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# Preparation and Field Application of A Cellulose Triacetate-Based Optode for Cr(VI) Detection in Environmental Water Samples

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***Abstract—*** In this study, the optode was fabricated by incorporating 1,5-diphenylcarbazide and the ion carrier Aliquat 336 into a cellulose triacetate polymer matrix, which was subsequently modified using a dual-plasticizer system consisting of oleic acid and acetophenone. The successful synthesis of the optode was justified through FTIR spectroscopy to confirm functional group immobilization and screw micrometer measurements to ensure membrane thickness uniformity. A linear response was obtained within the concentration range of 0.02–0.40 ppm, with a determination coefficient ($R^2$) of 0.9979, a limit of detection of 0.0108 ppm, a limit of quantitation of 0.0328 ppm, precision expressed as a relative standard deviation of 4.458%, and accuracy of 97.51%. The optode demonstrated high analytical sensitivity, as evidenced by a molar absorptivity of $2.262 \times 10^7$ $M^{-1}$ $cm^{-1}$, along with excellent selectivity against common potentially interfering ions, including Fe(III), Pb(II), Zn(II), and Cd(II). The formed color complex exhibited good stability, remaining unchanged for up to five days. When applied to the determination of Cr(VI) in water samples, the optode yielded a concentration of 0.0664 ppm with satisfactory precision and accuracy. Although this value differed from the concentration obtained using UV-Vis spectrophotometry (0.0881 ppm), the overall performance of the optode was validated. Furthermore, a functional prototype was successfully developed and evaluated using real samples, producing favorable results. Collectively, these outcomes highlight the strong potential for further development and optimization of the proposed system.

***Keywords—*** *Cellulose triacetate; Environmental monitoring; Hexavalent chromium; Optode; Performance evaluation*

## 1. INTRODUCTION

Massive industrial activity, particularly in leather tanning, electroplating, and dye manufacturing, represent major contributors to chromium contamination in aquatic environments [1]. In natural waters, chromium predominantly occurs in two oxidation states, trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)). While Cr(III) is an essential trace element involved in various biological processes, Cr(VI) is highly toxic and carcinogenic, posing serious threats to human health and ecological sustainability. Moreover, environmental conditions, including variations in pH, may facilitate the oxidation of Cr(III) to the more hazardous Cr(VI) species [2].

In perspective of its significant health and environmental risks, regulatory agencies have established stringent limits for permissible Cr(VI) concentrations in water. In Indonesia, the Indonesian National Standard (SNI) 01-3553-2006 and Government Regulation of the Republic of Indonesia No. 82 of 2001 specify a maximum allowable concentration of 0.05 ppm for Cr(VI) in water. Likewise, the United States Environmental Protection Agency (US EPA) established a limit of 0.1 ppm for Cr(VI) in surface waters in 2011 Therefore, regular and accurate monitoring of Cr(VI) levels is crucial.

Established analytical techniques, including atomic absorption spectroscopy (AAS), inductively coupled plasma-mass spectrometry (ICP-MS) [3], ion chromatography, and UV-Vis spectrophotometry [4], provide high sensitivity and selectivity for the

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determination of Cr(VI) through well-validated approaches such as colorimetric analysis and calibration-based quantification. Nevertheless, the practical application of these methods is constrained by several drawbacks, including time-consuming sample preparation procedures, substantial capital and operational costs [5], and the lack of capability for in situ measurements, thereby limiting their suitability for rapid on-site monitoring.

The development of membrane-based optical sensors (optodes) has become a focus of research as a simple, economical, and portable alternative method [6]. The working principle of these optodes is based on the immobilization of active components (dye reagents) in a polymer matrix. The matrix will produce an optical response, such as a color change, when it selectively reacts with the target analyte, the intensity of which is proportional to the analyte concentration. The use of optodes can reduce preparation costs, increase sensitivity and selectivity, and allow their use in test strips or kits, allowing for *in situ* analysis [6-8].

A wide variety of recent sensor platforms have been created for Cr(VI) detection in water, aiming for high sensitivity and field deployability. Cellulose triacetate (CTA) has been extensively employed as a membrane matrix for Cr(VI) sensing due to its high selectivity, with reported transport efficiencies exceeding 90–99% when applied to real water samples using conventional approaches [9,10]. In parallel, carbon dots have emerged as low-toxicity fluorescent probes for Cr(VI) detection, where signal quenching occurs through inner filter effects or related mechanisms. Notably, N,Zn-doped and Mn-doped carbon dots have demonstrated exceptionally low detection limits and have been successfully applied to the analysis of environmental water samples [11,12].

