G-Tech : Jurnal Teknologi Terapan
Vol. 9, No. 3, July 2025, p. 1592-1601
E-ISSN: 2623-064X | P-ISSN: 2580-8737

Reduction of Cu and Cr Metal Content in Electroplating Industrial Liquid Waste Using the Ion Exchange Method

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Article Information

Article History

Received : June 16, 2025
Revised : July 05, 2025
Published : July 18, 2025

***Keywords*:**

Ion Exchange; Atomic Absorption Spectrophotometry; Electroplating Industrial Waste Water.

ABSTRACT

Electroplating industrial waste contains toxic chemicals that pose risks to health and environment, especially if they enter household wastewater systems. Therefore, treatment is necessary to reduce heavy metal content using the ion exchange method. This study utilized Amberlite IR 120Na resin as the ion exchange medium in electroplating waste. This study aims to reduce metal content in electroplating industrial wastewater using the ion exchange method by evaluating the effects of resin height and flow rate. The process was conducted with variations in flow rate (100 ml/min, 200 ml/min, 300 ml/min, 400 ml/min, 500 ml/min) and resin height (3 cm, 6 cm, 9 cm, 12 cm, 15 cm). The waste was passed through the ion exchange column, and the remaining Cu and Cr metal concentrations were measured. The results indicated that the optimal conditions occurred at a flow rate of 100 ml/min and a resin height of 15 cm, achieving a reduction of Cu metal by 90.16% and Cr metal by 83.36%. The Cu concentration after the process met quality standards under all conditions, while the Cr concentration met quality standards at resin heights of 12 cm and 15 cm. The ion exchange method proved effective in reducing heavy metal pollution.

INTRODUCTION

Electroplating industrial wastewater contains hazardous substances, particularly heavy metals. Heavy metals in water are essential for various metabolic processes in living organisms. However, excessive amounts of heavy metals can cause poisoning. Heavy metals become pollutants when their concentrations exceed established quality standards (Permata, 2018). Such as copper (Cu) and chromium (Cr) which pose significant risks to environmental quality and human health. These heavy metals can accumulate in the environment, leading to contamination of water bodies, soil, and eventually entering the food chain (Wardhana, 1999). Therefore, it is crucial to treat this wastewater effectively before discharge to comply with environmental regulations and to minimize adverse health impacts. Various treatment methods have been explored, among which the ion exchange technique has gained considerable attention due to its efficiency and selectivity. In this study, the ion exchange method was employed using Amberlite IR 120Na resin, a strong acid cation exchange resin, to adsorb Cu and Cr ions from electroplating wastewater. This resin was selected based on its high selectivity for copper ions compared to chromium ions (Harvey, 2000). The selective adsorption capability of the resin is critical in optimizing the removal process, ensuring that heavy metal concentrations are reduced to acceptable levels before the treated water is released into the environment (Jayatiningrum, 2017). Previous research by Soemargono (2008) investigated the reduction of chromium concentration using Dowex resin, achieving an efficiency of 40.64%. However, the effectiveness was limited due to the mismatch between the resin's capacity and the ion concentration in the wastewater. This highlights the importance of selecting appropriate resin types and optimizing operational parameters to maximize treatment efficiency. Furthermore, reverse osmosis (RO) systems have also been employed in wastewater treatment due to their ease of control and high stability under varying flow rates and resin bed heights. However, RO systems tend to be more energy-intensive and costly compared to ion exchange methods (Saputri, 2020).

Ion exchange is a separation technique that relies on the selective interchange of ions between a solid resin and a liquid solution, governed by the ions' charge and affinity. The resins utilized in this process are generally composed of complex hydrocarbon frameworks functionalized with charged groups that enable ion exchange. Specifically, cation exchange resins possess negatively charged functional groups that facilitate the exchange of positively charged ions (cations), whereas anion exchange resins contain positively charged groups that allow for the exchange of negatively charged ions (anions) (Shahab, 2023). The fundamental principle of ion exchange involves replacing specific ions in the solution with ions attached to the resin in equivalent amounts to maintain charge neutrality. When a solution containing cations or anions passes through the resin bed, ions in the solution are exchanged with ions on the resin surface. For example, in the case of cation exchange resins, H^+ ions on the resin are replaced by metal cations such as Cu^{2+} and Cr^{3+} from the wastewater. This exchange continues until the resin reaches its capacity or equilibrium is established (Ziaee, 2020).

