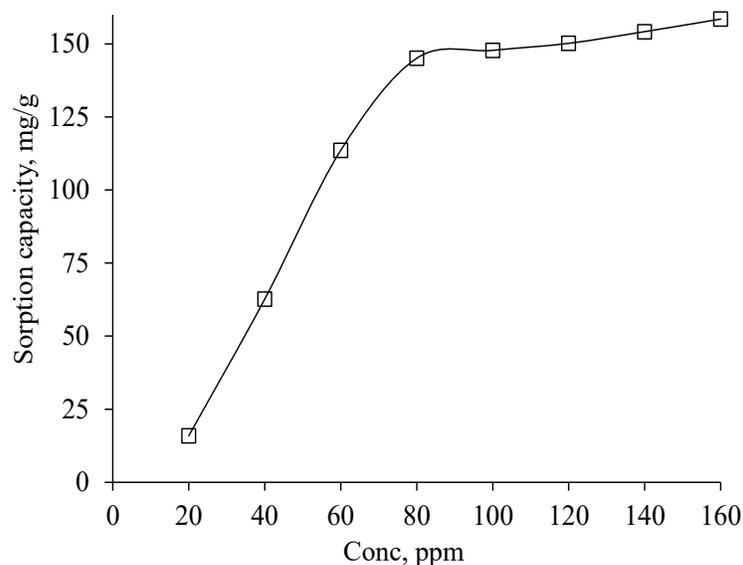


Fig. 3 Effect of concentration

### 3.4. Effect of interaction time

Fig. 4 displays the impact of contact time on sorption capacity of sorbent (HEC-Adip-Na). This effect was employed to make decisions regarding the sorption mechanism and to construct kinetic models. It was determined that over 90 percent of  $\text{Co}^{2+}$  ions were eliminated from DW in the initial 30 min. It translates to, no less than 90 percent of the  $\text{Na}^+$  ions on the sorbent surface was replaced by the metal ions in solution during the 30 min interval. Any contact time over 30 min displayed no active sites available on the surface of the sorbent to exchange with metal ions. [32,33] Therefore, no further significant rise in the sorption capacity was detected after the optimum time, which was 30 min.

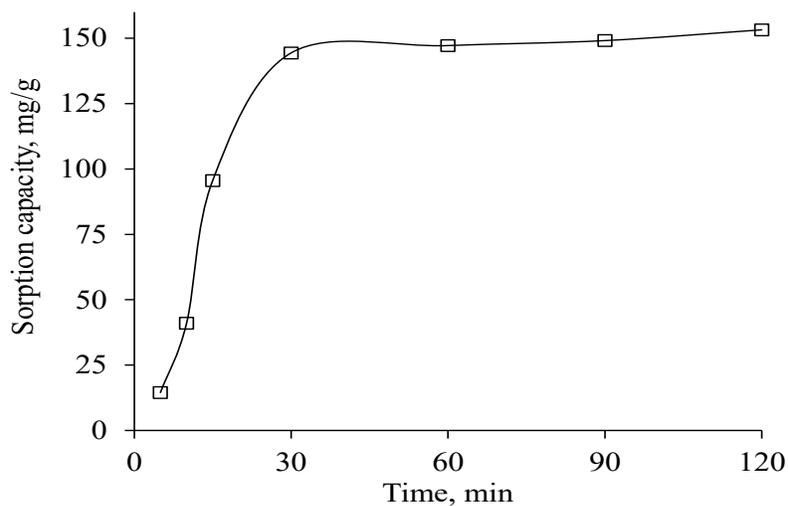


Fig. 4 Effect of time

### 3.5. Effect of temperature

The impact of temperature on the sorption capacity of sorbent was carried out to project the thermodynamic aspect of the sorption process. The findings indicated that as the temperature rose between 298-338 K, the sorption capacity of SSAVH on the uptake of  $\text{Co}^{2+}$  reduced as

indicated in Fig. 5. It is attributed to the fact that at low temperature the interaction of  $\text{Co}^{2+}$  with the active site of sorbent was stronger since  $\text{Co}^{2+}$  was not mobile and at high temperatures, the interaction was weaker because of kinetic energy and ion transport [34,35].

