**Dynamic Sorption and Desorption of Cu(II) and Ni(II) Ions and the Application of Ion Exchange for Wastewater Treatment**

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**Abstract:** Their adsorption characteristics on a novel ion-exchange resin derived from chlorinated polypropylene. The aim was to enhance our approach to wastewater management. It considered dynamic and total exchange capacities of resin, ion exchange rate of the resin when it was running unceasingly. This showed how well it was working and how well it could do its job. The fact that the attachment and removal of Cu²⁺ and Ni²⁺ ions occurred on the chlorinated polypropylene. It is observed that matrix treated with polyethylenepolyamine was very efficient for the removal of heavy metal ions from water. It was clear that the sorption capacity improved substantially when the solution's flow rate was decreased. This is because the metal ions remain in contact with the active functional sites on the resin for a longer time, thus dissolving the ions better and makes the interactions stronger. The resin has been cleaned with 0.1 N hydrochloric acid several times. Also, dynamic adsorption performance remained virtually the same. That is to say, that the resin is very strong and can even be used again. The results reveal that the resin that was made passes the tight requirements for ion-exchange materials used in systems that filter water for industrial usage. It was especially good at getting rid of heavy metal ions when used with chlorinated polypropylene glue. This makes it look like a safe and long-lasting technique to get rid of industrial waste.

**Keywords:** ion exchanger, chlorinated polypropylene, polyethylene polyamine, sorption, purification, waste water.

**INTRODUCTION**

The fast rise of industry around the world has unleashed a lot more heavy metals and other dangerous substances into natural ecosystems. This is a serious concern for our planet. These metal ions are harmful to the environment and human health because they can cause metabolic disorders and a number of ailments. It is very important to clean up industrial wastewater that has zinc and nickel in it. This is because Zn²⁺ and Ni²⁺ ions are known to be hazardous pollutants that are quite toxic and tend to persist in the environment for long. Nickel is used widely in it's really vital to get it back and maintain track of it. Nickel is utilized a lot in a a lot of various fields, so it's really crucial to get it back and control it. Arsenic, mercury, chromium, cadmium and lead are toxic metal ions that can accumulate in sources of drinking water when untreated or poorly disposed industrial waste is discharged. This forms a large-scale public health problem. They tend to accumulate in human tissues when ingested and may cause serious health issues. You may remove heavy metals out of wastewater in a number of techniques, such as chemical precipitation, coagulation, electrocoagulation, reverse osmosis, and ion-exchange procedures. Adsorption-based treatments are believed to be the best of them since they work well, are easy to use, and don't cost much [1–3].

For the last fifty years, the ion-exchange approach has been a common way to get rid of harmful ions from water systems. In this physicochemical process, metal ions that are bound to the active sites of the adsorbent take the place of cations in wastewater. People usually employ synthetic ion-exchange resins and natural zeolites to clean things like this. People know that activated carbon is an excellent material for treatments that operate by adsorbing substances, but it isn't used very much because it costs a lot to create and is hard to recycle. A lot of industries have a lot of solid trash since they haven't dealt with it correctly. But these materials can be valuable when they are made into cheap adsorbents. Red mud, coal fly ash, and lignin are some of these by-products from industry. When you burn coal, you get coal ash. When heated, it is usually gray, alkaline, and stable. The primary ingredients in it are silicon dioxide (60–65%), aluminum oxide (25–30%), and ferric oxide (Fe₂O₃, 6–15%). This makes it a useful base for building cement and, more recently, a cheap way to soak up other substances. Waste coal ash normally needs to be modified physically and chemically before it can be used in adsorption operations. This is because the untreated material is not particularly active. Earlier research used coal ash to pull Cu(II) and Ni(II) ions out of water, using both Langmuir and Freundlich isotherms to explain how the ions were adsorbed. The adsorption of these metal ions was predominantly governed by a diffusion-controlled mechanism, signifying that the process was mainly characterized by physical adsorption. Experiments were conducted under static settings utilizing coal ash and activated carbon as adsorbents, facilitating a comparative evaluation of their sorption efficiency. The optimum pH for the removal of Cu(II) and Ni(II) with activated carbon was found as 6, but for the coal ash it was 5. The studies used 8 g/L of adsorbent and lasted an hour. Under these conditions, coal ash removed 97% of Cu(II) and 78% of Ni(II), while activated carbon removed 95% and 63%, respectively. These results affirm that coal ash has a higher adsorption capacity in than activated carbon [4–7].