Ion exchange resins are classified into four main types based on their functional groups and strength:

- **Strong acid cation resins** (e.g., Amberlite IR-120): These resins have sulfonic acid groups and are effective in exchanging a wide range of cations, including heavy metals.
- **Weak acid cation resins** (e.g., Amberlite IRC-50): Contain carboxylic acid groups and are more selective for certain metal ions but have lower capacity.
- **Strong base anion resins** (e.g., Amberlite IRA-4500): Contain quaternary ammonium groups and exchange anions such as chloride or sulfate.
- **Weak base anion resins**: Have tertiary amine groups and are used for specific anion removal applications.

(Nugroho, 2013)

In this study, the focus is on using Amberlite IR 120Na, a strong acid cation resin in the sodium form, to adsorb Cu and Cr ions from electroplating wastewater. The ion exchange process involves the resin exchanging its sodium ions (Na^+) with the heavy metal cations present in the wastewater. The mechanism can be summarized as follows: the resin releases Na^+ ions into the solution and simultaneously adsorbs Cu^{2+} and Cr^{3+} ions from the wastewater. The process maintains electrical neutrality by ensuring that the total charge of ions exchanged is balanced. This selective ion removal not only reduces the concentration of toxic metals but also regenerates the resin for reuse after appropriate treatment (Suharto, 2011).

The ion exchange process in an ion exchange column occurs when a solution containing cations or anions comes into contact with the ion exchange medium. The reaction mechanism for the ion exchange of Cu and Cr ions with the cation resin Amberlite IR 120Na can be described as follows:

1. Exchange mechanism of Cu^{2+} using the cation exchange resin Amberlite IR 120Na

$$2(C_8H_7 - SO_3^- Na^+)_{(s)} + Cu^{2+}{}_{(aq)} \rightarrow (C_8H_7 - SO_3^-)_2Cu_{(s)} + 2Na^+{}_{(aq)} \quad \ldots\ldots\ldots(1)$$

2. Exchange mechanism of Cr^{3+} using the cation exchange resin Amberlite IR 120Na

$$2(C_8H_7 - SO_3^- Na^+)_{(s)} + Cr^{3+}{}_{(aq)} \rightarrow (C_8H_7 - SO_3^-)_3Cr_{(s)} + 2Na^+{}_{(aq)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Note:
Cu^{2+} = Ion that will be separated
Cr^{3+} = Ion that will be separated
Na^+ = Ion in the ion exchange medium that will exchange with Cu and Cr ions
SO_3^- = Part of the functional group in the ion exchange medium
C_8H_7 = A compound that binds the functional group SO_3^-

(Faizin, 2015)

Atomic Absorption Spectrophotometry (AAS) has been recognized since the 19th century, with significant advancements made during the 1950s by Alan Walsh and a group of Australian chemists at the Chemical Physics Division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Melbourne, Australia. In the field of analytical chemistry, AAS is predominantly employed to quantify the concentration of specific metal elements within a sample. This technique is capable of analyzing over 62 different metal species in solution. While the conventional approach utilizes a flame for sample atomization, alternative atomization methods, such as graphite furnace systems, are also widely implemented (Wahab, 2022). The concentration of metals in wastewater can be precisely measured using Atomic Absorption Spectrophotometry (AAS), an analytical method that relies on the absorption of characteristic wavelengths by free atoms in a gaseous state. AAS is widely used for detecting a range of metal and metalloid elements because of its excellent sensitivity, allowing the identification of even trace amounts of pollutants. Moreover, the technique is cost-effective and provides quick results, making it well-suited for regular monitoring of heavy metals in environmental samples (Dewi, 2021).