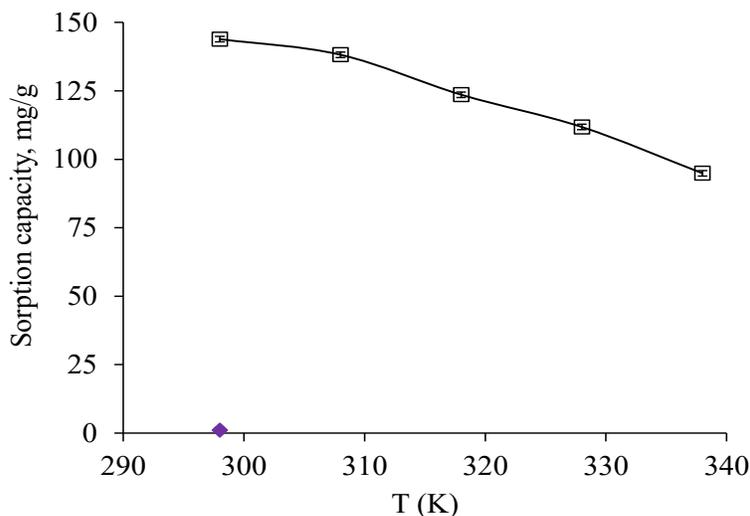


Fig. 5 Effect of temperature

#### 4. Conclusion

The efficacy of sodium salt of HEC in the remove  $\text{Co}^{2+}$  from DW has been tested and it presented as a super absorbent as indicated by the high sorption capacity. The sorption results indicated that the discussed sorbent seemed very effective and specific in the process of  $\text{Co}^{2+}$  absorption. Ion-exchange mechanism was used in sorption process and was successful in removing 90% of  $\text{Co}^{2+}$  within first 30 min. It was found that the sorbent could be re-generated at least five times with minimal reduction of sorption capacity that renders it a possible candidate in the industrial process. In conclusion, HEC-Adip-Na is a highly effective and recyclable supersorbent to  $\text{Co}^{2+}$  uptake from DW to be more utilized in uptake of other toxic metal ions to provide practical solutions to real world problems.

## REFERENCES

- [1] Qasem, N.A., Mohammed, R.H. and Lawal, D.U., 2021. Removal of heavy metal ions from wastewater: a comprehensive and critical review. *Npj Clean Water*, 4(1), 36.
- [2] WHO (World Health Organization), WHO Food Additive Series No. 46 World Health Organization, Geneva (2001).
- [3] Hawkins, M.J., 1998. Recovering cobalt from primary and secondary sources. *Journal of Minerals, Metals and Materials Society*, 50(10), 46-50.
- [4] Linna, A., Oksa, P., Groundstroem, K., Halkosaari, M., Palmroos, P., Huikko, S. and Uitti, J., 2004. Exposure to cobalt in the production of cobalt and cobalt compounds and its effect on the heart. *Occupational and Environmental Medicine*, 61(11), 877-885.
- [5] KIM, Y.H., 2000. Adsorption characteristics of cobalt on ZrO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> adsorbents in high-temperature water. *Separation Science and Technology*, 35(14), 2327-2341.
- [6] Khatoon, M., Ali, A., Hussain, M.A., Haseeb, M.T., Muhammad, G., Sher, M., Hussain, S.Z., Hussain, I. and Iqbal, M., 2025. A chia (*Salvia hispanica* L.) seed mucilage-based glucoxytan-grafted-acrylic acid hydrogel: a smart material for pH-responsive drug delivery systems. *Materials Advances*, 6, 2636-2647.
- [7] Hussain, M.A., Ali, A., Alsahli, T.G., Khan, N., Sharif, A., Haseeb, M.T., Alsaidan, O.A., Tayyab, M. and Bukhari, S.N.A., 2023. Polysaccharide-based hydrogel from seeds of *Artemisia vulgaris*: extraction optimization by Box–Behnken design, pH-responsiveness, and sustained drug release. *Gels*, 9, 525.
- [8] Hussain, M.A., Gul, S., Abbas, A., Ali, A. and Alotaibi, N.F., 2021. Chemically modified rhamnogalacturonans from linseed: a supersorbent for Cd<sup>2+</sup> and Pb<sup>2+</sup> uptake from aqueous solution. *Desalination and Water Treatment*, 221, 163-175.