In this study, CTA was chosen as the matrix polymer due to its superior hydrophobic properties, good transparency, and water-resistance, thus preventing the membrane from becoming opaque during testing. The optode membrane was prepared by dissolving cellulose triacetate (CTA) in the presence of a plasticizer system composed of oleic acid and acetophenone, together with an ion carrier, Aliquat 336 (trioctylmethylammonium chloride), and the chromogenic reagent 1,5-diphenylcarbazide (DPC). Aliquat 336 plays a crucial role in promoting the transfer of hexavalent chromium (Cr(VI)) from the aqueous phase into the hydrophobic membrane matrix, where it subsequently interacts with DPC. Within the membrane environment, Cr(VI) oxidizes DPC to diphenylcarbazone (DPCO) while being reduced to trivalent chromium (Cr(III)). Furthermore, the resulting Cr(III) ions will form a stable purple complex with DPCO, which serves as the basis for spectrophotometric quantification.

Initial research by Arif *et al.* [9] has successfully demonstrated good analytical performance of this optode, with a linear response range at concentrations of 0.02–0.40 ppm, a coefficient of determination ($R^2$) of 0.9968, and a detection limit of 0.0055 ppm. However, validation of its performance is still limited to standard solutions under laboratory conditions. A thorough validation of the optode system has previously been reported by Arif et al. [10]. In the present work, a comprehensive performance assessment was carried out to confirm the reliability of the optode as an in situ analytical platform for Cr(VI) monitoring, encompassing accuracy evaluation using real water matrices as well as long-term stability studies. The fabricated optode was directly applied to river water samples without extensive pretreatment. At this stage, the evaluation remains limited to conditioned samples and is based on a comparative analysis of results obtained using the proposed sensing approach.

## 2. EXPERIMENTAL SECTION

### 2.1. Materials

The materials used for this research were water sample from the IPB Ciapus River Water Treatment Unit (Bogor Regency), cellulose triacetate (CTA) (CAS No. 9012-09-3), oleic acid (CAS No. 112-80-1), acetophenone (CAS No. 98-86-2), chloroform (CAS No. 67-66-3), methanol (CAS No. 67-56-1), 1,5-diphenylcarbazide (DPC) (CAS No. 140-22-7), trioctylmethylammonium chloride (aliquot 336) (CAS No. 63393-96-4), potassium dichromate ($K_2Cr_2O_7$) (CAS No. 7778-50-9), cadmium nitrate ($Cd(NO_3)_2$) (CAS No. 10022-68-1), zinc sulfate heptahydrate ($ZnSO_4{\cdot}7H_2O$) (CAS No. 7446-20-0), iron(III) chloride hexahydrate ($FeCl_3{\cdot}6H_2O$) (CAS No. 10025-77-1), lead(II) nitrate ($Pb(NO_3)_2$) (CAS No. 10099-74-8), sulphuric acid ($H_2SO_4$) (CAS No. 7664-93-9), nitric acid ($HNO_3$) (CAS No. 7697-37-2), phosphoric acid ($H_3PO_4$) (CAS No. 7664-38-2), acetone (CAS No. 67-64-1), sodium hydroxide (NaOH) (CAS No. 1310-73-2), and hydrochloric acid (HCl) (CAS No. 7647-01-0). All chemicals used in this study were of analytical reagent grade and were purchased from Merck (Darmstadt, Germany).

### 2.2. Instrumentation

A range of analytical instruments was employed, including an analytical balance (OHAUS AX224/E), magnetic stirrer, sonicator, and oven, along with a pH meter (Hanna HI 2211). Optical and vibrational analyses were conducted using a UV–Vis spectrophotometer (Ocean Optics Vis-NIR USB4000) and an FTIR spectrometer (ABR, 4000–400 $cm^{-1}$).