Several factors influence metal ion exchange efficiency when using resin. The amount of ion exchange media directly impacts capacity, as larger quantities provide more binding sites for ions, enhancing overall exchange potential. Contact time is critical, with longer durations improving absorption efficiency until equilibrium is reached, where maximum capacity occurs (Prasetyaningrum, 2018). pH significantly affects resin performance: strong acid/base resins operate optimally at pH 7–9, while weak acid/base types require pH >6. Finally, dissolved ion concentration inversely affects exchange rates; higher concentrations reduce reaction speed and limit ion availability due to the resin's finite capacity (Syaifie, 2019).

This study aims to reduce metal content in electroplating industrial wastewater using the ion exchange method by evaluating the effects of resin height and flow rate, and to assess the effectiveness of Amberlite IR 120Na resin in removing copper and chromium in accordance with the effluent standards set by the East Java Governor Regulation No. 52 of 2014.

RESEARCH METHODS

Materials and Equipments

The materials used in this research are electroplating industrial waste from PT Sinar Permata and the cation resin Amberlite IR 120Na. The equipment used in this research is a series of ion exchange tools consisting of an ion exchange column, pump, valve, and collection tank. In this study, a reverse osmosis (RO) device was used.

Procedure

Analyzing the copper and chromium content contained in the used electroplating industrial waste samples. Assembling an ion exchange device consisting of a waste column, ion exchange column, pump, valve, and collection tank. Insert the resin into the ion exchange column according to the specified height variations (3 cm, 6 cm, 9 cm, 12 cm, and 15 cm). Insert the ion exchange column into the waste column and flow the waste into the waste column. Collect the waste with the specified flow rate variations (100 ml/min, 200 ml/min, 300 ml/min, 400 ml/min, 500 ml/min). The wastewater that has passed through the resin is collected in an amount of 300 ml to analyze the copper and chromium content.

Analysis of Cu and Cr Metals

The analysis conducted is Atomic Absorption Spectrophotometry (AAS) analysis referring to SNI 6989.78:2019 to determine the copper and chromium content in electroplating industry samples before and after the ion exchange process.

RESULTS AND DISCUSSION

This research was conducted to reduce the heavy metal content, namely copper (Cu) and chromium (Cr), in the liquid waste of the electroplating industry using the ion exchange method with Amberlite IR 120Na resin. The analysis results show that the initial concentrations of Cu and Cr were 0.61 mg/L and 1.28 mg/L, respectively, which exceed the established quality standards. Meanwhile, the quality standard for Cr is 0.5 mg/L, and for Cu, it is 0.6 mg/L. Based on the comparison with the established quality standards, the heavy metal content in this waste still exceeds the permissible threshold. Therefore, efforts are needed to reduce the levels of heavy metals Cr and Cu using the ion exchange method.

Table 1. Reduction of Cu Metal Concentration

Height of Resin (cm)	Flow Rate (ml/min)	Absorbed Cu Metal (mg)	Percentage Decrease (%)
3	100	0,2010	67,05%
	200	0,2140	64,92%
	300	0,2190	64,10%
	400	0,2270	62,79%
	500	0,2350	61,48%
6	100	0,1710	71,97%
	200	0,1780	70,82%
	300	0,1790	70,66%
	400	0,1820	70,16%
	500	0,1840	69,84%
9	100	0,0920	84,92%
	200	0,0945	84,51%
	300	0,0970	84,10%
	400	0,0995	83,69%
	500	0,1040	82,95%
12	100	0,0800	86,89%
	200	0,0850	86,07%
	300	0,0970	84,10%
	400	0,0960	84,26%
	500	0,1030	83,11%
15	100	0,0600	90,16%
	200	0,0620	89,84%
	300	0,0640	89,51%
	400	0,0690	88,69%
	500	0,0700	88,52%

