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# REMOVAL OF AZO DYES FROM TEXTILE INDUSTRY WASTEWATER USING ELECTROOXIDATION AND ELECTRO-FENTON PROCESSES

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**Abstract:** Wastewaters from the textile industry have a high content of organic matter, high coloration, various minerals and metals, and often toxic and carcinogenic substances. Azo dyes are the most common used dyes in the textile industry. Due to their complex structure, the removal of azo dyes from wastewater is challenging. In this study, electrooxidation and the electro-Fenton process, as one of the most effective Electrochemical Advanced Oxidation Processes (EAOPs) for the removal of organic pollutants in wastewater, were used for the treatment of synthetic wastewater containing “Bemacid Red” dye as a pollutant. Several process parameters affecting the efficiency of OH. formation and dye degradation were examined. Stainless steel (SS) was used as the cathode material, and the anodes used were mixed metal oxides (MMO) - Ru mixed oxide (titanium substrate coated with 6g Ru/m2) and Ru-Ir mixed oxide (titanium substrate coated with 6g Ru- Ir/m2). The results showed that the Ru:SS electrode pair is more efficient comapred to the Ru-Ir:SS pair, and that the electro-Fenton process is more efficient compared to electrooxidation.

**Keywords:** textile industry, wastewater, treatment efficiency.

## 1. INTRODUCTION

The wastewater of textile dyeing and finishing factories causes various environmental problems not only because of its huge quantity of poisonous organic pollutants, but also due to its color and the high water consumption in this industry [1]. The textile industry consumes enormous amounts of water during dyeing and finishing operations. Typical medium-scale textile factories produce approximately 1000 m$^3$ of wastewater per day. It is estimated that around 30% of the applied dyes remain unfixed and are discharged in the effluent [2]. General characteristics textile dyeing wastewater are, above all, a high content of organic matter, heavy metals and high coloration. The dye pollutant in water causes dangerous problems because those are products that are toxic, mutagenic, and carcinogenic to the life forms.

Azo dyes are the main components of the textile industry used in the dyeing process and constitute 60–70% of all dyestuff concerning textile production. These dyes are characterized by the functional group (-N = N-) uniting two symmetrical and/or asymmetrical identical or non-azo alkyl or aryl radicals. Between 60 and 70% of azo dyes are toxic, carcinogenic and mostly resistant to biodegradability due to their chemical structure. According to Annex XVII of the REACH regulation in EU, azo dyes that release aromatic amines listed in Appendix 8 in concentrations above 30 mg/kg (0.003% by weight) are prohibited for use in textile and leather products that come into direct and prolonged contact with the skin or oral cavity. Additionally, these products cannot be placed on the market unless they meet the specified requirements. Furthermore, azo dyes listed in Appendix 9 are restricted from being used or marketed in concentrations greater than 0.1% by weight for coloring textile and leather products [3].

Various physical approaches such as adsorption, ion exchange, and membrane filtration are used to treat dye-containing wastewater. Chemical approaches such as coagulation-flocculation, electrochemical, and advanced oxidation processes are used to treat dye-containing wastewater. Advanced oxidation processes are based on the *in situ* generation of hydroxyl radicals (OH·), which are powerful oxidizing agents used to treat dye containing wastewater. Photocatalysis, Fenton, photo-Fenton, ozonation, and electrochemical oxidation processes are examples of advanced oxidation methods. These methods are capable of removing dye under harsh conditions quickly and without the formation of sludge. The disadvantages of these methods are expensiveness, pH dependent, and producing toxic by-products. In recent years, three techniques have frequently been used to remove organic pollutants from wastewater, such as textile dyes: electrocoagulation, electro-Fenton and anodic oxidation. Electrochemical treatment technologies do not require the addition of chemicals and produce no sludge. However, the disadvantages of such approaches include high electricity costs and being less effective than other treatment technologies [4].

Recently, electrochemical advanced oxidation processes (EAOPs) have received great attention because they are environmentally clean and can produce a large amount of hydroxyl radicals under control of applied current. One of the most frequently investigated EAOPs in the treatment of organic pollutants are electrooxidation (EO) or anodic oxidation and electro-Fenton (EF) processes. Electrochemical *in situ* formation of OH·, as well as other accompanying reactions in the EO process are [5]

Anode: $$H_2O \rightarrow H^+ + (OH\cdot)_{ads} + e^- \qquad (1)$$

$$(OH\cdot)_{ads} \rightarrow O_{ads} \text{ or } O_2 + H^+ + e^- \qquad (2)$$

$$O_{ads} + O_2 \rightarrow O_3 \qquad (3)$$

Cathode: $$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \qquad (4)$$

The chemical formation of OH· can be caused by the classic Fenton reaction through a mixture of $H_2O_2$ and a soluble iron salt, the so-called „Fenton's reagent“:

$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH\cdot + OH^- \qquad (5)$$

On the other hand, electrochemistry offers an excellent way to generate and control the concentration of Fenton's reagent – by the electro-Fentonon process. This process can take place in four ways. In the first one, $H_2O_2$ is added, while $Fe^{2+}$ is formed by electrolytic dissolution of the sacrificial iron anode. In the second, $H_2O_2$ is formed at the cathode and $Fe^{2+}$ by sacrificing the anode. In the third, $Fe^{2+}$ is added, and $H_2O_2$ is formed at the $O_2$ diffusion cathode, while in the fourth way, both reagents are added manually and and electrogenerated in an electrochemical reactor [6].

