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Biosorption by *Escherichia coli* bacteria of polluting metals chromium Cr (VI) and copper Cu (II)

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Abstract

The increasing activity of the electroplating industry on environmental pollution comes from heavy metals such as chromium Cr(VI) and copper Cu(II) which are toxic. One method of waste treatment is the biosorption method using microorganisms, namely bacteria. This study aims to evaluate the biosorption ability of *Escherichia coli* towards Cr(VI) and Cu(II) metals, as well as the optimum conditions and ratio of absorbed metals. This study was conducted experimentally by culturing *Escherichia coli* in nutrient broth medium that had been given standard solutions of Cr(VI) and Cu(II) metals with varying concentrations (4, 8, 12 and 16 ppm) and ratios (1:1, 1:3 and 3:1). Metal absorption was analyzed using a UV-Vis spectrophotometer. The results showed that *Escherichia coli* was able to absorb both metals. The optimum biosorption percentage for Cr(VI) was 83.40% at a total concentration of 4 ppm in a 1:3 ratio, while Cu(II) was 75.08% at a 3:1 ratio, and the bacteria achieved maximum absorption capacity on day 6.

Keywords: Biosorption; Chromium; Copper; *Escherichia coli*

1. Introduction

Rapid industrial development has a significant impact on economic growth, but on the other hand, it also increases the risk of environmental pollution, especially due to waste containing hazardous materials [1]. Hazardous materials are high-density elements that are durable, difficult to decompose naturally, and can accumulate in the food chain, potentially endangering human health and the environment [2]. The presence of hazardous materials in aquatic environments is a very serious issue because they are toxic even at low levels and are capable of biological accumulation and multiplication. [3].

One of the heavy metals frequently found in industrial waste is chromium (Cr). Chromium exists in various oxidation states, including Cr(III) and Cr(VI), with Cr(VI) being known to have greater toxicity, being a mutagen and carcinogen, and being readily soluble in water, making its movement in the environment very significant [4]. In addition to chromium, copper (Cu) is also frequently found as a heavy metal contaminant. Although Cu is an essential metal in limited quantities, excessively high levels can trigger health problems such as liver, kidney, and digestive system damage [5]. Therefore, the presence of these two metals in liquid waste must be seriously monitored before being discharged into the environment.

Sources of Cr and Cu metal pollution arise not only from the electroplating sector, but also from various other industrial activities such as leather processing, the textile industry, mining, metal dyeing, pigment and paint manufacturing, wood processing, battery production, and waste from households and agricultural activities [6]. One industrial sector known to produce waste with quite high concentrations of heavy metals is electroplating. The electroplating process is a metal coating technique based on electrochemical reactions to strengthen corrosion resistance, increase surface strength, and improve the appearance of metal products [7]. Waste produced from this process generally exhibits characteristics such

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as very high or low pH, significant concentrations of heavy metal ions such as Cr, Cu, Ni, and Zn, and the presence of additional chemicals such as cyanide, strong acids, and surfactants [4].

In response to these issues, researchers have conducted numerous studies to understand how to address environmental challenges. Generally, industries have processes in place to treat the waste they produce. However, it is undeniable that some waste can inadvertently enter the environment, causing accumulation in water bodies and soil. Various methods for treating heavy metal waste have been introduced, one of which is biosorption [8]. Biosorption refers to the use of biomass or microbes to bind and remove heavy metal ions from solutions through physicochemical processes that include ion exchange, complex formation, and surface adsorption. This approach is considered environmentally friendly, affordable, and offers high efficiency in reducing heavy metal levels in wastewater [7].