Table 2. Reduction of Cr Metal Concentration

Height of Resin (cm)	Flow Rate (ml/min)	Absorbed Cu Metal (mg)	Percentage Decrease (%)
3	100	0,7010	45,23%
	200	0,7543	41,07%
	300	0,7675	40,04%
	400	0,8108	36,66%
	500	0,8340	34,84%
6	100	0,6820	46,72%
	200	0,6820	46,72%
	300	0,6850	46,48%
	400	0,6870	46,33%
	500	0,6890	46,17%
9	100	0,4650	63,67%
	200	0,5035	60,66%
	300	0,5620	56,09%
	400	0,5905	53,87%
	500	0,6590	48,52%
12	100	0,3670	71,33%
	200	0,3993	68,81%
	300	0,4115	67,85%
	400	0,4438	65,33%
	500	0,4560	64,38%
15	100	0,2130	83,36%
	200	0,2235	82,54%
	300	0,2540	80,16%
	400	0,2845	77,77%
	500	0,2950	76,95%

Based on Table 1, it can be seen that the best reduction in Cu concentration occurs at a flow rate of 100 ml/min with a resin height of 15 cm, reaching 90.16%, while Table 2 shows that the Cr concentration decreases by 83.36% under the same conditions. This study also indicates that a lower flow rate and a greater resin height increase the efficiency of metal ion absorption, with a longer contact time between the waste and the resin. These results indicate that Amberlite IR 120Na resin is effective in reducing heavy metal content to meet quality standards, thereby providing a significant solution in the treatment of liquid waste from the electroplating industry.

Test results show that the ion exchange process successfully reduced the Cr metal content in electroplating industrial waste, with the best conditions at a flow rate of 100 ml/min and a resin height of 15 cm, achieving a reduction of 83.36%. At this flow rate, the amount of Cr absorbed was the highest, while a higher flow rate caused a decrease in Cr absorption due to a shorter residence time. Conversely, a lower flow rate increased the contact time between the solution and the resin, making Cr absorption more effective. Based on the East Java Governor's Regulation No. 52 of 2014, the maximum Cr content in waste is 0.5 mg/L, and this study shows that under the best conditions, the remaining Cr content is only 0.21 mg/L, meeting the quality standards. In addition, the combination of resin heights of 12 cm and 15 cm meets the standards at all flow rate variations, while the 9 cm resin height only meets the standards at a flow rate of 100 ml/min.

Table 3. Reduction of Cu and Cr Metal Concentration

Metal	Initial Concentration (mg/L)	Final Concentration (mg/L)	Percentage Decrease (%)
Cu	0,61	0,06	90,16%
Cr	1,28	0,21	83,36%

