

DECOLORIZATION OF DYE SOLUTION CONTAINING REACTIVE JAKOFIX YELLOW BY ELECTROCOAGULATION PROCESS: INVESTIGATION OF SOME ELECTROCHEMICAL VARIABLES

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ABSTRACT

Dye removal from effluent is one of the major environmental problems in textile industry concerning water pollution. Nowadays the optimization of the decolorization processes is a considerable topic in that minimizing the negative impact on the environment,. The present work deals with the decolorization of reactive dye solutions containing Jakofix Yellow dye in a batch-stirred electrocoagulation (EC) cell using three different types of electrode pair. Different operating conditions, such as current density, operating time, electrode type and initial pH value were tested with the dye solutions in order to optimise the treatment. Optimum operation conditions achieved in the tests were: current density of 196 A m⁻², initial pH of 5.5 which its natural value and Fe electrodes for the batch-stirred setting. Results clearly show that EC process is quite simple and effective treatment method for decolorization of wastewaters containing textile dye jakofix yellow and clay minerals can be used in order to increase the efficiency of this technique.

Keywords: Electrocoagulation, reactive dye, jakofix yellow, dye removal

REAKTİF JAKOFİX YELLOW İÇEREN BOYA ÇÖZELTİLERİNİN ELEKTROKOAGÜLASYON PROSESİ İLE RENK GİDERİMİ: BAZI ELEKTROKİMYASAL DEĞİŞKENLERİN İNCELENMESİ

ÖZ

Atıksudan boya giderimi, tekstil endüstrisinin su kirliliği ile ilgili başlıca çevresel problemlerinden biridir. Günümüzde çevre üzerindeki olumsuz etkisini azaltma açısından renk gideriminin optimizasyonu önemli bir husustur. Bu çalışma, üç farklı tür elektrot çifti kullanarak kesikli-karıştırmalı bir sistemde Jakofix Yellow boyası içeren reaktif boya çözeltilerinin renk giderimi üzerine yapıldı. Arıtımı optimize etmek için akım yoğunluğu, işlem zamanı, elektrot tipi ve başlangıç pH değeri gibi farklı işletme şartları boya çözeltilerinde test edildi. Yapılan denemelerde elde edilen optimum işletme koşulları: kesikli-karıştırmalı sistem için akım yoğunluğu 196 A m⁻², başlangıç pH'sı doğal pH değeri olan 5.5 ve Fe-elektrotlardır. Elde edilen bu sonuçlar, Jakofix Yellow tekstil boyası içeren atıksuların renk giderimi için EC prosesinin oldukça basit ve etkili bir arıtım metodu olduğunu ve bu tekniğin etkinliğini arttırmak için kil minerallerinin kullanılabileceğini net bir şekilde göstermektedir.

Anahtar Kelimeler: Elektrokoagülasyon, reaktif boya, jakofix yellow, boya giderimi.

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1. INTRODUCTION

Textile industry has a key position in the industrialization and development of any country. On the other hand, textile industry is a main creator of effluent wastewater due to ultra consumption of water used in different wet processing operations. Dyes and pigments are one of the most problematic groups of effluents, which are emitted into wastewaters from various industrial branches, mainly from the dye manufacturing and textile finishing as well as food coloring, cosmetics, paper and carpet industries [1,2]. Discharge of wastewaters originating from textile industry into the water resources is destructive to the aquatic lives. Color ingredient of the effluent changes the structure of water and inhibits the daylight inlet into the stream and minimizes photosynthetic activity [3,4]. It must be noted that wastewaters containing textile dyes are very difficult to treat, because these chemicals are resistant to traditional aerobic digestion [5]. Additionally textile wastewaters are one of the significant pollutants for the environment due to high COD concentration, evident color, high pH, temperature and low biodegradability [6]. Particularly strong color of wastewater if not removed would cause disturbance to the ecological system of the receiving waters [7].

Main treatment processes for colored effluents include physicochemical, chemical, biological oxidation, coagulation and adsorption. These processes are quite ineffective in color removal of wastewater as most commercial dyes are toxic to organisms used in the biological process while the physicochemical treatment provides only a phase transfer of dyes and generates huge volumes of hazardous sludge. As a result their low-yield depuration or high costs frequently cause problems during operation [8].