In this study, *Escherichia coli* bacteria were used as biosorbents. *Escherichia coli* is a type of small rod-shaped bacteria (coccobacilli). This bacterium belongs to the group of gram-negative bacteria and has dimensions between 0.4 µm to 0.7 µm × 1.4 µm [9]. This research was conducted based on the research by Anugerah et al. (2022) on "Method Verification and Absorption of Cr^{6+} Ions by the Bacterium *Pseudomonas sp*." The study found that *Pseudomonas sp*. adsorbed 85.72% of Cr(VI) on day 6 with a Cr(VI) concentration of 5 ppm. At this concentration, it also absorbed up to 96.92% of Cr(VI) over 14 days of exposure [10]. Research by Riki et al. (2021) showed that *Pseudomonas sp*. adsorbed 36.388% of Pb^{2+} on day 14 with an optimum concentration of 4 ppm [11]. Research by Setiawan et al. (2022) showed that *Pseudomonas sp*. adsorbed 84.447% of Cu at a concentration of 3 ppm [12]. And research conducted by Kartika et al., (2023) using *Scenedesmus sp* microalgae absorbed Cr(VI) well 99.93% after twelve days of incubation in a medium containing 1.0 ppm chromium. Twelve days of incubation in a medium with 3.0 ppm chromium only resulted in 50% absorption. Medium with 5.0 ppm and 7.0 ppm chromium is toxic to microalgae, with very little chromium absorbed. This technique can be used as an environmental bioindicator for companies that produce Cr(VI) ion waste in their processes to test their wastewater before discharging it into water bodies or the environment [13]. Based on these empirical results, this study was conducted to test the metal absorption capacity of *Escherichia coli* bacteria when exposed to two metals simultaneously under the same conditions and medium. The experimental design was designed to simulate competitive biosorption conditions by simultaneously exposing *Escherichia coli* to Cr(VI) and Cu(II) at controlled total concentrations and determined molar ratios (1:1, 1:3, and 3:1). This design was chosen to evaluate not only the absorption of single metals but also the competitive interactions between metals for active binding sites on the bacterial cell wall. The total concentration variation (4, 8, 12 and 16 ppm) was intended to assess the adsorption efficiency under increasing metal pressure and to identify potential saturation or toxicity thresholds.

2. Methodology

2.1. Materials and Tools

The equipment used in this study includes stirring rods, measuring cups, Erlenmeyer flasks, filter paper, autoclaves, analytical balances, spatulas, micro pipettes, dropper pipettes, measuring pipettes, volume pipettes, spray bottles, hotplates, magnetic stirrers, Bunsen burners, Buchner funnels, vacuum pumps, sterile cotton swabs, incubators, Schott bottles, desiccators, laminar air flow and UV-Vis spectrophotometers (Thermoscientific evolution one).

The materials used in this study include *Escherichia coli* bacteria, solid $K_2Cr_2O_7 \cdot 7H_2O$, solid $CuSO_4 \cdot 5H_2O$, 1,5-diphenylcarbazide, Na-diethyl dithiocarbamate, concentrated HNO_3 solution, 0.2 N H_2SO_4, 5% NH_4OH solution, Nutrient Broth, distilled water, and 0.45 µm Millipore membrane.

2.2. Research Procedures

Determination of the maximum wavelength of Cr(VI) solution: A 5 ppm Cr(VI) standard solution (10 mL) is added to a 100 mL volumetric flask. 0.25 mL of concentrated H_3PO_4 solution is added to the 100 mL volumetric flask, followed by distilled water up to the mark, and the mixture is homogenized. Then, 2 mL of 0.5% 1,5-diphenylcarbazide solution is added and mixed thoroughly. The solution is left to stand for 5–10 minutes until a purple-red color forms. The absorbance of the solution is then measured using a visible spectrophotometer in the wavelength range of 500–560 nm [14].

Determination of the maximum wavelength of Cu(II) solution: A 10 mL sample of 10 ppm Cu(II) standard solution was added to a 50 mL volumetric flask. The solution was then mixed with 5 mL of 5% NH_4OH and 5 mL of 1% Na-diethyldithiocarbamate. Distilled water was added up to the mark and the mixture was homogenized. The solution is left to stand for 5 minutes until a yellowish-brown color forms. The absorbance of the solution is then measured using a visible spectrophotometer in the wavelength range of 400-600 nm [15].

Standard of Cr(VI) Curve Creation: Standard Cr solutions (0; 0.5; 0.75; 1; 1.25, and 1.5 ppm) were each added to 100 mL volumetric flasks. 0.25 mL of concentrated H_3PO_4 solution was added to a 100 mL volumetric flask, and distilled water was added up to the mark and homogenized. Then, 2 mL of 0.5% 1,5-diphenylcarbazide solution was added and homogenized. The solution was left to stand for 5–10 minutes until a purple-red color formed. The absorbance of the solution was then measured using a visible spectrophotometer at the maximum wavelength obtained (540 nm) [14].