### 2.3. Fabrication of Optode Membrane

Membrane fabrication was performed following the procedures reported in references [9,10], with minor adjustments. A cellulose triacetate (CTA) stock solution was prepared by dissolving 0.1350 g of CTA in 10 mL of chloroform. In parallel, a solution of 1,5-

diphenylcarbazide (DPC) was obtained by dissolving 5 mg of the reagent in 5 mL of methanol. Subsequently, the CTA solution was supplemented with 0.30 mL of a plasticizer system consisting of oleic acid (0.03 mL) and acetophenone (0.27 mL), together with 0.07 mL of Aliquat 336. The resulting mixture was stirred magnetically for 15 min, after which the DPC solution was introduced and further stirred for an additional 15 min. Homogenization was enhanced by sonication for 5 min. The final mixture was cast onto a Petri dish and left to dry at ambient temperature for 48 h. The resulting optode membrane was then cut into strips measuring 1 × 3 cm.

### 2.4. Characterization of Optode Membrane

Characterization of optode membranes with FTIR spectroscopy to prove the presence of bond changes in the process of preparing and using optode membranes. Measurements were taken in the wavenumber range of 4000–400 $cm^{-1}$. The optode membrane was placed in a sample holder and the instrument was operated. The characterized membranes consisted of CTA only, CTA+DPC, and CTA+DPC+Cr(VI). The obtained IR spectra were then analyzed for functional groups.

The thickness of the optode membrane was evaluated by selecting six membrane strips (1 × 3 cm) from each of three Petri dishes. Measurements were performed using a screw micrometer, and the resulting thickness values were recorded and categorized accordingly. Statistical analysis was carried out using a two-way t-test at a 95% confidence level. The corresponding hypothesis is expressed in Equation (1).

$$H_0\text{: } \bar{x}_1 = \bar{x}_2\text{; } H_A\text{: } \bar{x}_1 \neq \bar{x}_2 \quad (1)$$

Where $H_0$ is no significantly difference in the mean of the two data set, and $H_A$ is significantly difference in the mean of the two data set.

### 2.5. Performance Test of Optode Membrane

Each optode membrane was immersed in 25 mL of Cr(VI) standard solutions with concentrations varying from 0 to 1 ppm, adjusted to pH 3. The membranes were allowed to interact with the solutions for 15 min. Following exposure, the resulting color response of the optode was quantitatively evaluated by recording absorbance spectra using a UV–Vis spectrophotometer over the wavelength range of 400–700 nm.

Evaluation of the optode membrane began with determination of the appropriate working concentration range. The analytical performance of the optode was subsequently assessed in terms of linear response, limits of detection and quantification, as well as precision, accuracy, sensitivity, selectivity, and signal stability. All measurements were performed at the wavelength of maximum absorbance using a UV–Vis spectrophotometer.

### 2.6. Detection of Cr(VI) in Water Sample

A series of Cr(VI) calibration standards covering the concentration range of 0.02–0.4 ppm was prepared, with each solution transferred into an individual 25 mL volumetric flask. To each flask, two drops of phosphoric acid ($H_3PO_4$), 2 mL of 2 M sulfuric acid ($H_2SO_4$), and 0.5 mL of the chromogenic reagent 1,5-diphenylcarbazide (DPC) were sequentially added. The DPC reagent was freshly prepared by dissolving 0.125 g of 1,5-diphenylcarbazide in 25 mL of acetone. After thorough mixing to ensure homogeneity, the absorbance of the resulting solutions was recorded at 542 nm using a UV–Vis spectrophotometer.

The sample used for the determination of Cr(VI) is water from river (Ciapus River) in the Dramaga District, Bogor. Samples were taken in the morning before 10 AM using plastics vials. pH Measurement of samples were conducted and the average was 6.80. The optode membrane was immersed in the sample solution, adjusted to pH 3, for an interaction period of 15 min. The sample matrix was prepared by combining 10 mL of distilled water with 15 mL of the collected water sample. Following exposure, the chromatic response of the optode was quantitatively evaluated by measuring absorbance at the maximum wavelength of 550 nm using a UV–Vis spectrophotometer. In addition, the precision and accuracy of the optode were assessed using the same sample solution.

