

Research Article

Removal of the Rhodamine B Dye at Ti/Ru_{0.3}Ti_{0.7}O₂ Anode Using Flow Cell System

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The electrochemical oxidation of the Rhodamine B dye (Rh-B) was carried out using dimensionally stable type anode (DSA, Ti/ $Ru_{0,3}Ti_{0,7}O_2$). The work was performed using the electrochemical flow cell system. The effect of several operating factors, such as supporting electrolytes, current density, electrolysis time, temperature, and initial concentration of Rh-B dye, were investigated. The UV-visible spectroscopy and chemical oxygen demand (COD) measurements were conducted to monitor the removal and degradation of Rh-B. The best color removal achieved was found to be 98.3% after 10 min applying 3.9 mA·cm⁻² as a current density using 0.07 mol·L⁻¹ of NaCl. Meanwhile, the highest COD removal rate (93.0%) was obtained for an applied current density of 3.9 mA·cm⁻² as the optimal operating condition after 180 min reaction time, with 2.98 kW h·m⁻³ as energy consumption. This shows that the best conditions for color removal are not certainly the same as those for the COD removal. The rises in the concentration of NaCl, and applied current increased the Rh-B color removal rate. The decline in Rh-B dye concentration followed pseudo-first-order kinetics. The obtained values of apparent rate constant were increased by increasing chloride ion concentration. It is concluded that the electro-oxidation on DSA electrode using a flow cell is a suitable process for the removal of Rh-B dye in aqueous solutions.

1. Introduction

Industrial wastewater coming from the textile industry holds several pollutants including a high content of organic substances, dissolved salts, and suspended masses [1]. Besides, they produce uncontrollable environmental dangers due to the presence of appreciable quantities of organic compounds that are non-biodegradable [2]. Furthermore, the existence of dyes can produce significant coloration in water courses, affecting the transparency to natural light (involves reducing photosynthesis) and reducing gas solubility. Moreover, dyes can also cause mutagenic and carcinogenic diseases [3, 4]. Several technologies of color removal from water have been proposed and are generally distributed into biological, chemical, and physical methods [5]. Among these methods, the electrochemical procedures constitute the developing methods for the treatment of wastewater coming for textile industries. These processes present different advantages such as being of high eco-friendly, mild operating conditions, low cost, ease of automation, and versatility [6–10]. In addition, highly oxidizing species (e.g., OH[•] and Cl₂) are electrochemically generated on anode surface without the need (in several cases) to add additional reagents [11–13].

In the electrochemical degradation process, the anode material nature plays an essential role [14, 15]. The requirements for a typical anode material must be taken into account depending on its cost-effectiveness, satisfactory efficiency, and stability even in extreme environments. A wide variety of electrode constituents have been tested and assessed for wastewater treatment, like noble metals (e.g., Pt) [16, 17], metal oxides (e.g., SnO₂ and PbO₂) [18, 19], and boron-doped diamond [20–23]. The dimensionally stable anode (DSA) with ruthenium is one of the best technological inventions in electrochemistry in the last 80 years. DSA is considered as an interesting anode material for degradation of organic pollutants due to its long lifetime, chemical stability, and low cost [24–27]. In the field of organic pollutants degradation, the DSA electrodes show greater chemical resistance during wastewater treatment and they are very cheap and have a large surface area and are therefore widely used for the removal of organics in electrochemical reactors [28–30].

The application of a DSA electrode to remove organic pollutants was typically accomplished with the presence of NaCl as supporting electrolyte due to its high electrocatalytic activity for chlorine evolution, and it can be used efficiently for organic degradation by indirect electrolysis by in situ generations of active chlorine through the oxidation of chloride ions that are present in the solution [31–34]. The Ti/Ru_{0.3}Ti_{0.7}O₂ composition is one of the most common DSA materials, and it has been widely used in the chloroalkali industry for the last 30 years [35, 36]. This DSA type has been shown to be effective for the oxidation of various dyes, such methylene blue [27, 37], reactive red [24], direct red [38], acid violet 1 [39], reactive blue 19 [40], methyl red [41], and reactive orange 16 [42].