Standard of Cu(II) Curve Creation: Standard Cu solutions (0; 0.5; 0.75; 1; 1.25, and 1.5 ppm) were each added to 100 mL volumetric flasks. Each solution was then mixed with 5 mL of 5% NH_4OH and 5 mL of 1% Na-diethyldithiocarbamate. Distilled water was added to the mark, and the mixture was homogenized. The solutions were allowed to stand for 5 minutes until a yellowish-brown color formed. The absorbance of the solutions was then measured using a visible spectrophotometer at the maximum wavelength obtained (450 nm) [15].

Regeneration of *Escherichia coli* bacteria: Add 1 gram of nutrient broth to 12 Erlenmeyer flasks (250 mL) and dissolve using 200 mL of distilled water. Boil using a hotplate at 60°C while homogenizing. Sterilize the medium using an autoclave at 121°C for 15 minutes. Take 10 mL of the sterilized medium and place it into a 50 mL Erlenmeyer flask. Inoculate 10 µL of *Escherichia coli* bacteria into the medium. Incubate the medium at 37°C for 24 hours before use.

Biosorption of Cr(VI) and Cu(II) Metals (4, 8, 12, and 16 ppm) by *Escherichia coli* Bacteria: 12 Erlenmeyer flasks containing Nutrient Broth medium were added with Cr(VI) standard solution and Cu(II) standard solution at 100 ppm, with the ratio between Cr(VI) and Cu(II) at each concentration being (1:1; 1:3, and 3:1 ppm) with the addition of each total concentration (4, 8, 12, and 16 ppm) in the following volumes: (4:4, 2:6, 6:2 mL); (8:8, 4:12, 12:4 mL); (12:12, 6:18, 18:6 mL) and (16:16, 8:24, 24:8 mL) of Cr(VI) standard solution and Cu(II) standard solution. Then, 1 mL of *Escherichia coli* bacterial starter was inoculated into each medium. The biosorption medium was incubated at 37°C, and metal concentrations were measured every 24 hours.

Testing for Cr(VI) in metals: 10 mL of bacterial medium sample solution was taken at each concentration of Cr(VI) and Cu(II) metals (4, 8, 12, and 16 ppm). The solution was filtered using a 0.45 µm Millipore membrane into a 50 mL Erlenmeyer flask. 0.25 mL of concentrated H_3PO_4 solution were added to the 50 mL Erlenmeyer flask. The pH of the solution was adjusted by adding 0.2 N H_2SO_4 (pH ± 0.5). Then, 2 mL of 0.5% 1,5-diphenylcarbazide solution was added and homogenized. The solution was left to stand for 5–10 minutes until a purple-red color formed. The absorbance value of the solution was measured using a visible spectrophotometer at a wavelength of 540 nm [14].

Testing for Cu(II) in metals: 10 mL of bacterial medium sample solution was taken at each concentration of Cr(VI) and Cu(II) metals (4, 8, 12, and 16 ppm). The solution was filtered using a 0.45 µm Millipore membrane into a 50 mL Erlenmeyer flask. Then, 5 mL of 5% NH_4OH and 5 mL of 1% Na-diethyldithiocarbamate were added. The solution was mixed thoroughly and let sit for 5 minutes until it turned yellowish-brown. The absorbance value of the solution was measured using a visible spectrophotometer at a wavelength of 450 nm [15].

2.3. Analysis of Results

The data were analyzed based on a standard curve created by plotting the absorbance on the y-axis and the concentration on the x-axis using a series of standard Cr and Cu solutions with concentrations of (0; 0.5; 0.75; 1; 1.25 and 1.5 ppm). This resulted in the following equation:

$$y = ax \pm b$$

Description:
a = *Slope*
b = *Intercept*
y = Sample Absorbance
x = Sample Concentration (ppm)

The biosorption percentage is obtained by calculating the difference between the metal concentration before biosorption and after biosorption using the following equation:

$$\% \text{ Biosorption} = \frac{C_a - C_b}{C_a} \times 100\%$$

Description:

C_a = Metal concentration before biosorption (ppm)
C_b = Metal concentration after biosorption (ppm) [12]

3. Results and Discussion

3.1. Determination of the Standard Curve of Cr(VI) Solution

Based on SNI 6989.71:2009, which shows that the complex compound between Cr(VI) metal ions and diphenylcarbazide solution forms a Cr-diphenylcarbazone complex that produces a red-purple solution color. This color is directly proportional to its absorbance with each increase in concentration. Therefore, a standard curve is created after determining the maximum wavelength of the standard solution. From the experiments conducted, the maximum wavelength was found to be 540 nm. Thus, a standard curve can be created by measuring the absorbance of a series of Cr(VI) standard solutions (0; 0.5; 0.75; 1; 1.25, and 1.5 ppm) at a wavelength of 540 nm using a visible spectrophotometer. The resulting graph is shown in Figure 1.;