- [9] Irfan, J., Ali, A., Hussain, M.A., Haseeb, M.T., Naeem-ul-Hassan, M. and Hussain, S.Z., 2024. Citric acid cross-linking of a hydrogel from Aloe vera (*Aloe barbadensis* M.) engenders a pH-responsive, superporous, and smart material for drug delivery. *RSC Advances*, 14, 8018-8027.
- [10] Ali, A., Hussain, M.A., Haseeb, M.T., Farid-Ul-Haq, M., Erum, A. and Hussain, M., 2024. Acute toxicity studies of methacrylic acid based composite hydrogel of *Salvia spinosa* seed mucilage: a potential non-toxic candidate for drug delivery. *Cellulose Chemistry & Technology*, 58, 45-53.
- [11] Ali, A., Haseeb, M.T., Hussain, M.A., Tayyab, Muhammad, Muhammad, G., Ahmad, N., Alotaibi, N.F., Hussain, S.Z. and Hussain, Irshad, 2022. Extraction optimization of a superporous polysaccharide-based mucilage from *Salvia spinosa* L. *Cell. Chem. Technol*, 56, 957-969.
- [12] Hussain, M.A., Shahzad, K., Ali, A., Haseeb, M.T. and Hussain, S.Z., 2025. Development of a novel smart bio-composite hydrogel based on dextran, citric acid, and glucoxytan for pH-dependent drug delivery and stimuli-responsive swelling and release. *Polymers and Polymer Composites*, 33, 09673911251350240.
- [13] Hussain, M.A., Raees, N., Ali, A., Tayyab, M., Muhammd, G., Uroos, M. and Batool, M., 2025. Optimization of rhamnogalacturonan extraction from linseed using RSM and designing a pH-responsive tablet formulation for sustained release of ciprofloxacin. *Cellulose Chemistry and Technology*, 59, 547-558.
- [14] Hussain, M.A., Taj, T., Ali, A., Haseeb, M.T., Hussain, S.Z., Muhammad, G. and Bukhari, S.N.A., 2025. Cross-Linking of hydroxypropylcellulose with flaxseed rhamnogalacturonans using citric acid produces a hemocompatible biocomposite

- for pH-responsive rifaximin delivery. *Journal of Applied Polymer Science*, 2025, e57486.
- [15] Iqbal, J., Kanwal, M., Siddique, A., Fawy, K.F., Sher, M., Nishan, U., ur Rehman, M.F., Abbas, M.A., Ali, A. and Abbas, A., 2025.  $\beta$ -Cyclodextrin-functionalized silver nanoparticles as a visual probe for selective tetrahydrocannabinol detection via host–guest induced plasmonic shifts. *Microchemical Journal*, 219, 202116177.
- [16] Hassan, R.N., Ali, F., Akhtar, S., Siddique, A.B., Fawy, K.F., Sher, M., Shaheen, M.A., ur Rehman, M.F., Nishan, U., Ahmad, T. and Ali, A., 2026. Tailoring strontium-nickel supported reduced graphene oxide nanostructure for synergistic catalytic hydrogen generation from sodium borohydride and photodegradation of organic pollutant. *Fuel*, 415, 138417.
- [17] Babar, S., Sheikh, F.A., Bukhari, S.N.A., Haseeb, M.T., Ali, A., Ul Khaliq, N., Alafar, R.A., Abdelgawad, M.A., Zafar, A. and Ahmad, N., 2026. Formulation design of glucuronoxylan-based stimuli-responsive microparticles for zero-order drug delivery. *Journal of Pharmaceutical Innovation*, 21, 171.
- [18] Ali, A., Bakhsh, A., Qasim, S., Sheikh, F.A., Ali, H., Khaliq, N.U., Haseeb, M.T., Dar, M. and Shaaban, I.A., 2026. Citric acid-mediated crosslinking of chia seed glucoxylan and hydroxypropyl cellulose: pH responsiveness, haemocompatibility and sustained drug release. *Chemistry & Biodiversity*, 23, e03389.
- [19] Amjad, F., Ali, A., Hussain, M.A., Haseeb, M.T., Farid-ul-Haq, M., Ajaz, I., Sher, M. and Imran, M., 2026. Fabrication of a superabsorbent and pH-responsive glucomannan-based hydrogel: crosslinking, characterization, toxicological evaluation, and sustained-release of itopride. *Materials Advances*, 7, 1495-1507.