Image Presentation

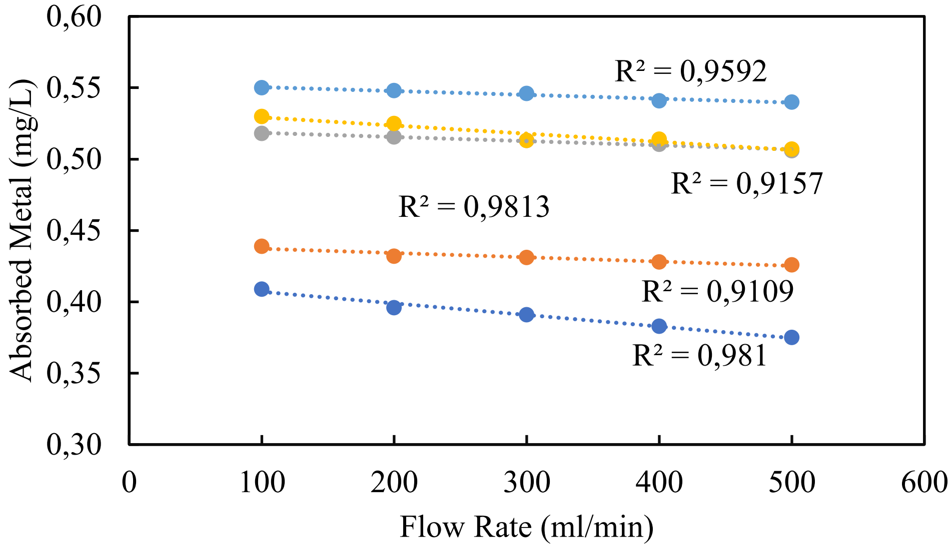

Figure 1. Effect of Flow Rate on Adsorbed Cu Metal

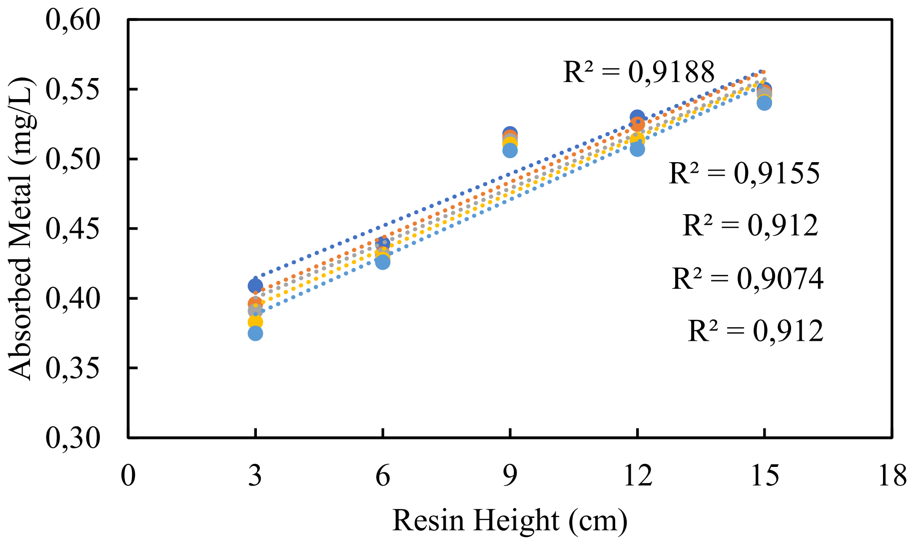

Figure 2. Effect of Resin Height on Adsorbed Cu Metal

In the ion exchange process, there is an interaction between Cu ions and Na^+ ions in the resin. This indicates that Cu metal ions can take over the position of Na^+ ions in the resin, which results in a decrease in the concentration of Cu metal in the sample. Based on the data in Table IV.2, the best conditions for Cu reduction occur at a flow rate of 100 ml/min and a resin height of 15 cm, with a percentage of Cu metal reduction reaching 90.16%. The results of this study when compared with Soemargono's study in 2008, the reduction in metal content was only 40.64% with the stirring method and dowex resin. This is because Amberlite IR120Na resin has a high ion exchange capacity, which means it can absorb a large number of ions before needing to be regenerated.

The level of copper (Cu) metal absorbed by the resin decreased as the flow rate increased. At a flow rate of 100 ml/min, Cu absorption reached its highest efficiency, resulting in the lowest final concentration of Cu metal in the electroplating wastewater. This indicates that when the applied flow rate is increased, the amount of metal absorbed by the resin tends to decrease. Conversely, reducing the flow rate leads to an increase in metal absorption (Yenial, 2017). The underlying reason for this behavior is that at lower flow rates, the contact time between the wastewater and the ion exchange resin is extended. This longer contact time allows for more effective and prolonged interaction between the resin and the Cu ions present in the electroplating industrial wastewater (Sani, 2019). As a result, there is a higher likelihood for Cu ions to exchange with Na^+ ions in the resin matrix. This enhanced ion exchange process ultimately leads to a more significant reduction in the concentration of heavy metals, improving the overall efficiency of the treatment process. Therefore, optimizing the flow rate is crucial in maximizing the removal of Cu ions and ensuring that the treated wastewater meets environmental discharge standards (Hasanuddin, 2023).