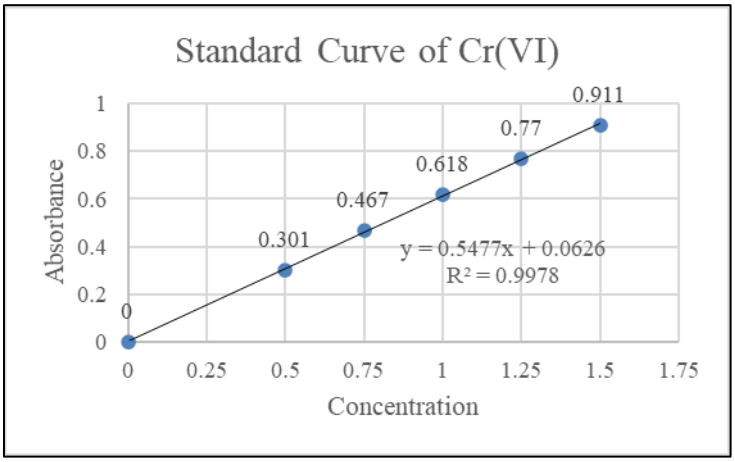


Figure 1 Standard Curve of Cr(VI) Solution

From the information shown in Figure 1, it can be seen that when the concentration of Cr(VI) increases by one unit, the measured absorbance value also increases by the same amount. The relationship between absorbance and concentration is shown by the regression equation y = 0.5477x + 0.0626 and a correlation coefficient of 0.9978. A correlation coefficient close to one indicates a strong relationship between concentration and absorbance.

3.2. Determination of the Standard Curve of Cu(II) Solution

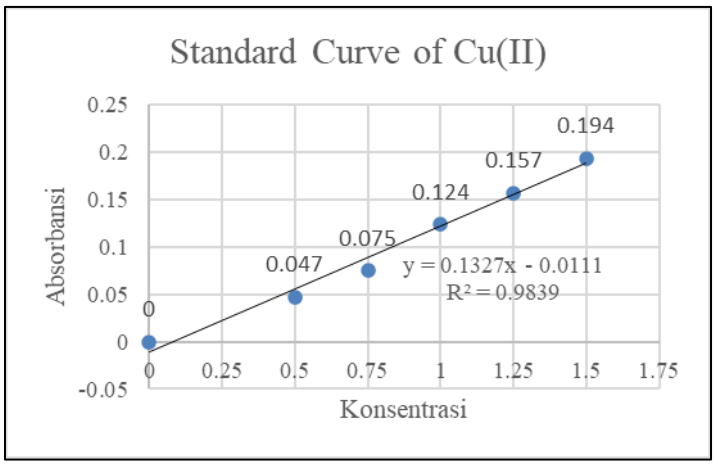


Figure 2 Standard Curve of Cu(II) Solution

The maximum wavelength is determined beforehand before creating the Cu(II) standard curve. Using a spectrophotometer, the Cu(II) solution reacts with Na-diethyldithiocarbamate to form a yellowish-brown Cu-