The Rhodamine B (Rh-B) is a major popular dye and has been widely used in many industrial applications, such as in the food, textile, and drug and cosmetic industries. Its usage in industrial fields, which is a menace to human health, brings about toxicity for organisms living in water. It may cause long-term unhealthy effects in aquatic environments, and it is harmful when it comes in contact with skin. On the other hand, Rh-B may cause congenital diseases and cancer, which is the worst disease of our age [43, 44]. Rh-B is a triphenylmethane dye with xanthene rings and aromatic compounds (Figure 1), which constitute an important source of environmental pollution. Due to the harmful effects of Rh-B, many countries have prohibited it from using in food samples. Moreover, Rh-B is stable in water in a wide pH range; therefore, it should be fully removed or decomposed before releasing Rh-B containing wastewater to the environment [45, 46]. In other words, Rh-B is a water pollutant and the removal of color from waste effluents becomes environmentally important because even a small quantity of dye in water can be toxic and highly visible.

According to the literature, no works on the treatment of polluted water by Rh-B dye using $Ti/Ru_{0.3}Ti_{0.7}O_2$ anode type have been achieved so far. In this light, the aim of the current work is to examine the electrochemical performance of this anode through the degradation of Rh-B dye solution. The influence of several factors, such as electrolyte support (type and concentration), current density, temperature, and Rh-B dye initial concentration on the extent of color removal from an aqueous solution was studied by means of UV-visible spectroscopy. In addition, the degree of COD removal was monitored after choosing the optimum operating conditions.

2. Experimental

2.1. Reagents and Chemicals. The used chemical compounds (i.e., Na₂SO₄, NaCl, Ag₂SO₄, HgSO₄, H₂SO₄ and



FIGURE 1: Molecular structure of Rh-B dye.

Rhodamine B) were obtained from SOLVACHIMI and Sigma-Aldrich, and they were used as received without further purification. The distilled water was used for the preparation of all solutions.

The Rh-B solution is prepared by dissolving required mass of the dye in the aqueous solution of different concentrations of supporting electrolyte. The electrolysis is performed for a solution volume of 200 mL (electrolyte reservoir). During the electrolysis treatment, the electrolyte samples were collected as a function of time, and their absorbance and concentration of Rh-B have been calculated.

2.2. Electrochemical Reactor. A single-compartment fitterpress cell was employed with a commercial Ti/Ru_{0.3}Ti_{0.7}O₂ plate (De Nora, Brazil) used as the anode and a stainless-steel plate as the cathode, and each one has an area of 14 cm². The reactor was mounted by positioning the electrodes between the Viton and Teflon spacers with variable thickness (Figure 2) as described elsewhere [42]. The solution was pumped from the reservoir containing treated dye through the cell using a pump with a flow rate of 30 L·h⁻¹. A DC power supply (GW-Instek GPS-3030DD model) was employed as a source of constant electrical current for all experiments. In order to stabilize the anode surface and to get reproducible results, before each experiment, the working electrode was activated at ambient temperature by applying 20 mA·cm⁻² as current density for 15 min in 0.5 M H₂SO₄ solution.

2.3. Analytical Procedures. The color removal of the dye was examined by using UV-2300 UV-visible spectrophotometry before and after electrolysis employing a quartz cuvette with 1 cm optical path. The concentration of Rh-B during the electrolysis was concluded based on the calibration curve. The color removal efficiency was calculated based on absorbance at $\lambda_{max} = 554$ nm (corresponding to maximum absorption) according to following relationship:

$$\% \text{ color removal} = \frac{A_0 - A}{A_0} \times 100, \tag{1}$$

where A_0 and A are, respectively, the absorbance before and after electrolysis for a determinate duration.

The chemical oxygen demand (COD) is measured according to the standard techniques of the wastewater examination [47]. The COD values of the initial and electrolyzed



FIGURE 2: Experimental setup of the treatment system.

samples were determined by the open reflux, dichromate titration method. The equation used to calculate the COD removal efficiency is

$$\% \text{COD} = \frac{\text{COD}_i - \text{COD}_i}{\text{COD}_i} \times 100, \qquad (2)$$

where COD_i and COD_t are the values of COD (mg.L⁻¹ of O₂) at initial time and at "t" time, respectively.

In addition, the energy consumption value for the electrodegradation was calculated in $kW \cdot h \cdot m^{-3}$ of treated Rh-B solution according to the following equation:

$$E_C = \frac{U_{\text{cell}} \times j \times t}{3600 \times V},\tag{3}$$

where U_{cell} , *j*, *t*, and *V* are the average cell voltage (by V), electrical current (by A), electrolysis time (by s), and volume of treated solution (by m³), respectively.