## 3. RESULT AND DISCUSSION

### 3.1. Characteristic of Optode Membrane

An optode fundamentally consists of a membrane that functions as the sensing element, enabling the monitoring of chemical interactions within a sample through coupling with spectroscopic techniques such as reflectance, absorbance, fluorescence, and/or luminescence detection. The membrane serves as an interface between the sample matrix and the immobilized reagent, allowing target ions to diffuse through organic or inorganic media and subsequently react with the sensing reagent to form a measurable colored complex [13,14]. Cellulose triacetate (CTA) membranes offer several advantageous properties, including high mass transport (flux), adequate mechanical strength, and insolubility in alcohol-based solvents [15]. The high flux characteristic reflects the presence of relatively large pore structures, which facilitate the immobilization of analyte-recognition components within the membrane matrix [14]. In this work, CTA was employed as the optode matrix with 1,5-diphenylcarbazide (DPC) incorporated as the active sensing component. Upon exposure to hexavalent chromium, DPC undergoes oxidation to diphenylcarbazone (DPCO), accompanied by the reduction of Cr(VI) to Cr(III). The resulting Cr(III) subsequently complexes with DPCO to form a purple-

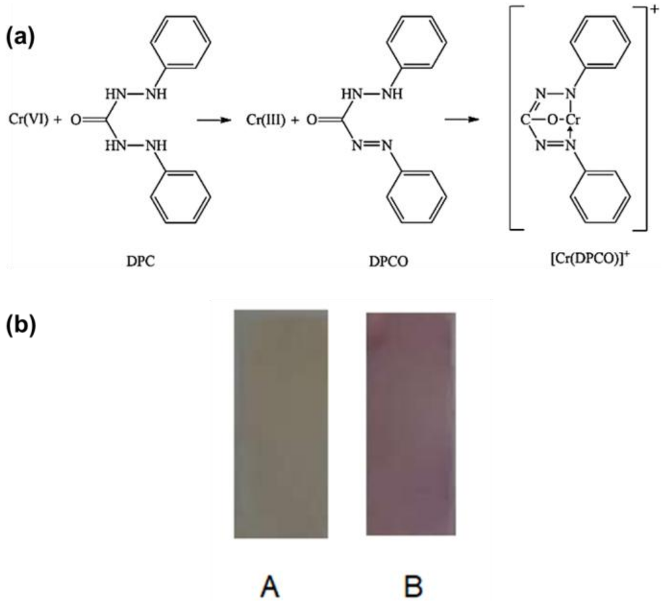

**Fig. 1** (a) Proposed reaction between Cr(VI) and DPC; (b) Color development of the optode membrane before (A) and after (B) exposure to a 1 ppm Cr(VI) standard solution.

colored DPCO-Cr(III) complex. The proposed reaction mechanism is illustrated in **Fig. 1a.**

The optode membrane produced met the requirements for a good optode because it was stable and transparent. The tested optode membrane produced a color change to purple after being placed in a Cr(VI) solution and did not experience any discoloration (**Fig. 1b**).

The spectral response of the optode membrane was examined across the wavelength range of 400–700 nm to determine its maximum absorbance. When exposed to a Cr(VI) solution, the optode exhibited absorption maximum at 550 nm, as illustrated in **Fig. 2a**. This λmax is lower than that reported by Arif et al. [9], who observed a maximum absorption at 585 nm The difference obtained was due to differences in conditions and materials used in the optode matrix.

Functional group characterization of the CTA membrane was performed using FTIR spectroscopy over the wavenumber range of 4000–400 cm$^{-1}$ to identify the chemical functionalities present in the membrane matrix. The CTA structure is characterized by the presence of C–H, C=O, and C–O functional groups [17]. The FTIR spectrum obtained from the fabricated membrane is presented in **Fig. 2b**. The results of optode membrane characterization with FTIR show peak profiles, namely υ(C=O) peak at of 1744-1759 cm$^{-1}$, υ(O-H) or υ(N-H) peak at of 3400-3500 cm$^{-1}$, υ(C-H) peak at 2854-2955 cm$^{-1}$, and peak υ(C-O) at 1041-1257 cm$^{-1}$.

Membrane thickness is one of the determining factors of optode performance. The average membrane thickness obtained from three different dishes was 0.051 mm, with a %RSD of 4.583%. The membrane thickness obtained in this study is appropriate for facilitating ion transport and complex formation between thiocyanate ions or chromophoric species during analyte detection. This suitability arises from the membrane being neither excessively thick (>100 µm) nor overly thin (<5 µm), thereby meeting the requirements for effective optical sensing applications [18]. Moreover, a membrane with uniform thickness is expected to promote homogeneous distribution of DPC or other chromophores within the sensing layer, enhancing analytical performance. A smooth and even membrane surface also ensures a consistent optical path length, such that absorbance measurements are governed primarily by the analyte concentration.