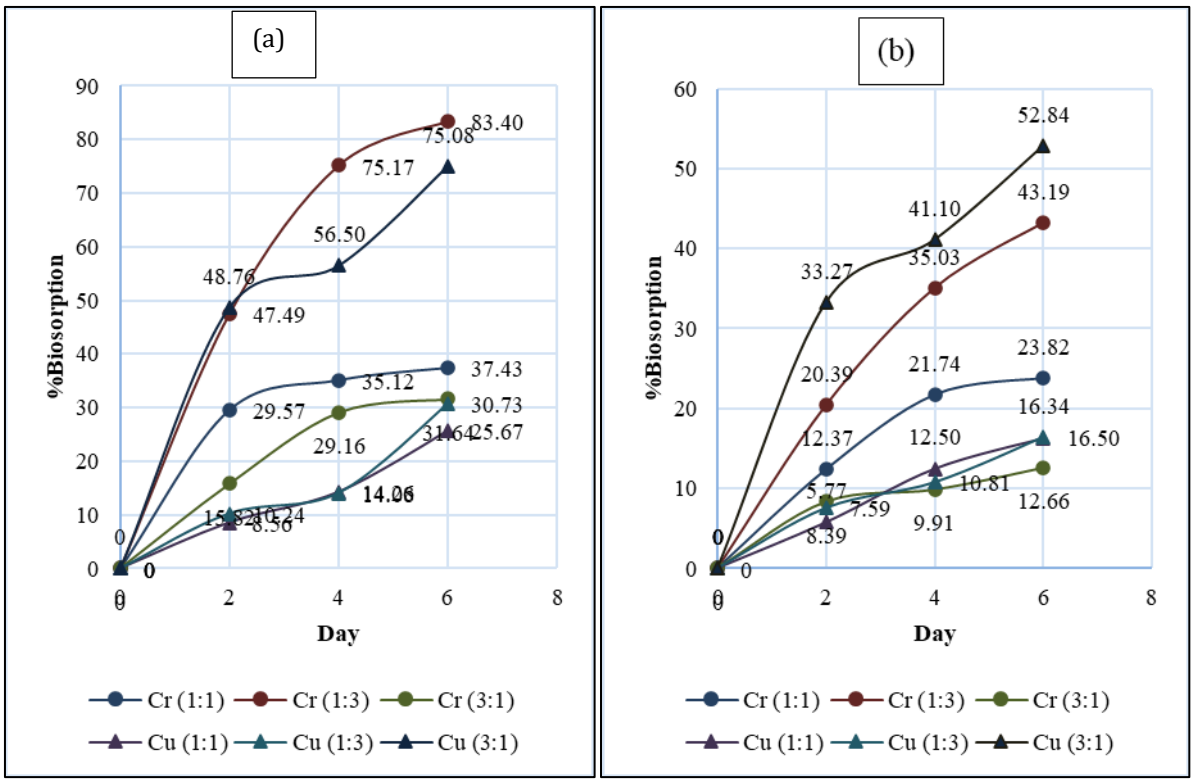
diethyldithiocarbamate complex. This color can be absorbed and is directly proportional to each increase in the concentration of the Cu(II) solution [11]. From the experiment conducted, the maximum wavelength obtained was 450 nm. Subsequently, a standard curve was created by measuring the absorbance of a series of standard Cu(II) solutions (0; 0.5; 0.75; 1; 1.25, and 1.5 ppm) at a wavelength of 450 nm using a visible spectrophotometer. The resulting graph is shown in Figure 2.

From the information shown in Figure 1, it can be seen that when the concentration of Cu(II) increases by one unit, the measured absorbance value also increases by the same amount. The relationship between absorbance and concentration is shown by the regression equation y = 0.1327x - 0.0111 and a correlation coefficient of 0.9839. A correlation coefficient close to one indicates a strong relationship between concentration and absorbance.

3.3. Biosorption of Cr(VI) and Cu(II) Metals by *Escherichia coli*

Two principles apply in the biosorption process. First, in the cell wall there is an exchange of singly charged ions such as Na + and doubly charged ions such as Mg^{2+} and Ca^{2+}, which are then replaced by heavy metal ions. Second, the formation of complexes between heavy metal ions and functional groups such as carboxyl, phosphate, hydroxyl, amine, and thiol groups [16]. In *Escherichia coli*, many of these groups are found in peptidoglycan, lipopolysaccharide (LPS) and surface proteins so that water and metal ions can interact in a complex through ion-ligand coordination [17].

Using *Escherichia coli* bacteria in this study, a variation in method was carried out by exposing two metals simultaneously to one bacterial medium. Cr(VI) and Cu(II) metals were exposed to the bacterial medium with varying concentrations of the mixture (4, 8, 12, and 16 ppm) at metal ratios of Cr(VI) to Cu(II) of 1:1, 1:3, and 3:1.