3. Results and Discussion

3.1. Effect of Supporting Electrolyte. In order to study the influence of supporting electrolyte on the degradation process of Rh-B (at 80 mg·L⁻¹), experiments were carried out at constant current density ($5.4 \text{ mA} \cdot \text{cm}^{-2}$) using NaCl and Na₂SO₄, and the results are shown in the Figure 3(a). As can be seen, when Na₂SO₄ was exchanged by NaCl, the color removal efficiency got improved from 20.8 to 99.4% after 15 min of electrolysis. This points out that the presence of chloride ions as electrolyte can improve the degradation

efficiency and reduce reaction time. In this case, the degradation of Rh-B can occur by indirect oxidation accomplished through the generation of chlorine (Cl₂) gas at the anode surface. Agreeing with the literature [10, 27, 41, 48], the improved rate of the organic compounds removal is attributed to the formation of chlorine and hypochlorite species, which are both potent oxidizing agents. The reaction of chlorine and hydroxide ions formed at the cathode leads to the formation of the hypochlorite ions (ClO⁻) via following equations [9, 49–51]:

$$2\text{Cl}^- \longrightarrow \text{Cl}_2 + 2e^-$$
 (4)

$$Cl_2 + 2HO^- \longrightarrow H_2O + ClO^- + Cl^-$$
 (5)

Afterwards, Cl_2 and ClO^- species react to oxidize the organic compounds in the solution, which causes an indirect oxidation process. For this purpose, the effect of NaCl concentration was evaluated. In addition to Figure 3, Figure S1 of supplementary materials shows the variation of the absorbance over time when using different NaCl concentrations during the electrolysis. An additional increase of chloride concentration to 0.07 mol·L⁻¹ enhanced the removal of color rate, permitting complete degradation of the Rh-B color to an extent of 99.4% of decolorization effectiveness within 20 min. It is clear that the increase of NaCl concentration rises the decolorization rate. This can be related to the mass transport process of the organic compounds to the electrode surface

FIGURE 3: Effect of NaCl and Na₂SO₄ and their concentration on the dye removal. (a) Color removal efficiency versus time and (b) their corresponding visible spectra after 90 min of electrolysis. Conditions: current density, $5.4 \text{ mA} \cdot \text{cm}^{-2}$; [Rh-B], $80 \text{ mg} \cdot \text{L}^{-1}$; *T*, 25° C; flow rate: $30 \text{ L} \cdot \text{h}^{-1}$.

as well as Cl₂ and ClO⁻ species responsible for achieving the oxidation in the bulk solution [9, 48, 52, 53]. The visible spectra of Rh-B solutions without and with different supporting electrolytes after 90 min of electrolysis are shown in Figure 3(b). It can be noted that the spectrum presented one absorption band at $\lambda_{max} = 554$ nm, and a decrease in the intensity of the absorption band was observed with increasing the chloride concentration. This band completely disappeared at 0.035 and 0.07 mol·L⁻¹ of NaCl by applying 5.4 mA·cm⁻² as current density, signifying total decolorization.

The Rh-B discoloration kinetics can be modeled by a pseudo-first-order kinetic model (equation (6)) due to the formation of the chloro oxidant species (e.g., Cl_2 and HClO); the same behavior was reported in the literature [9, 48, 54] during the electrochemical treatment of industrial textile wastewater using the DSA type electrode:

$$\ln\left(\frac{C_0}{C_t}\right) = K_{app} \times t,\tag{6}$$

where C_0 and C_t are the initial concentration of Rh-B and at time "t," respectively.

The values of apparent rate constants (K_{app}) of the reaction were frequently used to evaluate the degradation effectiveness, and they are concluded from the slop value of Ln (C_0/C_t) = f(t)plot (equation (6)). As presented in Figure 4, the K_{app} at 0.070, 0.060, 0.040, and 0.009 mol·L⁻¹ of NaCl and 0.035 mol·L⁻¹ Na₂SO₄ are 97.4×10⁻³, 43.0×10⁻³, 18.1×10⁻³, 16.8×10⁻³, and 2.8×10⁻³·min⁻¹, respectively. Such an outcome means that Na₂SO₄ outperformed NaCl in the electrochemical oxidation process, which is consistent with the literature. Figures S1 and S2 in supplementary material reveal the variations of Rh-B absorption spectra and color removal

FIGURE 4: Effect of NaCl and Na₂SO₄, as well as NaCl concentration on K_{app} values. Conditions: current density, 5.4 mA·cm⁻²; [Rh-B], 80 mg·L⁻¹; *T*, 25°C; flow rate, 30 L·h⁻¹.

efficiency with time at different NaCl and Na₂SO₄ concentrations as supporting electrolyte, respectively.