- [20] Ali, A., Ali, M., Qasim, S., Ali, H., Mumtaz, A., Fawy, K.F., Nishan, U., Shaheen, M.A. and Abbas, A., 2025. Maleate-bonded acemannan (Aloe vera leaf mucilage): Synthesis, characterization, efficient removal of Pb (II) from groundwater, kinetics, mechanism, and regeneration studies. *Polymer*, 244, 129498.
- [21] Farid-ul-Haq, M., Hussain, M.A., Ali, A., Haseeb, M.T., Muhammad, G., Tabassum, T., Ashraf, M.U., Tulain, U.R. and Erum, A., 2024. A pH-responsive *Artemisia vulgaris* mucilage-co-acrylic acid hydrogel: Synthesis, characterization, controlled drug release, toxicity studies, and MRI. *Journal of Drug Delivery Science and Technology*, 93, 105468.
- [22] Hussain, A., Fatima, S., Abbas, A., Ali, A., Amin, M., Muhammad, G. and Sher, M., 2023. Removal of Cr (III) and Ni (II) from aqueous solution using a mixed cellulose ether-ester hydroxyethylcellulose adipate. *Desalination and Water Treatment*, 283, 153-163.
- [23] Ali, A., Hussain, M.A., Haseeb, M.T., Bukhari, S.N.A., Tabassum, T., Farid-ul-Haq, M. and Sheikh, F.A., 2022. A pH-responsive, biocompatible, and non-toxic citric acid cross-linked polysaccharide-based hydrogel from *Salvia spinosa* L. offering zero-order drug release. *Journal of Drug Delivery Science and Technology*, 69, 103144.
- [24] Ali, A., Hussain, M.A., Haseeb, M.T., Tulain, U.R., Farid-ul-Haq, M., Tabassum, T., Muhammad, G., Hussain, S.Z., Hussain, I. and Erum, A., 2023. Synthesis, characterization, and acute toxicity of pH-responsive *Salvia spinosa* mucilage-co-acrylic acid hydrogel: A smart excipient for drug release applications. *Reactive and Functional Polymers*, 182, 105466.

- [25] Irfan, J., Hussain, M.A., Haseeb, M.T., Ali, A., Farid-ul-Haq, M., Tabassum, T., Hussain, S.Z., Hussain, I. and Naeem-ul-Hassan, M., 2021. A pH-sensitive, stimuli-responsive, superabsorbent, smart hydrogel from psyllium (*Plantago ovata*) for intelligent drug delivery. *RSC Advances*, 11, 19755-19767.
- [26] Abbas, A., Hussain, M.A., Ali, M., Irfan, M.I. and Paracha, R.N., 2017. Sodium hydroxyethylcellulose succinate: an efficient ion exchanger to remove Cd (II) from single and binary metal system. *Desalination and Water Treatment*, 64, 189-197.
- [27] Netzer, A. and Hughes, D.E., 1984. Adsorption of copper, lead and cobalt by activated carbon. *Water Research*, 18(8), 927-933.
- [28] Abbas, M., Kaddour, S. and Trari, M., 2014. Kinetic and equilibrium studies of cobalt adsorption on apricot stone activated carbon. *Journal of Industrial and Engineering Chemistry*, 20(3), 745-751.
- [29] Li, X.L., Chen, C.L., Chang, P.P., Yu, S.M., Wu, W.S. and Wang, X.K., 2009. Comparative studies of cobalt sorption and desorption on bentonite, alumina and silica: effect of pH and fulvic acid. *Desalination*, 244(1-3), 283-292.
- [30] Demirbaş, E., 2003. Adsorption of cobalt (II) ions from aqueous solution onto activated carbon prepared from hazelnut shells. *Adsorption Science & Technology*, 21(10), 951-963.
- [31] Rengaraj, S. and Moon, S.H., 2002. Kinetics of adsorption of Co (II) removal from water and wastewater by ion exchange resins. *Water Research*, 36(7), 1783-1793.
- [32] Ainsworth, C.C., Pilon, J.L., Gassman, P.L. and Van Der Sluys, W.G., 1994. Cobalt, cadmium, and lead sorption to hydrous iron oxide: residence time effect. *Soil Science Society of America Journal*, 58(6), 1615-1623.

- [33] Abbas, M., Kaddour, S. and Trari, M., 2014. Kinetic and equilibrium studies of cobalt adsorption on apricot stone activated carbon. *Journal of Industrial and Engineering Chemistry*, 20(3), 745-751.
- [34] Angove, M.J., Johnson, B.B. and Wells, J.D., 1998. The influence of temperature on the adsorption of cadmium (II) and cobalt (II) on kaolinite. *Journal of Colloid and Interface Science*, 204(1), 93-103.
- [35] Ogata, F., Imai, D., Toda, M., Otani, M. and Kawasaki, N., 2015. Adsorption of phosphate ion in aqueous solutions by calcined cobalt hydroxide at different temperatures. *Journal of Environmental Chemical Engineering*, 3(3), 1570-1577.