Degradation of pollutants in wastewater and the effectiveness of the EO and EF depends on numerous parameters, such as: initial pollutant concentration, nature and type of supporting electrolyte, current density ($j$) or applied current ($I$) or applied electrode potential ($E$), stirring speed in a batch or flow rate in a flow reactor, temperature, pH and numerous other parameters. Nevertheless, it was shown that the choice of electrode material has the greatest influence on the efficiency of the treatment, and that the electrocatalytic properties of the anode material determine the mechanism of electrooxidation [7]. Anodes having high oxygen evolution overvoltage like boron doped diamond (BDD) film electrodes or mixed metal oxide anodes (MMO) have shown to be more suitable for this process. The choice of cathode material is also of great importance for some EAOPs, and especially for EF, since $H_2O_2$ is formed *in situ* only on the appropriate cathode material (if it is not manually added), and further in the presence of $Fe^{2+}$ it gives OH· (5), which is responsible for oxidation pollutant. The oxidation power of the process can be significantly enhanced when using a cathode able to produce $H_2O_2$ [8].

Numerous papers have been published that follow the development of EO and EF processes in the field of textile industry wastewater treatment. Some research were based on the feasibility and applicability of EO and EF processes in the treatment of wastewater containing azo dyes, with the examination of process parameters such as: current density, electrolysis time, temperature, initial dye concentration, the type and concentration of supporting electrolyte and their optimization. Table 1 presents a comparison of different studies concerning the removal of some dyes by EF and EO process. In many studies, in addition to testing the efficiency of the process in terms of dye removal, the ability to decompose by-products and reduce total organic carbon (TOC) was monitored. These examples highlight very good performance of the EF and EO process  in removing dye from water.

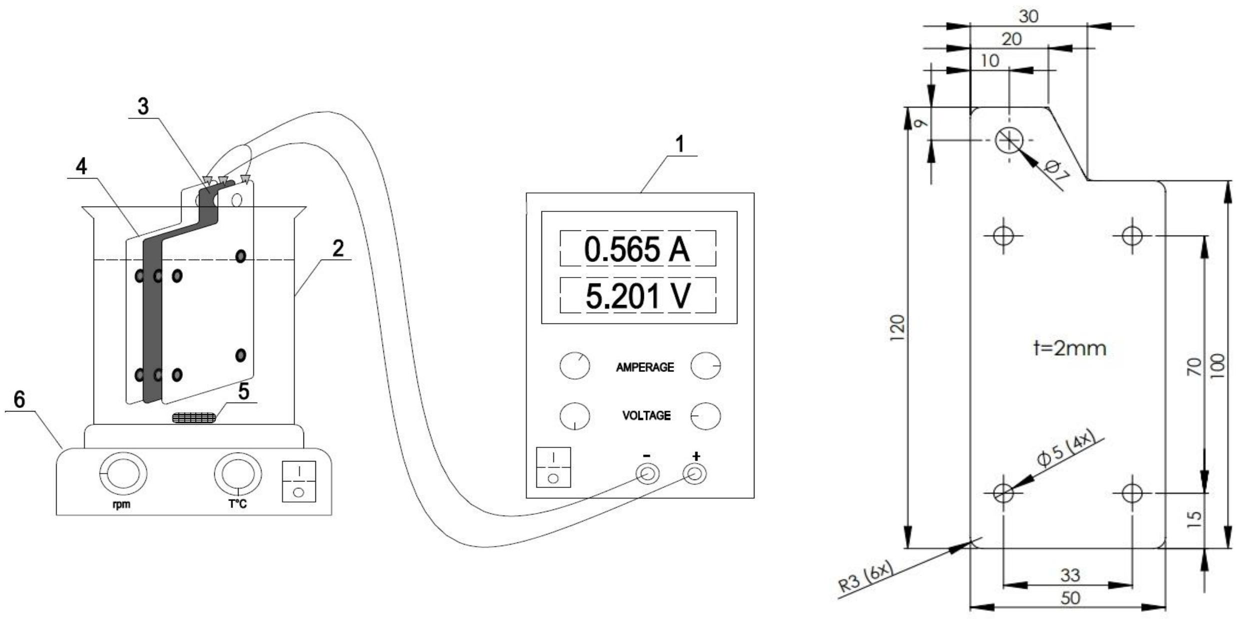
***Table 1.*** *Comparison of studies concerning the treatment of dyes by EF and EO processes*