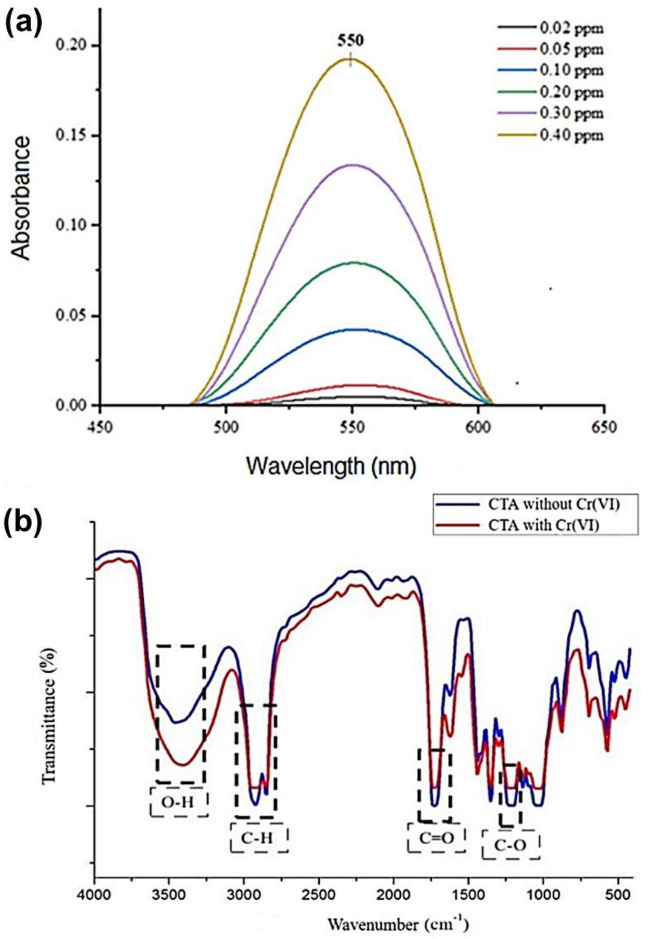

**Fig. 2.** (a) The maximum absorbance value of the optode at various concentrations of Cr(VI) standard solution; (b) FTIR spectra of optode membrane.

## 3.2. Working Range, Limit of Detection (LOD), and Limit of Quantitaion (LOQ)

The operational concentration range of the CTA-based optode was established by systematically varying the concentration of Cr(VI) standard solutions. This evaluation aimed to identify the minimum and maximum analyte levels over which an acceptable linear response could be achieved. Optode measurements conducted across the concentration range of 0.02–1 ppm yielded a coefficient of determination ($R^2$) of 0.9821, as shown in **Fig. 3a**. Based on the resulting calibration curve, six concentration levels exhibiting the highest correlation coefficient (r) were selected for subsequent analyses. The best linearity of the optode was in the range of 0.02-0.4 ppm with a coefficient of determination ($R^2$) of 0.9979 (**Fig. 3b**). According to AOAC [19], a coefficient of determination ($R^2$) value > 0.99 indicates good analysis results. This value indicates that increasing the analyte concentration significantly affects the signal increase.

The limits of detection (LOD) and quantification (LOQ) were calculated from the slope of the calibration curve and the associated standard deviation obtained from triplicate measurements. In this context, the LOD corresponds to the lowest analyte concentration that produces a detectable response from the optode membrane, whereas the LOQ denotes the minimum concentration that can be reliably quantified with acceptable precision [20].

The CTA-based optode membrane designed for Cr(VI) determination exhibited a limit of detection (LOD) of 0.0108 ppm and a limit of quantification (LOQ) of 0.0328 ppm. These analytical performance metrics demonstrate that both the CTA standard and the synthesized CTA optode membranes are capable of detecting Cr(VI) at concentrations well below the maximum permissible level of 0.05 ppm established by the Government of the Republic of Indonesia for drinking water, raw water sources, fisheries, and livestock-related water use [21].