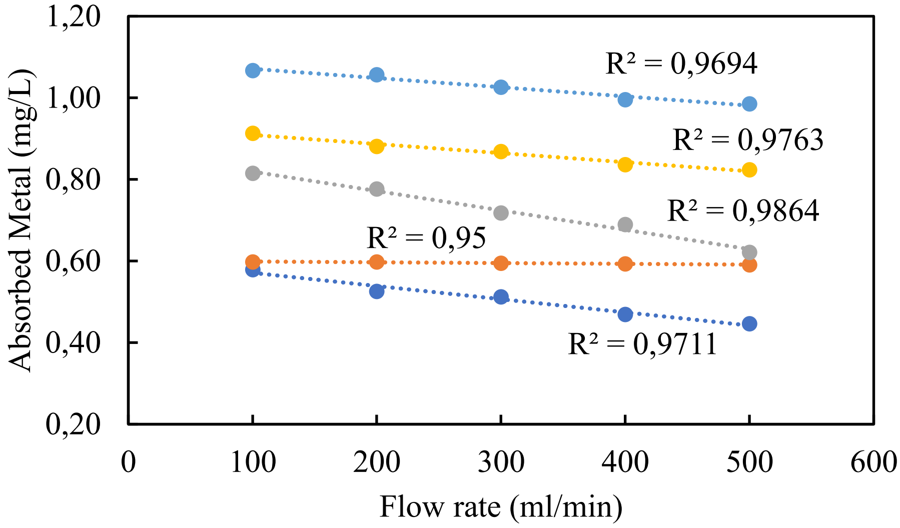

Figure 3. Effect of Flow Rate on Adsorbed Cr Metal

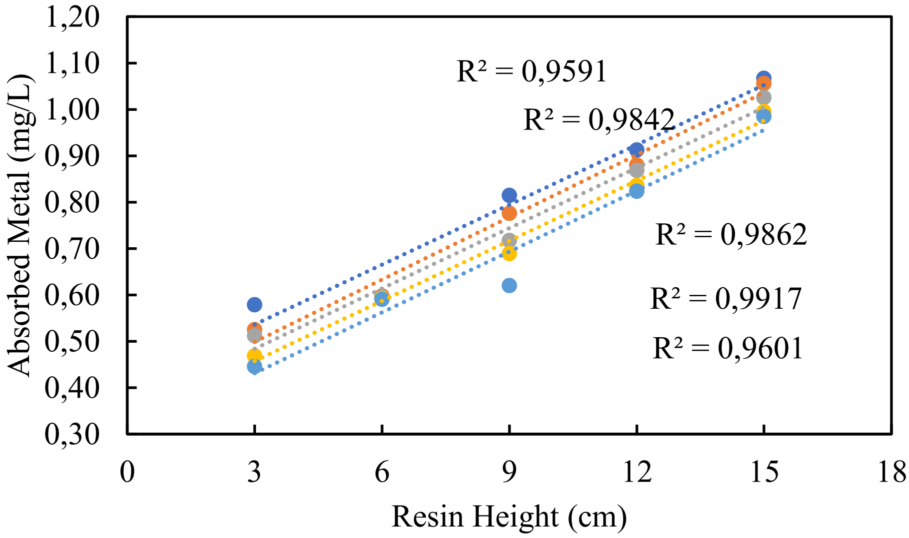

Figure 4. Effect of Resin Height on Adsorbed Cu Metal

The results of the Cr metal content test after going through the ion exchange process showed a decrease in the levels of heavy metals. This indicates that in the ion exchange column there is an exchange between Cr ions in the waste and Na^+ ions contained in the resin as in equation (2). Based on the data in Table IV.3, at a flow rate of 100 ml/minute with a resin height of 15 cm, the decrease in Cr metal content reached 83.36%. This study shows that at the combination of flow rate and resin height, the decrease in Cr metal content reaches the best condition level.