| Pollutant / process | Conditions | Removal efficiency / Energy consumption | Ref. |
|---|---|---|---|
| Direct Red 23 / EF | BDD anode – graphite cathode<br>$c_o$=60 mg/L; $j$= 2.5 – 15 mA/cm$^2$; pH= 3; $c_{NaCl}$= 25 mM; $c_{Na2SO4}$= 12.5 mM; $c_{Fe2+}$= 0. 5 - 0.5 mM | 90% (TOC) for 6h / 2.41 kWh/g | [9] |
| Real textile wastewater / EF | graphite cathode and anode<br>$j$= 6.5 – 10 mA/cm$^2$; pH= 2.5 – 3.5; $c_{Fe2+}$= 1 - 3 mM | 58% (TOC) for 30 min in continous mode and 45% (TOC) for batch mode / 16 kWh/m$^3$ | [10] |
| Malachite green / EF | steel cathode and anode<br>$c_o$= 200 - 3000 mg/L; $j$= 0 – 20 mA/cm$^2$; pH= 2 – 11; $c_{H2O2}$= 0 – 200 mg/L | 100% dye removal (95,3% TOC) for 30 min / - | [11] |
| Acid Orange 7 / EF | stainless steel anode – carbon fiber cathode<br>$c_o$= 0.16 mM; $I$= 170 mA; $U$= 2 – 2.7 V; pH= 2; $c_{Fe2+}$= 1 mM | 100% dye removal for 180 min / 1.4 kWh/m$^3$ | [12] |
| Acid Red 18 / EF | steel anode and cathode<br>$c_o$= 50 - 300 mg/L; $c_{NaCl}$= 1 – 200 mg/L; $U$= 10 – 40 V; pH= 2 - 9; $c_{Fe2+}$= 1 mM | 99.4% dye removal ($c_o$= 100 mg/L) for 5 min / - | [13] |
| Methyl green / EO | Ti/PbO$_2$ anode – Ti mesh cathode<br>$c_o$= 300 mg/L; $j$= 10 - 40 mA/cm$^2$; $c_{H2SO4}$= 0.5 M; $T$= 25 - 60°C | 100% dye removal for 15 min ($T$= 60°C) and 30 min $T$= 25°C) / 0.29 - 1.64 kWh/m$^3$ | [14] |
| Reactive Blue 21 / EO | Pt anode - glassy carbon cathode<br>$c_o$= 0.1 mM; $j$= 50 – 300 mA/cm$^2$; pH= 3 - 11; $c_{KCl}$= 0.1 M | 99% dye removal ($j$= 100 mA/cm$^2$) for 20 min / - | [15] |
| Rhodamine B / EO | graphite anode and cathode<br>$c_o$= 50 - 250 mg/L; $j$= 5 – 25 mA/cm$^2$; pH= 3 - 9; $c_{NaCl}$= 0.025 – 0.1 M | 100% dye removal ($j$= 15 mA/cm$^2$) for 40 min / - | [16] |
| Azure B / EO and EF | Pt and BDD anode - carbon felt cathode<br>$c_o$= 0.1 mM; $j$= 50 – 500 mA/cm$^2$; pH= 3; $c_{Na2SO4}$= 0.05 M $c_{Fe2+}$= 0.1 mM | 100% dye removal (for EF and EO) and 95% TOC removal for 8h / - | [17] |
| Amido black 10B / EO and EF | ZnO-TiO$_2$ deposited on graphite felt as anode and graphite felt cathode<br>$c_o$= 0.12 mM; $I$= 40 – 200 mA; $c_{Fe2+}$= 0 – 0.5 mM; pH= 3 | 100% dye removal (100 mA; 0.1 mM Fe$^{2+}$) and 65% TOC removal for 60 min (91% TOC removal for 6h) / - | [18] |

In this paper, EO and EF were used for the treatment of synthetic wastewater containing *Bemacid Red* dye as a pollutant, and several operating parameters that affect the efficiency of OH· generation and dye degradation were examined.

## 2. EXPERIMENTAL

The experimental part of the research presents the application of EO and EF processes for the removal of textile azo dye from synthetically prepared wastewater. The experimental setup is shown in



(a)

(b)

***Figure 1.*** *(a) Scheme of EO and EF process setup (1-electricity source, 2- electrochemical cell, 3- anode, 4-cathode, 5- magnet bar, 6- magnetic stirrer; (b) schematic view of electrode dimensions*

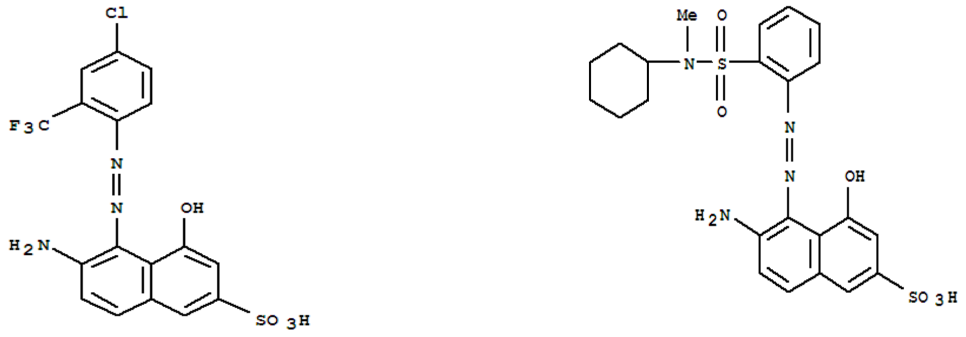
Figure 1. The electrochemical batch reactor (laboratory glass beaker) was 500 cm$^3$ volume capacity, with the possibility of constant mixing (300 rpm), in which electrodes of the same dimensions are placed. The dimensions of the electrodes are 60x50x2 mm. The total useful surface of one electrode is 51.86 cm$^2$, and the distance between the anode and each cathode was 1 cm. The electrodes are connected to a digital power source (GW Instek PSP-2010, Taiwan).