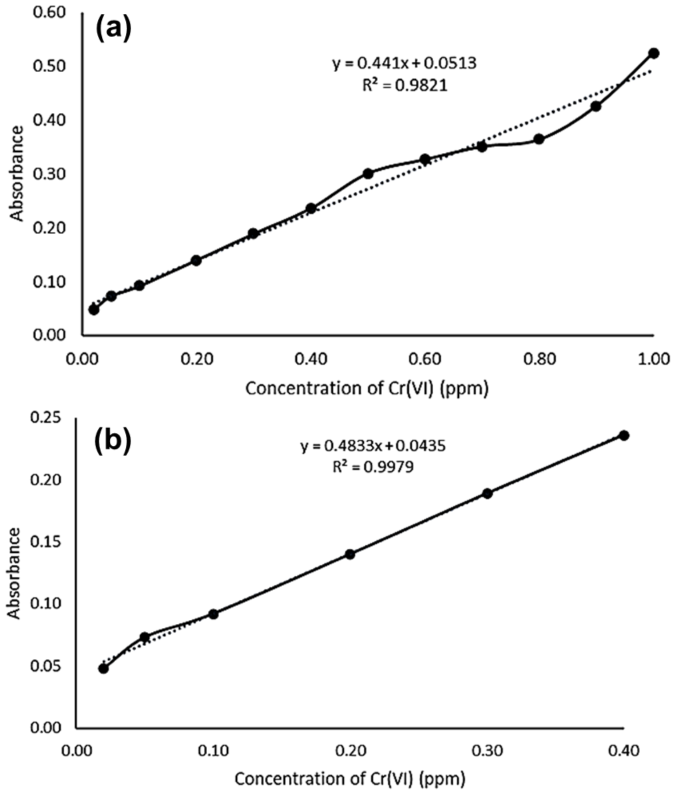

**Fig. 3** (a) Standard curve of optode with a concentration range of 0.02-1 ppm; (b) Standard curve of optode with a concentration range of 0.02-0.4 ppm

### 3.3. Precision and Accuracy

Method precision was evaluated based on the relative standard deviation (RSD) derived from multiple replicate measurements, with lower RSD values indicating higher precision [21]. Precision assessment generally encompasses repeatability, reproducibility, and intermediate precision. In the present study, precision was assessed in terms of repeatability, defined as the consistency of measurements obtained under identical conditions within a single analytical session, using the same analyst, instrumentation, materials, and laboratory environment [22]. For analyte concentrations below 1 ppm, an acceptable repeatability criterion corresponds to an RSD value of less than 11% [19]. The repeatability test yielded an RSD of 4.46%, indicating high measurement consistency. This low RSD value confirms that the proposed optode membrane provides reliable and accurate detection of Cr(VI) in aqueous samples.

Method accuracy was evaluated based on the percentage recovery, which represents the proportion of analyte successfully recovered during the analytical procedure [22,23]. Accuracy assessment was performed at three concentration levels (0.05, 0.20, and 0.40 ppm). The corresponding recovery values were 102.77%, 87.07%, and 102.68%, yielding an average recovery of 97.51%. These recovery results comply with the AOAC acceptance criteria, which specify an allowable recovery range of 80–110% for analyte concentrations between 0.1 and 1 ppm [19]. The findings demonstrate that the proposed optode membrane is capable of accurately quantifying Cr(VI) in real water samples, with measured values closely approximating the true analyte concentrations.

### 3.4. Sensitivity, Selectivity, and Stability

Sensitivity evaluation was performed to assess the ability of the optode membrane to discriminate variations in analyte concentration between different samples. Optode sensitivity was quantified using the specific absorptivity derived from the Beer–Lambert relationship. The mean specific absorptivity obtained was 43.492 $ppm^{-1}$ $mm^{-1}$, corresponding to a molar absorptivity of $2.262 \times 10^7$ $M^{-1}$ $cm^{-1}$. This absorptivity value exceeds that reported by Lace et al. [24], who reported a molar absorptivity of $2.02 \times 10^4$ $M^{-1}$ $cm^{-1}$. The markedly high molar absorptivity indicates that the developed optode membrane exhibits excellent sensitivity and strong potential for analytical applications as an *in situ* analysis tool.