The graph of the effect of flow rate on the amount of Cr metal absorbed shows that at a flow rate of 100 ml/min, the Cr metal absorbed is greater than other flow rate variations. This indicates that at this flow rate, the final concentration of Cr in the electroplating industry wastewater reaches its lowest level. In other words, the higher the flow rate applied, the less Cr metal can be removed. On the other hand, the lower the flow rate, the more Cr can be absorbed. This is because at a lower flow rate, the solution stays in the system longer, giving the resin and ions in the waste an opportunity to exchange longer and more efficiently. As a result, Cr ions in the waste have a higher chance of interacting with Na^+ ions in the resin, thereby reducing heavy metal levels more significantly (Larasati, 2017).

Amberlite IR 120Na resin is effective in reducing the levels of Cu and Cr metals in electroplating waste to meet quality standards, with a reduction of Cu by 90.16% and Cr by 83.36%. These results illustrate the ion exchange mechanism that occurs in the ion exchange column using Amberlite IR 120Na resin. The highest percentage reduction was obtained for Cu metal followed by Cr. This shows that Cu ions exchange faster with Na^+ ions in the resin compared to Cr ions. Based on the percentage obtained, the order of metal ion exchange with Na^+ ions in the resin is Cu first, followed by Cr. This order is in accordance with existing theories. The selectivity value of ion exchange is influenced by the charge of the ion to be exchanged. The first ion to be exchanged by the resin is the ion with the larger charge. If the exchanged ions have the same charge, then the ion to be exchanged first is the ion with the largest atomic mass (Yunisha, 2021). The atomic weight of Cu metal is 63.5 gr/mol; and Cr metal is 51.9 gr/mol. Based on the atomic weight of the metal, the metal that is exchanged first is Cu, then Cr, so it is in accordance with the results obtained in the study.

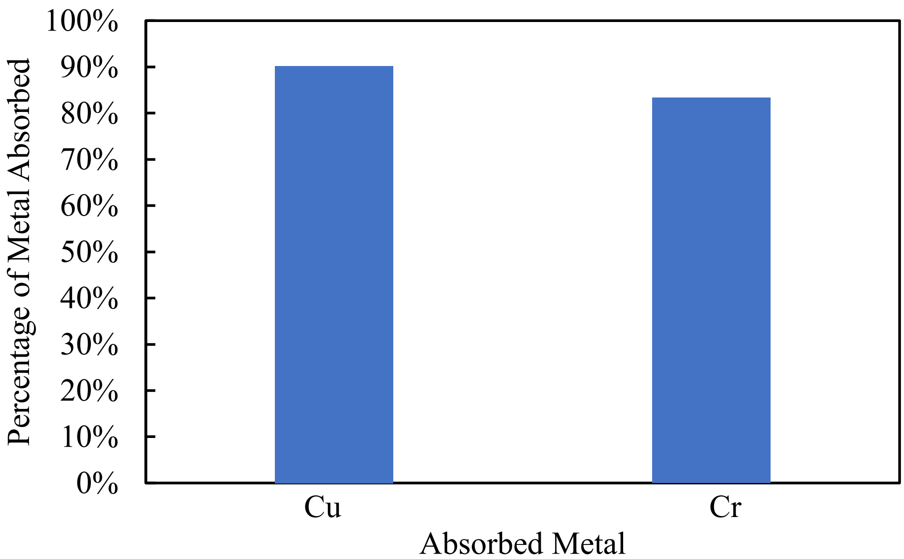

Figure 5. Graph of Percentage of Metal Adsorbed

CONCLUSION

This research demonstrates that the ion exchange method using Amberlite IR 120Na resin is effective in reducing heavy metal levels of copper (Cu) and chromium (Cr) in electroplating industrial wastewater. Under optimal conditions—flow rate of 100 ml/min and resin height of 15 cm—the reduction percentages reached 90.16% for Cu and 83.36% for Cr. These results comply with the quality standards set by the East Java Governor Regulation No. 52 of 2014, making this method an effective solution for wastewater treatment and environmental pollution reduction. It is hoped that further researchers can conduct research on other ion exchange column filling media and combine them.

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