Continued growth in the global industrial production has resulted in an increasing emission of hazardous and heavy metal contaminants into the environment, leading to significant ecological issues. High amounts of these metal ions that are higher than what is healthy for humans can harm their health by messing up their metabolism and triggering a range of disorders [8–10].

It is very vital for the environment to remove zinc and nickel ions from wastewater. Zinc and Ni(II) ions are thought to be harmful pollutants since they are exceedingly poisonous and do not break down on their own. Nickel is utilized a lot in factories and industries, which can pollute water systems. So, it's very vital to use ion-exchange procedures to retrieve them back and make them more concentrated. Quaternary ammonium salts are the best at moving anions across ionogenic functional groups. Tertiary amine-based anionic exchangers are also quite common since they are very stable chemically. The number of heavy metals in freshwater bodies keeps steadily increase, primarily because of what people do, especially when factories dump waste into them. Some of the most common contaminants are chromium, copper, nickel, zinc, cobalt, arsenic, lead, and mercury. These metals dissolve quickly in water, which means they can get into living organisms through water. You can receive heavy metals into your body by eating, breathing, or drinking water. They pile up in the body and can cause major health concerns. These parts don't break down in the body, therefore they stay there for a long period. The greatest strategy to lower the health risks and pollution from heavy metals is still to adequately treat wastewater [11–13].

**METHODS**

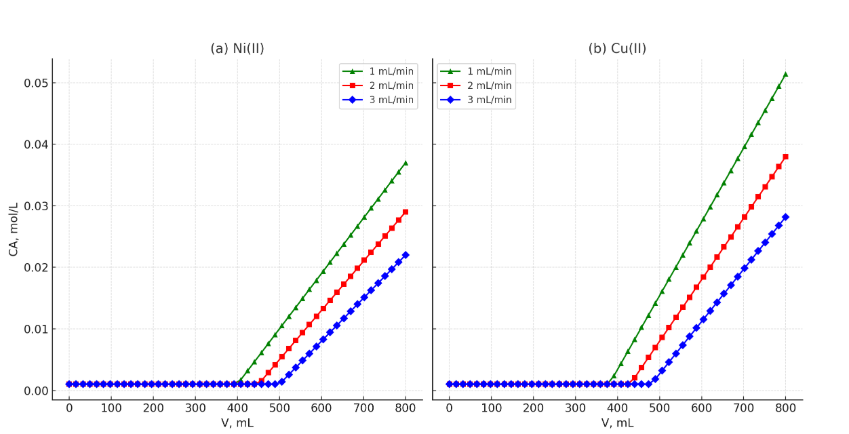
Ion-exchange materials are often put into specific column systems when treating wastewater and getting back uncommon or heavy metals. Then, dirty solutions move through these systems in a dynamic way. To see how well ion exchangers perform, you need to look at their dynamic exchange capability. One huge problem with ion exchangers that are made using quaternary ammonium is that they don't perform well with chemicals and heat, especially when the pH is high. These exchangers normally operate best when the temperature is between 35 °C and 60 °C. Polystyrene that has been crosslinked with divinylbenzene is what most industrial anion-exchange resins are made of. This is because the polymer is easy to work with and doesn't cost much to create. Vinylbenzyl chloride is a popular monomer employed in this synthesis. Benzylmethylene functional groups are used to introduce the ion-exchange centers to the polymer matrix [14,15].

You commonly employ 4% hydrochloric (HCl) or sulfuric acid (H₂SO₄) solutions to get cation-exchange resins working again. To get anion-exchange materials back to their operating state, you can employ alkaline reagents like 4% sodium hydroxide (NaOH) or sodium chloride (NaCl) solutions. Ion-exchange technologies are used in a lot of different areas, like softening drinking water, separating chemical compounds by chromatography, different chemical processing tasks, hydrometallurgy, selectively recovering metal ions from water, and cleaning up wastewater that has toxic ionic contaminants in it [16,17].

A comprehensive review of the literature reveals that the continuous expansion of global industrial activities has significantly increased the demand for ion-exchange materials. Most of these materials are polymers with functional groups that have nitrogen in them. This study helps to tackle this problem by proving that it is possible to manufacture chlorinated polypropylene on a big scale by chlorinating polypropylene made in the United States. This procedure creates chlorinated polymer, which is a useful raw material for a wide range of applications. It can also be sent to other nations to be used more and then chemically modified to generate ion-exchange materials that work better [18,19].