All experiments were performed at ambient temperature (≈20°C) with a volume of synthetic wastewater of 400 cm$^3$. Before each treatment, the electrodes are cleaned and degreased and the current density was adjusted to the desired value.

### 2.1 Materials and chemicals

For the preparation of model wastewater Bemacid Red (BR) dye (CHT GmbH, Germany) was used. The mentioned dye is harmful to aquatic life with a long-lasting effect, causing serious eye irritation [19].

Figure 2. Chemical composition of BR dye: (a) - sodium 6-amino-5-[[4-chloro-2-(trifluorometh-



a)

b)

***Figure 2.*** *Chemical composition of BR dye: (a) - sodium 6-amino-5-[[4-chloro-2-(trifluoromethyl)phenyl] azo]-4-hydroxynaphthalene-2-sulfonate; (b) - sodium 6-amino-5-[[2-[cyclohexylmethylamino)sulfonyl]phenyl] azo]-4-hydroxynaphthalene-2-sulfonate [19]*

yl)phenyl]azo]-4-hydroxynaphthalene-2-sulfonate; (b) - sodium 6-amino-5-[[2-[cyclohexylmethylamino)sulfonyl]phenyl]azo]-4-hydroxynaphthalene-2-sulfonate [19]

All other chemicals used in the experiments were p.a. Sodium chloride, 99.5% NaCl (Lachner, Czech Republic) was used as supporting electrolyte, iron(II)sulfate heptahydrate, $FeSO_4$ x $7H_2O$ (Buchs SG, Switzerland) was used as a source of $Fe_2$+ ions and hydrogen peroxide, 30% $H_2O_2$, (Zorka Šabac, Serbia) as was added in one set of experiments.

Stainless steel (EN 1.4301/AISI 304; max. 0.007% C, max. 18.1% Cr, max. 8.2% Ni) was used as cathode. Mixed metal oxide anodes (MMO anodes) were used as anodes: Ru mixed oxide (titanium substrate coated with 6g Ru/$m^2$ (Metakem, Germany)) and Ru-Ir mixed oxide (titanium substrate coated with 6g Ru-Ir/$m^2$ (Metakem, Germany)).

Based on literature data [9 - 18], in the EF processes the pH of synthetic wastewater was adjusted to the recommenden optimal value pH=3 by addition of 0.1M HCl (Lachner, Czech Republic) and at pH=6 by addition of 1M NaOH (Lachner, Czech Republic).

Wastewater samples were analyzed before and after treatment for the following parameters: concentration of dye, pH and conductivity (κ). The analysis of dye concentration was determined spectrophotometrically on a UV-VIS spectrophotometer (Perkin-Elmer, LAMBDA 25) and pH and conductivity (κ) on a multimeter (Consort C861).

In the all experiments NaCl was chosen as the supporting electrolyte as one of the commonly used supporting electrolytes [20]. For the EF process, in addition to NaCl, Fenton's reagents ($Fe^{2+}$ and $H_2O_2$) were added. According to Rahmani et al. [6] there are four types of EF process. In this research, two EF processes were performed. In the first, EF-1 process, $Fe^{2+}$ catalyst was manually added, and $H_2O_2$ was electrogenerated in an electrochemical reactor. In the second, EF-2 process, both Fenton's reagents were manually added and then electrolytic regenerated during the treatment. Initial experimental conditions for the EO, EF-1 and EF-2 processes are show the in the Table 2.

## 3. RESULTS AND DISCUSSION

The results of BR dye removal from synthetic wastewater by the EO and EF processes are expressed through the removal efficiency (E, %) and calculated according to the following equation:

$$E = \frac{c_i - c_f}{c_i} \cdot 100\% \qquad (6)$$

where $c_i$ and $c_f$ are the initial and final concentration of BR expressed in mg/L.

Analysis of the costs of electrochemical wastewater treatment shows that the main costs are investment and electricity costs for electrolysis. In order to these costs be as low as possible in relation

***Table 2.*** *Experimental conditions for the EO, EF-1 and EF-2 processes*

| Parameter | Value | | |
|---|---|---|---|
| | EO | EF-1 | EF-2 |
| Concentration of BEMACID RED dye in synthetic wastewater | 100 mg/L | | |
| Concentration of supporting electrolyte (NaCl) | 1.46 g/L (0.025 M) | | |
| Concentration of catalyst ($Fe^{2+}$) | 0 | 0.5; 1; 2 mM | 1 mM |
| Concentration of $H_2O_2$ | 0 | 0 | 0.15 mL/L 30% |
| Conductivity | ≈ 2.5 mS/cm | | |
| pH | 4.24 | 3; 4.6; 6 | 3 |
| Wastewater volume | 400 mL | | |
| Anode surface | 51.86 $cm^2$ | | |
| The distance between the electrodes | 1 cm | | |
| Stirring (rpm) | 300 | | |

to the designed capacity, it is necessary to achieve such conditions that will achieve the maximum removal of pollutant per time unit and per unit of reactor volume, with minimal consumption of electricity. Therefore, the electrical energy used to remove a unit of pollutant represents one of the most important technological indicators of the operation of an electrochemical reactor, because it affects the overall cost of treatment. Specific electricity consumption (Wsp) is calculated according to the following equation:

$$W_{sp} = \frac{U \cdot I \cdot t}{m_{pollutant}} \left[ \frac{kWh}{kg_{pollutant}} \right] \qquad (7)$$

where I- is current [A], U- voltage on the electrochemical reactor [V], t- time [h], m- mass of the removed pollutant [kg].