3.2. Effect of Current Density. It was disclosed above that the use of NaCl as supporting electrolyte was more appropriate for the electrochemical degradation of Rh-B solution than using Na₂SO₄. In the other hand, the applied electrolysis current density is another important operating parameter which can affect the dye degradation kinetics and the process economic costs. The influence of applied current density (ranged from 1.1 to 5.4 mA·cm⁻²) on the rate of Rh-B dye decolorization as a function of time was investigated using 80 mg·L⁻¹ of Rh-B and





% color removal



FIGURE 5: Effect of applied electrical current density on the electrodegradation of Rh-B. (a) Variation of concentration of Rh-B. (b) Color removal efficiency versus electrolysis time. Conditions: [NaCl], $0.07 \text{ mol} \cdot \text{L}^{-1}$; [Rh-B], $80 \text{ mg} \cdot \text{L}^{-1}$; T, 25° C; flow rate, $30 \text{ L} \cdot \text{h}^{-1}$.



FIGURE 6: Temperature influence on the decay of Rh-B concentration during the electrolysis treatment. Conditions: [NaCl], $0.07 \text{ mol}\cdot\text{L}^{-1}$; [Rh-B], 80 mg·L⁻¹; current density, 3.9 mA·cm⁻²; flow rate, 30 L·h⁻¹.

 $0.07 \text{ mol} \cdot \text{L}^{-1}$ of NaCl. The results are presented in Figure 5. As estimated, the increase of electrical current density caused a faster decolorization of the Rh-B solution. This can be attributed to a greater charge entering to the cell, which enhances the electro-generation of the chlorooxidant species [35]. For example, at 5.4 mA·cm⁻², the color was entirely removed after 15 min of electrolysis. These behaviors point out that under these conditions, the oxidation of Rh-B compound is controlled by mass transport mechanism and a rise of the applied electrical current density favors the second reaction of water reduction (oxygen evolution) [55]:

$$2\mathrm{H}_2\mathrm{O} \longrightarrow \mathrm{O}_2 + 4\mathrm{H}^+ + 4e^- \tag{7}$$

Consequently, most studies have reported that an increase of the mass transport coefficient has an adverse effect on the degradation of the organic pollutants mediated by electrogenerated active chlorine [33, 56–58]. However, the formation of hydroxyl radicals (OH^{\bullet}) depends only on the density of electrical current used. It has been proposed that OH^{\bullet} radicals were generated by water oxidation reaction (equation (8)), which can be either oxidized to dioxygen (equation (9)) or contributed to the oxidation of the Rh-B molecules (equation (10)):



FIGURE 7: Spectra of samples taken at various times of electrolysis in different temperatures. Conditions: current density, $3.9 \text{ mA} \cdot \text{cm}^{-2}$; [NaCl], 0.07 mol·L⁻¹; [Rh-B], 80 mg·L⁻¹; flow rate, 30 L·h⁻¹.

$$H_2O \longrightarrow OH^{\bullet} + H^+ + e^-$$
 (8)

$$OH^{\bullet} \longrightarrow \frac{1}{2}O_2 + H^+ + e^-$$
(9)

 $Dye (Rh - B) + OH^{\bullet} \longrightarrow CO_2 + H_2O + NO_3$ (10)

Nevertheless, the adsorption of molecule dye and its byproducts on the anode surface plays an essential role in the electro-oxidation treatment. Based on the effect of applied current densities, it can be realized that the charge needed for an equivalent decrease in concentration rises with current density. The decoloration rate is practically independent of the applied current density. This is can be explained by the diffusion of Rh-B molecules from the bulk to the anode/ solution interface and not by the electron flow rate.