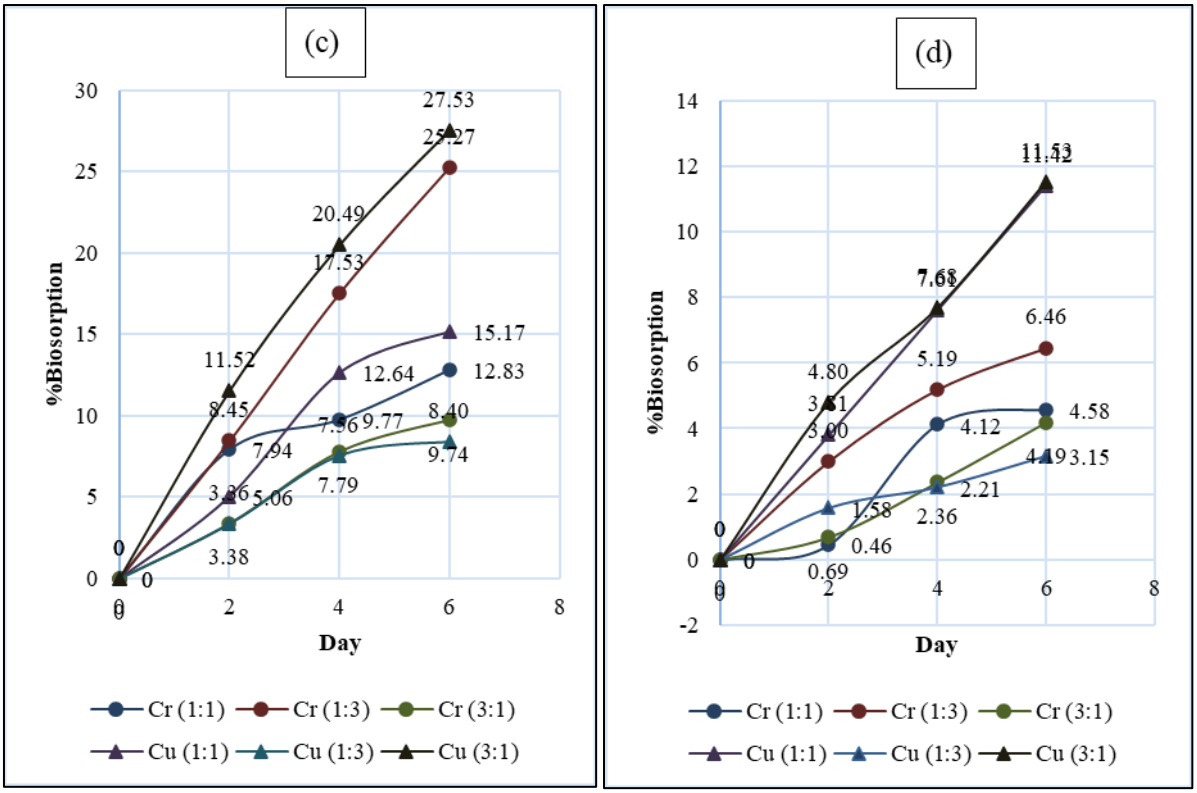


Figure 3 Graph of % biosorption of Cr(VI) and Cu(II) metals, (a) total concentration 4 ppm; (b) total concentration 8 ppm; (c) total concentration 12 ppm; and (d) total concentration 16 ppm (Source: https://drive.google.com/file/d/1ah2tnrduy0VD2PXTc_m5ItHLWBoY742y/view?usp=drive_link**)**

From Figure 3, it can be seen that the comparison of the percentage of Cr(VI) and Cu(II) metal biosorption at each concentration ratio exposed to *Escherichia coli* bacteria. The results show that at a total concentration of 4 ppm Cr(VI) metal, the highest percentage of biosorption was obtained at a ratio of 1:3, with a biosorption percentage of 83.40%, followed by ratios of 1:1 and 3:1, with biosorption percentages of 37.43% and 31.64%, respectively. Meanwhile, for Cu(II) metal, the highest adsorption was obtained at a ratio of 3:1 with a biosorption percentage of 75.08%, followed by ratios of 1:3 and 1:1 with biosorption percentages of 30.73% and 25.67%, respectively. At a total concentration of 8 ppm Cr(VI) metal, the highest adsorption was achieved at a ratio of 1:3 with a biosorption percentage of 43.19%, followed by ratios of 1:1 and 3:1 with biosorption percentages of 23.82% and 12.66%, respectively. Meanwhile, for Cu(II) metal, the highest adsorption was obtained at a ratio of 3:1 with a biosorption percentage of 52.84%, followed by ratios of 1:3 and 1:1 with biosorption percentages of 16.50% and 16.34%, respectively. The adsorption results decreased with increasing concentration, with the highest adsorption results obtained at a total concentration of 12 ppm Cr(VI) metal at a ratio of 1:3 with a biosorption percentage of 25.27%, followed by ratios of 3:1 and 1:1 with biosorption percentages of 12.83% and 9.74%, respectively. Meanwhile, for Cu(II) metal, the highest adsorption was obtained at a ratio of 3:1 with a biosorption percentage of 27.53%, followed by ratios of 1:1 and 1:3 with biosorption percentages of 15.17% and 8.40%, respectively. Similarly, at a total concentration of 16 ppm Cr(VI) metal, the highest adsorption was obtained at a ratio of 1:3 with a biosorption percentage of 6.46%, followed by ratios of 1:1 and 3:1 with biosorption percentages of 4.58% and 4.19%, respectively. Meanwhile, for Cu(II) metal, the highest adsorption was obtained at a ratio of 3:1 with a biosorption percentage of 11.53%, followed by ratios of 1:1 and 1:3 with biosorption percentages of 11.42% and 3.15%, respectively.