In this research, the impact of: anode material, electrolysis duration, current density, catalyst concentrations (for EF process) and pH on dye removal efficiency were examined.

### 3.1. Influence of anode material and electrolysis time

The anodes used in this research belong to active anodes with low oxygen evolution overpotential, electrocatalytic activity for oxygen evolution and known for their electrocatalytic activity for chlorine evolution. These anodes have good electrocatalytic properties, but also long-term mechanical and chemical stability. Thanks to these properties, chlorine evolution activity can be effectively utilized for disposal of organics through the generation of active chlorine via indirect oxidation [20, 21]. Based on the obtained results shown in Figure 3, it can be observed that Ru anode is more efficient compared to Ru-Ir anode in the EO process at all examined treatment times. In the EF-1 process, Ru anode shows higher efficiency within shorter treatment times, while in the EF-2 process there is almost no difference in the achieved efficiencies with both examined anode materials. The EF-2 process characterizes high efficiency at the very beginning of the treatment. Addition of Fenton's reagents results in approximately 90% dye removal, while further electroregeneration of Fenton's reagents in an electrochemical reactor removes approximately 95% of the dye with both anode materials in only 5 minutes of treatment. By prolonging the treatment, the dye is completely removed.

Although the EF-2 process proved to be significantly effecient in terms of dye removal, significant amounts of waste sludge were generated (as in the classic chemical Fenton process), compared to the EF-1 process, which generated less sludge

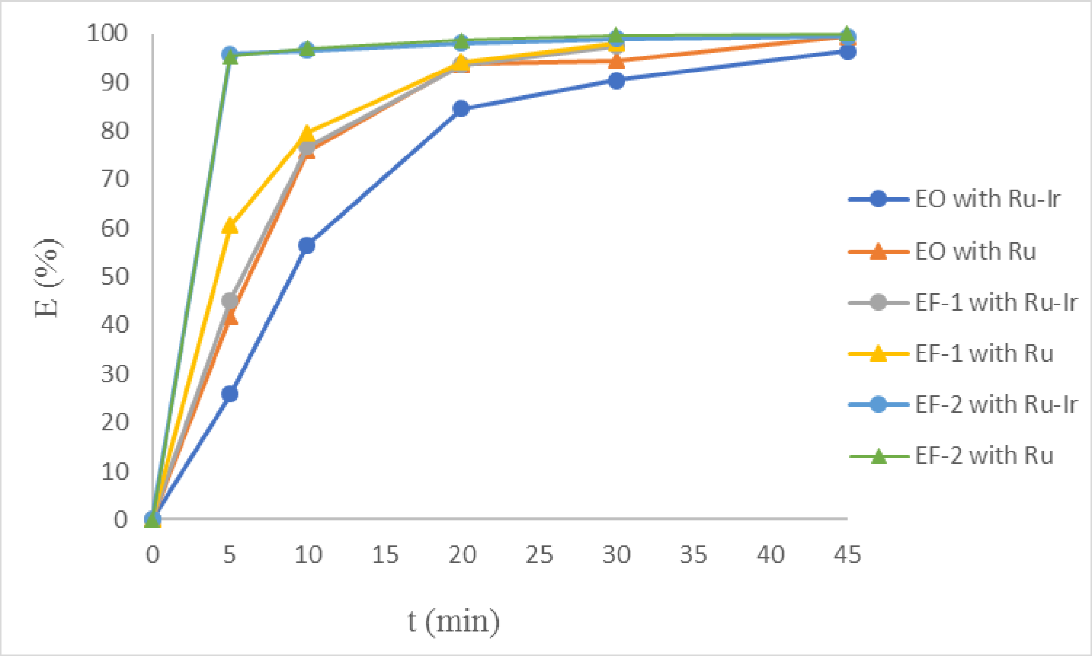


***Figure 3.*** *Influence of anode material on dye removal efficiency at different EO, EF-1 and EF-2 treatment times ($j=2.5$ mA/cm$^2$, $c_{dye}=100$ mg/L, $c_{NaCl}=1.46$ g/L, stirring 300 rpm)*

(with longer treatment times) and the EO process in which there is no sludge formation at all. Since the sludge generated during the treatment is a problem in terms of further disposal, in the continuation of the research, attention is paid only to the EO and EF-1 processes, which do not produce sludge or produce a small amount of sludge. Due to the higher efficiency of the Ru anode compared to the Ru-Ir anode, only the electrode pair Ru (anode) - stainless steel (cathode) was used in the further research.