3.3. Effect of Temperature. Figure 6 shows the effect of temperature variation (from 18 to 45° C) on the dye decolorization as a function of treatment time using Ti/Ru_{0.3}Ti_{0.7}O₂ anode. In general, the higher temperature level can improve the activity of catalyst. Consequently, the dye oxidation and the oxygen evolution are favored synchronously with increasing temperature. Nevertheless, in our study, when the temperature was above 25°C, the degradation efficiency has been reduced, which



FIGURE 8: Effect of initial concentration on the Rh-B dye removal. Conditions: current density, $3.9 \text{ mA} \cdot \text{cm}^{-2}$; [NaCl], $0.07 \text{ mol} \cdot \text{L}^{-1}$; *T*, 25° C; flow rate, $30 \text{ L} \cdot \text{h}^{-1}$.

is most likely due to the adsorbed pollutants derived from the catalyst surface. At high temperatures, the mass transport mechanism controlling the reduction of ClO⁻may also be the cause for a decreased of decolorization efficiency according to the following reaction [59]:

$$\text{ClO}^- + \text{H}_2\text{O} + 2e^- \longrightarrow \text{Cl}^- + 2\text{OH}^-$$
 (11)

Since the reaction between the electrogeneration of hydroxyl radicals and the Rh-B molecule is a quick reaction and it is to some extent affected by temperature variation, this behavior can be clarified in terms of mass transfer increase of dye molecules from bulk solution to the anode surface [20]. It was observed (Figure 6(a)) that the color removal percentage at temperatures of 18°C and 25°C was 65% and 94%, respectively, after 480s of reaction time. Nevertheless, when the temperature further increased, i.e., 45°C, it is only increased up to 98% after 960 s, and this influence might underline that the higher temperature level promoted the molecule dye degradation and the formation of some highly oxidizing species for the treatment of byproducts compounds. This leads to the reinforcement on color degradation which was not so emotive at higher temperatures. Figure 6(b) displays the temperature effect on the concentration of Rh-B dye as a function of charge of electrolysis. Consequently, the greatest decolorization efficiency can be accomplished at 25°C.

Figure 7 shows the decolorization performance of Rh-B via the anodic oxidation process at different temperature values. At $T=25^{\circ}$ C, the variations of Rh-B absorbance spectra with time showed the best decolorization performance and the Rh-B absorbance peaks were rapidly plummeting. After 8 min of treatment, the peak at 554 nm was completely disappeared, indicating the breakdown of the Rh-B dimmer and the destruction of chromophore groups. In other tested temperature values (i.e., 35°C or 45°C), the Rh-B absorption peak did not decrease as rapidly as those at $T=25^{\circ}$ C.

3.4. Effect of Initial Dye Concentration. As it is known, the initial concentration of treated pollutants is one of the main factors to be considered in the wastewater decontamination process. Figure 8 shows the influence of the initial Rh-B concentration (ranging from 80 to $400 \text{ mg} \cdot \text{L}^{-1}$) on the color removal efficiency during electrolysis by applying a density current of 3.9 mA·cm⁻² in the presence of NaCl at $0.07 \text{ mol} \cdot \text{L}^{-1}$ and with a flow rate of $30 \text{ L} \cdot \text{h}^{-1}$ at 25°C. As can be seen in Figure 8(a), the required time for the color elimination was reduced by decreasing initial concentration of Rh-B. For instance, the required time for the color elimination of $80\,mg\,L^{-1}$ Rh-B is 20 min and 70 min for $300 \text{ mg} \cdot \text{L}^{-1}$ of Rh-B concentration. The Figure 8(b) shows the consequence of used initial Rh-B dye concentration on the color removal efficiency. The results illustrated that, when the concentration was $80 \text{ mg} \cdot \text{L}^{-1}$, the color elimination percentage was 96.9% within 20 min. However, by increasing dye concentration, the color removal percentage decreased, as noted in case of 400 mg·L⁻¹, which equals to 33.5%.

These results indicate that the complete decolorization was achieved for all tested Rh-B initial concentrations, but the required time for the optimum dye decolorization increased by the concentration increase. This behavior can be understood in terms of a rise in the dye molecules in the solution during the electrolysis. Furthermore, it can be elucidated by the fact that Rh-B molecules tend to associate by rising the initial concentration to clusters of low-diffusivity property [60].

Hence, working at higher dye concentration may reduce the energetic cost of the treatment process. This points out that the color elimination rate and procedure effectiveness are directly related to the dye concentration.