The results of the study showed that bacterial activity in absorbing metals occurred well at lower concentrations, indicating higher absorption. Similarly, when viewed from the total concentration exposed, lower concentrations provided higher absorption. As the concentration exposed to bacteria increased, there was a decrease in the percentage of metal absorption [15]. High metal concentrations can also have a toxic effect on bacteria, affecting bacterial growth activity, thereby preventing optimal metal absorption by bacteria [15]. Significant differences in the percentage of Cr(VI) and Cu(II) metal biosorption can also be seen in the graphs presented at each total concentration. The results showed that Cr(VI) metal absorption was more effective by *Escherichia coli* compared to Cu(II) metal absorption. Because *Escherichia coli* bacteria are gram-negative bacteria, which have a lipopolysaccharide (LPS) layer that functions

as a highly adsorbent reactive surface for anions such as Cr(VI) metal. This structure can support better absorption than Cu(II) metal which often requires complex bonds [18].

The higher absorption of Cr(VI) compared to Cr(II) is caused by Cr(VI) often not only being physically adsorbed to the cell surface, but also being biologically reduced to the less toxic Cr(III). *Escherichia coli* bacteria have a chromate reductase enzyme that can reduce Cr(VI), so that the Cr(VI) attracted to the cell surface remains retained [19]. Meanwhile, the different metal Cu(II) must be influenced by pH and the condition of the active surface sites compared to Cr(VI) [16]. Likewise, when viewed from the total concentration exposed, it shows that a smaller concentration provides a higher absorption. The higher the concentration exposed to bacteria, the lower the percentage of metal absorption [16]. High metal concentrations can also have a toxic effect on bacteria that affects bacterial growth activity so that metal absorption by bacteria is not optimal [20].

4. Conclusion

It can be concluded that *Escherichia coli* bacteria are capable of absorbing Cr(VI) and Cu(II) metals with optimal absorption of Cr(VI) metal at 83.40% at a ratio of 1:3 and optimal absorption of Cu (II) is 75.08% at a ratio of 3:1 with a total concentration of 4 ppm on day 6.

Compliance with ethical standards

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Disclosure of Conflict of Interest

The authors declare that they have no conflicts of interest related to the publication of this paper.

References

[1] Prastuti, O. P., and Erliansary, D. R. (2023). Adsorption of PB metal using activated carbon from coconut fiber. Industria: Jurnal Teknik Kimia, Vol 11, No 2.

[2] Amalina, Y. N., Salimin, Z., and Sudarno. (2015). The Effect of pH and Process Time on the Removal of Heavy Metals Cr, Fe, Zn, Cu, Mn and Ni in Electroplating Industrial Wastewater with Biochemical Oxidation Process. Jurnal Teknik Lingkungan, Vol 4, No. 3.

[3] Purwanto and Huda, S. (2005). Electroplating Industry Technology. Universitas Diponegoro: Semarang.

[4] Maisarah and Dian, R. (2024). Development of Algae-Based Biosorbents and the Use of the Life Cycle Assessment (LCA) Method as a Decision-Making Support in Assessing Environmental Impacts. Pustaka Aksara: Surabaya.

[5] Kunsah, B., Ariana, D., Wahyuningsih, E., and Wahyuningsih, R. (2023). Clinical Toxicology. Rena Cipta Mandiri: Malang.