Selectivity defined as the ability of a method to distinguish the target analyte from other potentially interfering species, is expressed by the selectivity coefficient ($K_{A,I}$) [23]. In this study, Fe(III), Pb(II), Zn(II), and Cd(II) ions were evaluated as potential interferents. The selectivity assessment involved varying the analyte-to-interferent concentration ratios at 1:1 and 1:2

under pH 3 conditions. The effect of these metal ions can be seen from the $K_{A,I}$ in **Table 1**. If the $K_{A,I}$ value is <1, then other metal ions do not interfere with the analyte and if the $K_{A,I}$ value is > +1 or $K_{A,I}$ < −1 then other metal ions will interfere with the analyte [22]. The $K_{A,I}$ value for all additions of interfering ions is < 1, demonstrating that the developed optode membrane exhibits high selectivity toward Cr(VI) and is minimally affected by the presence of these competing ions.

**Table 1.** Value of selectivity coefficient of optode membrane

| Ion | Ratio concentration [Cr(VI) : other ion] | $K_{A,I}$ |
|---|---|---|
| - | 1 : 0 | - |
| Fe(III) | 1 : 1 | 0.243 |
| | 1 : 2 | 0.263 |
| Pb(II) | 1 : 1 | 0.012 |
| | 1 : 2 | 0.055 |
| Zn(II) | 1 : 1 | 0.039 |
| | 1 : 2 | 0.024 |
| Cd(II) | 1 : 1 | 0.017 |
| | 1 : 2 | 0.065 |

The fabricated optode membrane is proposed as a potential tool for in situ Cr(VI) monitoring, which necessitates high stability. The stability of the color complex within the membrane was evaluated over a 5-day storage period, showing that its Cr(VI) detection capability remained consistent with the initial measurements. The average absorbance recorded during this period was 0.499 ± 0.044, as illustrated in **Fig. 4**. The absorbance value produced on the optode membrane experienced an increase or decrease when compared to daily measurements. The absorbance value produced on the optode membrane experienced an increase or decrease when compared to daily measurements. Tavallali and Dorostghoal [25] stated that the optode membrane remained stable for 6 weeks.

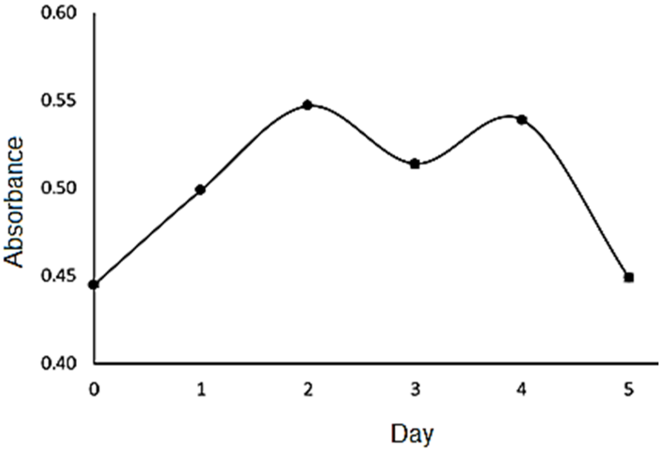

**Fig. 4.** Absorbance values of the optode from day 0 to day 5

### 3.5. Detection of Cr(VI) in Water Sample

Performance evaluation of the optode membrane in standard solutions demonstrated that it possesses suitable characteristics for Cr(VI) detection in real water samples. Cr(VI) concentrations in water samples were determined using both the optode membrane and a UV-Vis spectrophotometer. Measurements with the optode indicated a Cr(VI) concentration of 0.040 ± 0.00087 ppm, whereas the UV-Vis spectrophotometric analysis yielded a slightly different value of 0.039 ± 0.001263 ppm, highlighting the comparable performance of both methods. The results of sample detection showed that the sample concentration exceeded the surface water threshold according to the Regulation of the Minister of Health of the Republic of Indonesia Number 32 [21], which is 0.05 ppm.

Cr(VI) concentrations in water samples were determined using both the CTA optode membrane and UV-Vis spectrophotometry, and the mean values were statistically compared using a two-tailed Student's t-test at a 95% confidence level. This analysis was conducted to assess potential systematic differences between the two measurement methods. The resulting t-value (1.7337) was lower than the critical t-value (2.228), indicating that there is no statistically significant difference between the mean concentrations obtained by the two approaches. Both methods can be used interchangeably in the measurement process. The findings of this study are in agreement with those reported by Arif et al., particularly with respect to the color development process, pH optimization, and performance characteristics [9,10].