3.5. COD and Color Removal. The effect of electrolysis time on the color and COD removal under optimum conditions (i.e.,



FIGURE 9: COD and color removal during the electrochemical treatment of Rh-B under optimal conditions: [NaCl], 0.07 mol·L⁻¹; [Rh-B], 200 mg·L⁻¹; current density, 3.9 mA·cm⁻²; *T*, 25°C; flow rate, 30 L·h⁻¹.



FIGURE 10: Evolution of energy consumption (E_C) with COD removal during the electrochemical treatment under optimum conditions ([NaCl]: 0.07 mol·L⁻¹, [Rh-B]: 200 mg·L⁻¹, current density: 3.9 mA·cm⁻², *T*: 25°C, flow rate: 30 L·h⁻¹).

 $[Rh-B] = 200 \text{ mg} \cdot \text{L}^{-1}$, electrical current density = 3.9 mA·cm⁻², $[NaCl] = 0.07 \text{ mol} \cdot \text{L}^{-1}$, and $T = 25^{\circ}\text{C}$) was examined. As can be perceived from Figure 9, the color and COD removal raised with the time of electrolysis. A complete decolorization was achieved with 32% of COD removal after 60 min of the treatment, thus suggesting that the cleavage of chromophore group at the beginning of Rh-B electrodegradation, and then the aromatic rings are susceptible to the degradation, thus contributing to the continuation of the COD removal. The COD removal during the electrolysis is less; this can be attributed to the formation of aliphatic compounds with lower molecular weight, which exhibits resistance to oxidant agent (e.g., chlorine/hypochlorite) attack.

3.6. Energy Consumption. The energy consumption is an important parameter to evaluate the treatment economic costs for the industrial purpose. Figure 10 presents the variation of

energy consumption calculated according to equation (3) as a function of COD removal under the optimum operating conditions reported previously (current density: $3.9 \text{ mA} \cdot \text{cm}^{-2}$, [NaCl] = 0.07 mol·L⁻¹, $T = 25^{\circ}$ C, and [Rh-B] = 200 mg·L⁻¹). For lower COD removal, the specific energy consumption ($E_{\rm C}$) increased almost linearly before getting an exponential decrease after that. It can be probably explained by the formation of more refractory by-product compounds, like carboxylic acid compounds, which are hardly degradable intermediates [61, 62], as well as by the decrease of organic charge in the bulk solution.

4. Conclusion

In this study, the electrochemical degradation of an aqueous solution containing Rh-B dye employing flow cell system with a DSA anode (composition: $Ti/Ru_{0.3}Ti_{0.7}O_2$) has been carried out under various experimental conditions. This study revealed the following conclusions:

- (i) Complete decolorization of Rh-B solution and a COD removal higher than 93% were achieved under the following conditions: [NaCl], 0.07 mol·L⁻¹; electrical current density, $3.9 \text{ mA} \cdot \text{cm}^{-2}$; *T*, 25°C; [Rh-B], 80 mg·L⁻¹; flow rate, 30 L·h⁻¹
- (ii) The degradation of Rh-B using Ti/Ru_{0.3}Ti_{0.7}O₂ anode type was attributed to the formation of oxidant chlorine/hypochlorite species and hydroxyl radicals
- (iii) The oxidation of Rh-B was controlled by mass transport mechanism, and the color elimination was described better by the pseudo-first-order kinetic model
- (iv) The obtained results suggest that this decontamination system (i.e., flow cell system) using Ti/Ru_{0.3}Ti_{0.7}O₂ anode can be feasible and economically suitable for the treatment of wastewater containing such dye

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

Figure S1: spectra of samples of electrolysis in different NaCl concentrations from solutions containing 80 mg.L^{-1} of Rh-B (current density: $3.9 \text{ mA} \cdot \text{cm}^{-2}$; flow rate: $30 \text{ L} \cdot \text{h}^{-1}$;

and T: 25°C) for 90 min. Figure S2: spectra of samples of electrolysis in different Na₂SO₄ concentrations from solutions containing 80 mg·L⁻¹ of Rh-B (current density: $3.9 \text{ mA} \cdot \text{cm}^{-2}$; flow rate: $30 \text{ L} \cdot \text{h}^{-1}$; and T: 25°C) for 90 min. (Supplementary Materials)

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