**RESULTS AND DISCUSSIONS**

To investigate the dynamic exchange capacity and desorption characteristics of the synthesized ion-exchange material derived from chlorinated polypropylene (CP) modified with polyethylenepolyamine (PEPA), a granularion exchanger exhibiting a static exchange capacity of 4.6 mEq/g (evaluated using HCl) was assembled into a column in its activated state. We verified this by measurement of the concentration of the feed solution at the start, and the concentration of the effluent that flowed out of the column. The experiment went on until such periods when the concentrations of the Cu²⁺ and Ni²⁺ ion solutions, which were initially different, were equal to the concentration of the effluent. That was when the answers were as good as they could be . We used the reverse-flow method to find out how much dynamic exchange capacity there was. We introduced metal ion solutions to the column at a rate of 1, 2, or 3 mL per minute during this time. During this time, the column was loaded with metal ion solutions at a rate of 1, 2, or 3 mL/min. We utilized a Perkin Elmer (USA) microplate reader to see how much of each sample was in the solution before and after it was absorbed.



**FIGURE 1.** The dependence of the dynamic sorption capacity of Cu2+ (a) and Ni2+ (b)   
ions on an ion exchanger utilizing XPP (C = 500 mg/l).

As the amount of solution that flows through the CPP–PEPA ion-exchange column fluctuates, Figure 1 shows how the amount of metal ions in the effluent changes.

Figure 1 (a, b) illustrates that the ion-exchange resin can absorb more metal ions when the solution passes through the column more slowly. This improvement is feasible because the contact duration is longer. It helps the resin's active functional groups work better with the metal ions, which makes the binding work better overall.

Table 1 illustrates the resin's dynamic exchange capacity (DEC), total exchange capacity (TEC), and ion-exchange rate when it is acting dynamically. It is evident that all of these parameters grow greater as the flow rate of the solution via the ion exchanger goes down. When the flow rate is reduced, ions move more easily toward the resin surface. This makes it simpler for coordination (chelate) bonds to form between the metal ions and the amino groups in the ion-exchange material. The ion exchanger may take in more Cu²⁺ ions than Ni²⁺ ions.

This result can be explained by the fact that Cu²⁺ ions interact with the functional groups of the ion-exchange resin better than Ni²⁺ ions do. Cu²⁺ has a larger atomic mass and polarizability, which means it clings better and stays in the ion-exchange matrix longer.

**TABLE 1.** Repeated dynamic rates of Cu2+ and Ni2+ ion sorption on ionite

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| F, ml/min | V, ml (volume missed) | Vion , ml (volume of ion exchanger in the column) | DEC  mol-equiv/m3 | TEC  mol-eq/m 3 | a |
| Ni++ | | | | | |
| 1 | 590 | 30 | 693 | 932 | 0.79 |
| 2 | 520 | 30 | 564 | 804 | 0.74 |
| 3 | 480 | 30 | 456 | 697 | 0.63 |
| Cu++ | | | | | |
| 1 | 720 | 30 | 894 | 1060 | 0.88 |
| 2 | 620 | 30 | 765 | 902 | 0.86 |
| 3 | 560 | 30 | 577 | 795 | 0.68 |

For ion-exchange materials to be helpful in industry, they need to be able to be employed in different operational cycles over and over again. After the sorption stage, the ion-exchange resin can be brought back to life by using the correct chemicals to desorb it. The present study involved five successive sorption–desorption cycles of Cu²⁺ and Ni²⁺ ions on the CPP–PEPA ion exchanger, with the results presented in Table 2 below.

**TABLE 2.** Re-sorption of Cu2+ and Ni2+ ions on an XPP-based ion exchanger under dynamic circumstances

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| No | F , ml/min | V, ml (volume missed) | Vion , ml (volume of ion exchanger in the column) | DEC mol-equiv/ m3 | TEC  mol-equiv/m 3 | A |
| Cu ++ | | | | | | |
| 1 | 1 | 600 | thirty | 1022 | 12 6 0 | 0,88 |
| 2 | 1 | 600 | 30 | 1022 | 12 6 0 | 0,88 |
| 3 | 1 | 600 | 30 | 1022 | 12 6 0 | 0,88 |
| 4 | 1 | 600 | 30 | 1022 | 12 6 0 | 0,88 |
| 5 | 1 | 600 | 30 | 1018 | 12 6 0 | 0.88 |
| 6 | 1 | 600 | 30 | 1008 | 1255 | 0.84 |
| Ni++ | | | | | | |
| 1 | 1 | 600 | 30 | 964 | 983 | 0.81 |
| 2 | 1 | 600 | 30 | 964 | 983 | 0.81 |
| 3 | 1 | 600 | 30 | 964 | 983 | 0,81 |
| 4 | 1 | 600 | 30 | 964 | 983 | 0,81 |
| 5 | 1 | 600 | 30 | 963 | 983 | 0,81 |
| 6 | 1 | 600 | 30 | 962 | 933 | 0,80 |