### 3.2. Influence of current density

The influence of current density (1.25, 2.5 and 5 mA/cm$^2$) on the dye removal efficiency by EO and EF-1 process was examined. This parameter is of great importance for the EF process because it governs the formation rate of $H_2O_2$ (reaction 4) and the regeneration rate of the catalyst ($Fe^{3+} + e^- \rightarrow Fe^{2+}$) and consequently the generation rate of OH· via the Fenton reaction (5) as well as the formation rate of OH· on the anode surface (reaction 1) [8]. From Figure 4 it can be seen that removal efficiency increases with increasing current density. At higher current densities (2.5 and 5 mA/cm$^2$) there is no significant difference in the achieved efficiencies of the EO and EF-1 processes, but at the lowest tested current density (1.25 mA/cm$^2$) the EF-1 process proved significantly more efficient compared to EO. This probably indicates that in addition to the formation of OH· on the surface of the anode, $H_2O_2$ was electrogenerated on the cathode, which further in the presence of the catalyst led to the (electro)-Fenton reaction of the formation of additional amounts of OH·, which affected the increase in the efficiency of the dye decomposition.

Figure 5 shows the specific energy consumption for the EF-1 process at the tested current densities. It is obvious and expected that with the increase in current density the energy also increases. In addition to high efficiency, the EF-1 process is very economical in terms of energy consumption, considering that in 45 minutes of treatment using a current density of 1.25 mA/cm$^2$, an efficiency of 87.04% of dye removal was achieved, and 1.371 kWh/kg$_{dye}$ was consumed. Since the energy consumption is significantly lower at 1.25 mA/cm$^2$ and at this current density the highest efficiency was achieved with EF-1 process, in further experiments different process parameters (catalyst concentration and the pH) were examined, in order to determine whether the efficiency can be additionally increased by adjusting these parameters.

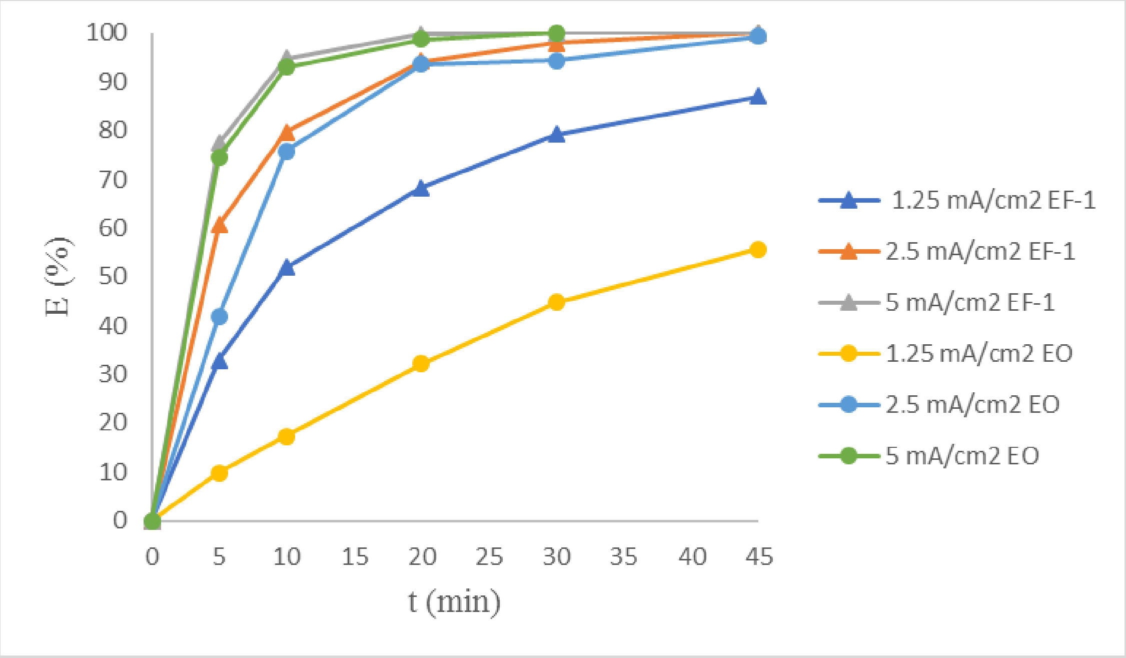


***Figure 4.*** *Influence of current density on dye removal efficiency by EO and EF-1 treatments ($c_{dye}$=100 mg/L, $c_{NaCl}$=1.46 g/L, stirring 300 rpm, pH =4.2, $c_{Fe2+}$=1mM)*