### 3.6. Simple Prototype Optode for Cr(VI)

A simple prototype based on this research data has also been created, aimed for capability detecting Cr(VI) ions in water samples. The prototype development began with the preparation of the optode based on known data, both in terms of formulation or manufacturing processes tailored to the target metal ion. The prototype is prepared with an optode membrane containing chromoionophore, aliquat-336, along with a plasticizer, and then allowed to settle and formed into a membrane sized 1 × 3 cm.

The formation of color from the reaction between DPC and Cr(VI) will be formed optimal at pH 3, according to this study's results. The creation of this color standard also adopts a pattern of several different concentrations across various scopes. The results displayed are preliminary and need further evaluation to achieve a better appearance (**Fig. 5**).

The samples tested were treated the same as the standards, that is, the pH was adjusted to 3 with the same contact time of 15 minutes. The use of pH 3 and the same contact time as previous analyses is the optimal color formation process outlined in the early stages of this study. The analysis results show that the color formed does not indicate the presence of Cr(VI). The color is lighter than the color standard used. This result provides a quick overview of the potential for detecting Cr(VI) ions. This method has proven to produce a color change that reflects the results according to the color change, but for more accuracy, it needs to be validated with standard methods for analysis. The color formation in the water samples has not occurred properly. This is due to the different matrix from the standard color produced. This staining requires further evaluation to produce a more uniform and clearer color to reduce analysis bias.

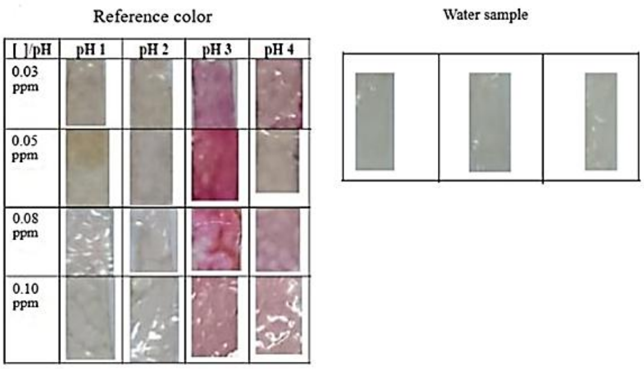

**Fig. 5.** Simple prototype coloring for Cr(VI) optode

Color formation was subsequently compared with the coloe developed from the standard membrane. The results indicated that sample taken from sample river developed color exhibited no significant chromatic difference when compared to the reference standard.

These findings suggest that the developed simple optode holds significant potential as a rapid, straightforward, and efficient approach for the quantification of hexavalent chromium in water samples.

## CONCLUSION

Cellulose triacetate-based optode membranes incorporating 1,5-diphenylcarbazide (DPC) as the active component offer a promising alternative for Cr(VI) detection in water samples. The optode exhibits a linear response over the concentration range of 0.02–0.40 ppm, with a coefficient of determination ($R^2$) of 0.9979, a limit of detection of 0.0108 ppm, and a limit of quantification of 0.0328 ppm. It demonstrates high precision, reflected by a relative standard deviation of 4.458%, and excellent accuracy, with an average recovery of 97.51%. Furthermore, the optode shows strong sensitivity, indicated by a molar absorptivity of $1.139 \times 10^7$ $M^{-1}$ $cm^{-1}$. The optode is selective towards interfering ions such as $Fe^{3+}$, $Pb^{2+}$, $Zn^{2+}$, and $Cd^{2+}$. The optode color complex is stable up to day 5. The detection of Cr(VI) in water sample solutions shows that the water sample has a concentration of $0.040\pm(0.87\times10^{-3})$ ppm, however, its value differs from the detection using UV-Vis spectroscopy which is $0.039\pm(1.263\times10^{-3})$ ppm. The developed prototype demonstrated positive results during the experimental trials and shows potential for further application development.

## SUPPORTING INFORMATION

There is no supporting informationin this paper. The data that support the findings of this study are available on request from the corresponding author (ZA).

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## CONFLICT OF INTEREST

The authos have no conflict of interest in this publication.

## AUTHOR CONTRIBUTIONS

ZA, EF, FG carried out the experiment and data calculations. ZA, F prepared manuscript draft. ZA, SS, ER, IB improved manuscript. All authors collaborated on writing and revising manuscript. All authors approved the final version of the manuscript.

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