[6] Nurhasni, Salimin, Z., and Nurifitriyani, I. (2013). Electroplating Industrial Waste Treatment Using Coagulation Flocculation Process. Valensi, Vol 3, No 1. https://doi.org/10.15408/JKV.V3I1.328

[7] Agustina, T., Pane, E. R., and Legasari, L. (2024). Analysis of Copper (Cu) Metal Content in Soil Using Atomic Absorption Spectrophotometer (AAS). Jurnal Kimia Dan Pendidikan Kimia, Vol 13, No 1. https://doi.org/10.36709/sains.v13i1.57

[8] Setiawan, A., Basyiruddin, F., and Dermawan, D. (2019). Biosorption of Heavy Metal Cu(II) Using Saccharomyces Cerevisiae Waste. Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan, Vol 16, No 1. https://doi.org/10.14710/presipitasi.v16i1

[9] Wahyuningsih, E. S., Gunarti, N. S., Fikauniar, L., and Fajriyani, A. (2023). Organoleptic and Microbiological Tests of Refilled Drinking Water Around UBP Karawang. Open Journal Systems, Vol 17, No 9. https://doi.org/10.33578/mbi.v17i9.365

[10] Anugerah, D., Kartika, R., and Gunawan, R. (2022). Method Verification and Absorption of Cr^{6+} Ion by the Bacterium Pseudomonas sp. AIP Conference Proceedings, Vol 2668, Issue 1. https://doi.org/10.1063/5.0112011

[11] Riki, R., Kartika, R., and Gunawan, R. (2022). Biosorption of Pb2+ Ion by Bacterium Pseudomonas sp. AIP Conference Proceedings, Vol 2668, Issue 1. https://doi.org/10.1063/5.0112190

[12] Setiawan, A. D., Kartika, R., and Gunawan, R. (2022). Adsorption of Cu(II) ion in aqueous solution by Pseudomonas sp. Biosorbent. AIP Conference Proceedings, Vol 2668, Issue 1. https://aip.scitation.org/doi/abs/10.1063/5.0112558

[13] Kartika, R., Ritonga, A. H., Sulastri, L., Nurnila, S., Irawan., and Simanjuntak, P. (2023). Biosorption of Hexavalent Chromium Cr(VI) using Microalgae Scenedesmus sp as Environmental Bioindicator. International Journal of Technology, 14(4), 791-799.

[14] National Standardization Agency, Water and Wastewater: Test Method for Hexavalent Chromium (Cr-VI) in Test Samples Spectrophotometrically, vol. 6989. Indonesia: Badan Standarisasi Nasional, 2009. [Online]. Available: https://wiac.info/docdownloadv2-pdf-sni-698971-2009-cr-6-spektro dl_8dc7281b8a43041de5518d1a38ae6659?data_code=6a645281905caa37f893c4236c78b355

[15] Pratiwi, N. A., and Sunarto. (2018). Comparison Validation Of Analytical Methods Ion Copper (II) Without Complexing and With Complexing Na-diethyldithiocarbamate By UV-Vis Spectrophotometry. Jurnal Kimia Dasar, Vol 7, No. 3.

[16] Ratnawati, E., Ermawati, R., and Naimah, S. (2010). Biosorption Technology By Microorganisms, An Alternative Solution For Decrease Heavy Metal Pollution. Jurnal Kimia dan Kemasan, Vol 32, No 1. https://doi: 10.24817/jkk.v32i1.2739.

[17] Pham, V. H. T., Kim, J., Chang, S., and Chung, W. (2022). Bacterial Biosorbents, an Efficient Heavy Metals Green Clean-Up Strategy: Prospects, Challenges, and Opportunities. Microorganisms, 10, 1-16. https://doi.org/10.3390/microorganisms10030610

[18] Ramya, D., and Thatheyus, A. J. (2018). Microscopic Investigations on the Biosorption of Heavy Metals by Bacterial Cells. Science International, 6(1), 11-17. https://doi.org/10.17311/sciintl.2018.11.17

[19] Rahman, Z., and Thomas, L. (2021). Chemical- Assisted Microbially Mediated Chromium Cr(VI) Reduction Under the Influence of Various Electron Donors, Redox Mediators, and Other Additives: An Outlook on Enhanced Cr(VI) Removal. Frontiers in Microbiology, 11, 1-19. https://doi.org/10.3389/fmicb.2020.619766

[20] Diantariani, N. P., Sudiarta, I. W., and Elantiani , N. K. (2008). Biosorption and Desorption Process of Cr(VI) Ions on Seaweed Biosorbent. Jurnal Kimia, Vol. 2, No. 1.