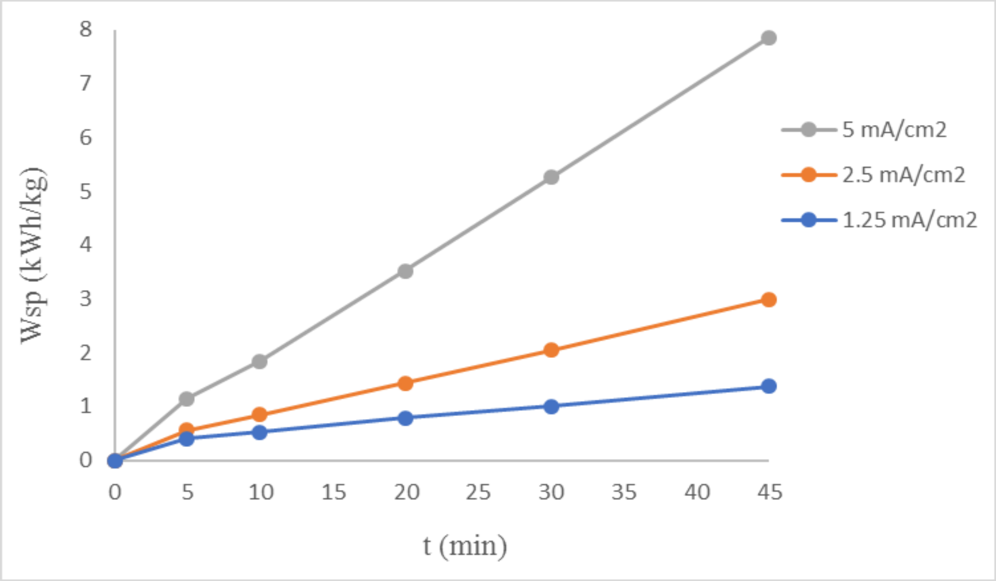


***Figure 5.*** *Specific energy consumption for EF-1 process depending on the applied current density ($c_{dye}$=100 mg/L, $c_{NaCl}$=1.46 g/L, stirring 300 rpm, pH =4.2, $c_{Fe2+}$=1mM)*

### 3.3. Influence of catalyst concentration

The influence of the catalyst concentration (0.5, 1 and 2 mM) on the EF-1 process efficiency of the was examined. The optimal catalyst concentration depends on the type of cathode material and the type of pollutant and is determined experimentally. Low iron ion concentrations are not sufficient to efficiently catalyze the Fenton reaction, while high concentrations (more than the optimal value) increase the rate of the OH· consumption reaction and reduce the oxidation ability of the process (according to the reaction $OH^{\bullet} + Fe^{2+} \rightarrow Fe^{3+} + OH^{-}$) [8]. In Figure 6 it can be seen that at the highest concentration of the catalyst tested (2 mM) there is a decrease in the efficiency of the treatment. At shorter treatment times (5 and 10 minutes) the process is more effective with 1 mM $Fe^{2+}$, while at longer times (30 and 45 minutes) the treatment is more effective with 0.5 mM $Fe^{2+}$ as a catalyst.

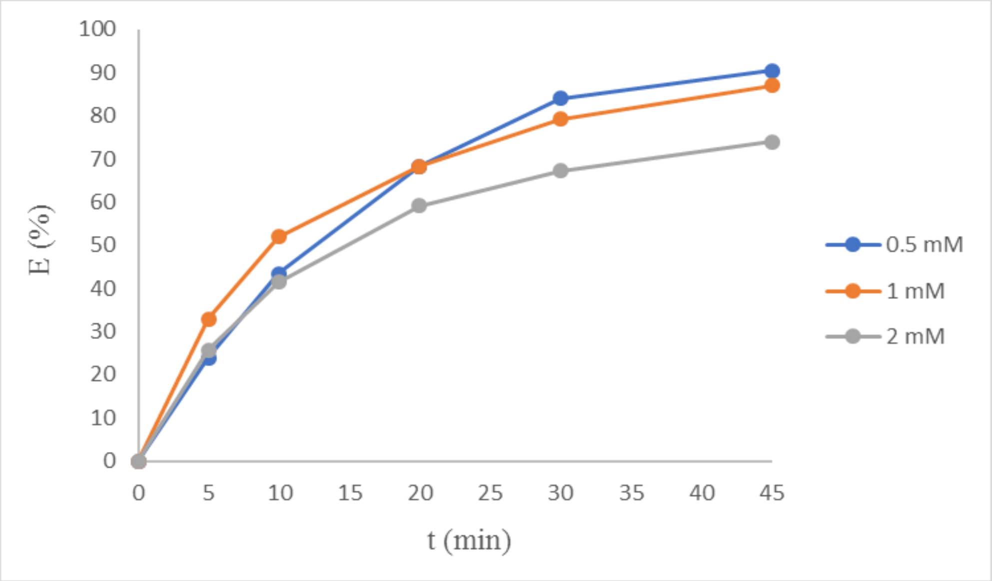


***Figure 6.*** *Influence of catalyst concentration on the dye removal efficiency at different treatment times (j=1.25 mA/cm$^2$, $c_{dye}$=100 mg/L, $c_{NaCl}$=1.46 g/L, stirring 300 rpm, pH =4.2)*

### 3.4. Influence of pH

The impact of pH on the efficiency of the EF-1 process was examined. It is already well known that the EF process is most efficient at pH≈3, but that the process can be efficiently performed in the range 2.5<pH<3.5. High pH values cause the loss of the catalyst by precipitation of ferric ions, while low pH values lead to the formation of peroxonium ions ($H_3O_2^+$) from protonation of $H_2O_2$. This species is electrophilic and less reactive towards $Fe^{2+}$ [8]. Based on the obtained results (Figure 7), it can be seen that the efficiency of the EF-1 process is the lowest at pH=3, and the highest at pH=6, which is not in accordance with literature recommendations. A possible reason for such results is the fact that with an increase in the pH value, there is precipitation of the catalyst in the form of iron hydroxide ($Fe(OH)_3$) and ferric oxyhydroxide ($FeOOH^{2+}$) and leaving the Fenton reaction [13], which actually led to the (electro)coagulation of the dye in addition to the EF and thus to an increase in the efficiency of the treatment.