Table 2 reveals that 0.1 N hydrochloric acid was used to remove Cu²⁺ and Ni²⁺ ions and then put them back into the ion-exchange resin while it was being regenerated. The results show that the material's dynamic exchange capacity (DEC) stayed almost the same after a few cycles in a row. This consistency reveals that the ion exchanger is very stable and meets the basic performance parameters needed for industrial ion-exchange applications.

A lot more wastewater is being dumped into the environment because industrial activity is growing so quickly. This has hurt ecosystems and living creatures. Stopping the release of heavy and toxic metals and dangerous gasses is one of the most critical environmental issues of our day. There exists a variety of techniques for the removal of heavy metal ions in wastewater, but ion-exchange one of the best technologies is. This mechanism operates through the transfer of ions between solid and liquid phases. There are several clear advantages of ion exchange over other methods of purification. For example, it is inexpensive to operate, more selective, generates minimal secondary waste, and can recover important metal ions [20].

In an aqueous solution, we studied the behavior of Ni²⁺ and Cu²⁺ ions when in motion. The before the testing, the wastewater samples were filtered to remove any floating particles. The activated ion-exchange material, which had a static exchange capacity (SEC) of 4.6 mEq/g in HCl, was then introduced into a column system. After being treated, the effluent was poured into the column and flowed up at a rate of 0.5 mL/min. We used a Perkin Elmer microplate spectrophotometer (USA) the change in concentration of metal ions during the sorption process was monitored by taking aliquots at various times: showed that the sum of all the metal ions in the wastewater was equivalent to an exchange capacity of 650 mmol-eq/m³.

The chemical analysis laboratory at the Electrochemical Plant utilized an amine-functionalized ion exchange material to separate various ions from wastewater by measuring the amounts of metal ions. A Perkin Elmer microplate spectrophotometer (USA) was used to determine the extent with which the ion exchanger absorbed ions. Table 3 lists main cations which must be removed. To make if, indeed, the cleaning of wastewater is ensured, these are the main pollutants that must be reduced.

**TABLE 3.** Using an ion exchange resin based on CPP to sorptively reduce ions in wastewater

|  |  |  |
| --- | --- | --- |
| Available ions | Cu2+ | Ni2+ |
| Initial amount, mg/dm 3 | 1820 | 10.5 |
| From sorption the following amount, mg/dm 3 | 320.5 | 1.26 |

We used water with different amounts of metal ions to see how well Ni2+ and Cu2+ ions adhered to an amine-functionalized ion exchanger made of chlorinated polypropylene (CPP–PEPA). To ascertain the impact of the experimental conditions on the results, we examined how variations in initial ion concentration (0.025, 0.05, 0.075, and 0.1 M), temperature (303 K, 313 K, and 323 K), and contact duration (two to twenty-four hours) affected the sorption process. The exchange method used a device that was like a column to get rid of metal ions. The ion exchanger, which was placed inside the column, was receiving a constant flow of wastewater samples. This technique allowed solution to come in and go out at the same rate.

**CONCLUSION**

The findings of this study reveal that the ion-exchange resin retards the flow of the column, which allows the Ni2+ and Cu2+ ions to adhere to it more easily. If the flow rate is reduced, the metal ions and the active functional groups in the resin may touch each other and make stronger linkages. This is the reason for the change that is happening. Cleaning the ion-exchange material with hydrochloric acid a few times didn't seem to make much of a difference. This happened because the chemical and physical properties of the resins did not change much. In most industrial ion chlorinated polypropylene ion-exchange resin is ideal for ion exchange processes. Therefore, it is an environmentally friendly material as it is capable of removing harmful metal ions from factory waste. The resin is an excellent way of cleaning up a lot of wastewater due to the fact that it is long-lasting and can be reusable.

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