## 4. CONCLUSION

Based on the previously presented results and discussion, the following conclusions can be highlighted:

- The electrode pair Ru anode - stainless steel cathode proved to be more effective for the BR dye removal from wastewater, compared to the pair Ru/Ir anode -stainless steel cathode;
- The EF-2 process proved to be significantly effective in terms of dye removal, but this process produces significant amounts of waste sludge, compared to the EF-1 process, which produced small amount of sludge, and the EO process, which which does not produce any sludge;
- At the lowest tested current density (1.25 mA/cm$^2$), the EF-1 process proved to be significantly more efficient than EO;
- For 45 minutes of treatment with applied current density of 1.25 mA/cm$^2$, dye removal efficiency of 87.04% was achieved, with the specific energy consumption 1.371 kWh per kilogram of removed BR dye;
- The optimal concentration of the $Fe^{2+}$ catalyst depends on the duration of the treatment;
- The effect of pH on the treatment is different from previous literature claims. The efficiency of the EF-1 process is the lowest at pH=3, and the highest at pH=6, which probably indicates that in addition to the electro-Fenton process, the process of electrocoagulation of the dye also takes place.

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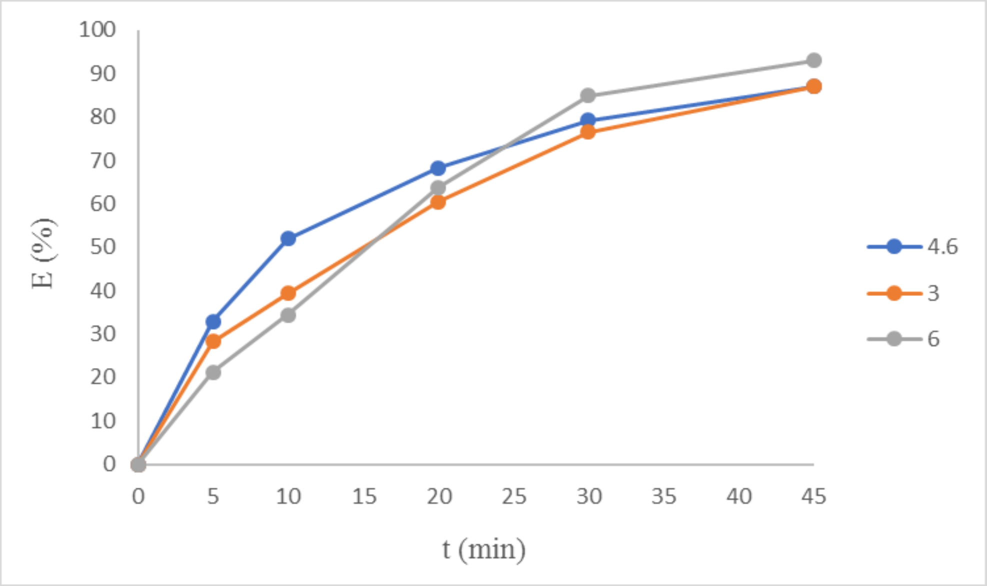

***Figure 7.*** *Influence of pH on the dye removal efficiency at different treatment times (j=1.25 mA/cm$^2$, $c_{dye}$=100 mg/L, $c_{NaCl}$=1.46 g/L, $c_{Fe2+}$=1Mm, stirring 300 rpm)*

## 5. LITERATURE

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# УКЛАЊАЊЕ АЗО-БОЈА ИЗ ОТПАДНИХ ВОДА ТЕКСТИЛНЕ ИНДУСТРИЈЕ КОРИШЋЕЊЕМ ЕЛЕКТРООКСИДАЦИЈЕ И ЕЛЕКТРОФЕНТОН ПРОЦЕСА

**Сажетак:** Отпадне воде текстилне индустрији имају висок садржај органских материја, високу обојеност, различите минерале и метале, а често и токсичне и канцерогене материје. Од свих боја које се користе у текстилној индустрији, најзаступљеније су азо-боје. Азо боје су по структури сложена једињења и њихово уклањање из отпадних вода није једноставно. У овом раду електрооксидација и електрофентон процес, као једни од најефикаснијих електрохемијских напредних оксидацијских процеса за уклањања органских загађивача у отпадним водама, коришћени су за третман синтетске отпадне воде која садржи „Bemacid Red“ боју као загађивач. Испитано је неколико процесних параметара који утичу на ефикасност настанка OH. и разградњу боје. Као катодни материјал коришћен је нерђајући челик (SS), а кориштене аноде су од мијешаних металних оксида (MMO) - Ru мијешани оксид (титанијумски супстрат превучен са 6g Ru/m$^2$) и Ru-Ir мијешани оксид (титанијум супстрат превучен са 6 g Ru-Ir/m$^2$). Резултати су показали да је електродни пар Ru : SS ефикаснији у у односу на пар Ru-Ir : SS, као и да је електрофентон процес ефикаснији у поређењу са електрооксидацијом.

**Кључне ријечи**: текстилна индустрија, отпадне воде, ефикасност третмана.

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