Nowadays, great interests are focused on electrochemical treatment of the effluents originated from textile industries. Electrocoagulation is an effective method between electrochemical treatment processes to treat various wastewaters such as; landfill leachate [9], restaurant wastewater [10], salina wastewater [11], urban wastewater [12], laundry wastewater [13], textile wastewater [14] and chemical mechanical polishing [15,16].

Electrocoagulation is an electrochemical treatment process used electro-dissolvable metal electrodes and so metallic hydroxides flocs clean the polluted solution. Tiny pollutants could be removed with this method compared with conventional coagulation and flocculation. The smallest charged particles could coagulate more easily because field directs them in motion. It has also the advantage of producing a relatively low amount of sludge [12]. Three main processes occur during EC; (i) electrolytic reactions developed at electrode surfaces, (ii) formation of coagulants in the bulk, (iii) adsorption of soluble or colloidal impurities on coagulants, and departure by sedimentation or flotation. The main reactions at the electrodes are:



OH⁻ ions produced from H₂ evolution at high pH may also chemically act on cathode by that reaction [17]:



Al³⁺ and OH⁻ ions produced throughout (1) and (2) reactions react to create some monomeric species such as Al(OH)₂⁺, Al(OH)₂²⁺, Al₂(OH)₂⁴⁺, Al(OH)₄⁻, and polymeric species such as Al₆(OH)₁₅³⁺, Al₇(OH)₁₇⁴⁺, Al₈(OH)₂₀⁴⁺, Al₁₃O₄(OH)₂₄⁷⁺, Al₁₃(OH)₃₄⁵⁺ and as a result these species transform enigmatically into Al(OH)₃ according to precipitation kinetics [7].

Based on the existing literature, many works about electrocoagulation have been studied with batch reactor to depurate textile dyeing effluents. The aim of the study is to optimise the decontamination conditions of textile dyes from model solutions using three types of sacrificial electrodes. The effect of operating time, electrode type, initial pH of the solution and current density was evaluated on color removal efficiency in batch-stirred system. In this paper to our knowledge for the first time the comparison of three electrode types for decolorization of the reactive dye, Jakofix Yellow, has been investigated by electrocoagulation process. Also the effect of clay minerals on process performance was studied. Dye pollutants were effectively and rapidly removed with iron, aluminum and zinc electrodes at certain operating conditions.

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2. MATERIAL VE METHOD

The commercially available reactive dye Jakofix Yellow (JY) was supplied from a local textile industry located in Manisa, Turkey. The characteristics and the chemical structure of the dye are presented in Table 1. Model dye solutions were prepared by dissolving JY dye in distilled water to minimize interferences.

Table 1. Characteristics and chemical structure of the Jakofix Yellow dye

Colour index name	M (g mol ⁻¹)	λ _{max} (nm)	Chemical structure
Reactive Yellow 145	1026.25	420	

The schematic view of electrocoagulation unit is shown in Figure 1. The batch electrocoagulation cell was constructed of a 0.6 L glass beaker equipped with a cathode and an anode, all of them made of iron or aluminum or zinc and installed in parallel. The distance between the electrodes influencing the amount of energy was 5.5 cm. The dimension of each electrode was 20cmX6cmX0.2cm. The total effective area of electrode is calculated to be (8.5cmx6cm) 51 cm². In each run 0.5 L of model solution was placed into the electrolytic cell and electrodes were dipped in the electrochemical reactor. The electrodes were connected to a DC power supply (SUNLINE SL-3010D) providing a controlled voltage up to 30 V and regular electricity current up to 3 A. All the runs were performed at room temperature and treatment solution was agitated using a magnetic stirrer by the speed of 200 rpm which was optimum stirring rate in the literature [18]. The pH and conductivity of the samples were measured with a Hanna edge apparatus. The electrical conductivity of the leachate sample was not sufficient for electrocoagulation, so sodium chloride salt (Merck, 99.9% purity) was added to adjust the initial conductivities of the solutions. As a part of the study, two clay minerals (kaolinite and colemanite) were added to the solution at optimum conditions in order to investigate the effect of the addition the clays on decolorization efficiency. The EC process was given a start as soon as current density was regulated for intention value.

Throughout the tests, samples were collected at 5 min intervals, centrifuged and analyzed to determine the residual dye concentration. Samples from process were periodically withdrawn and immediately centrifuged at 3000 rpm for further analysis. After centrifugation, samples were directly subjected to color analysis utilising the spectrophotometer.

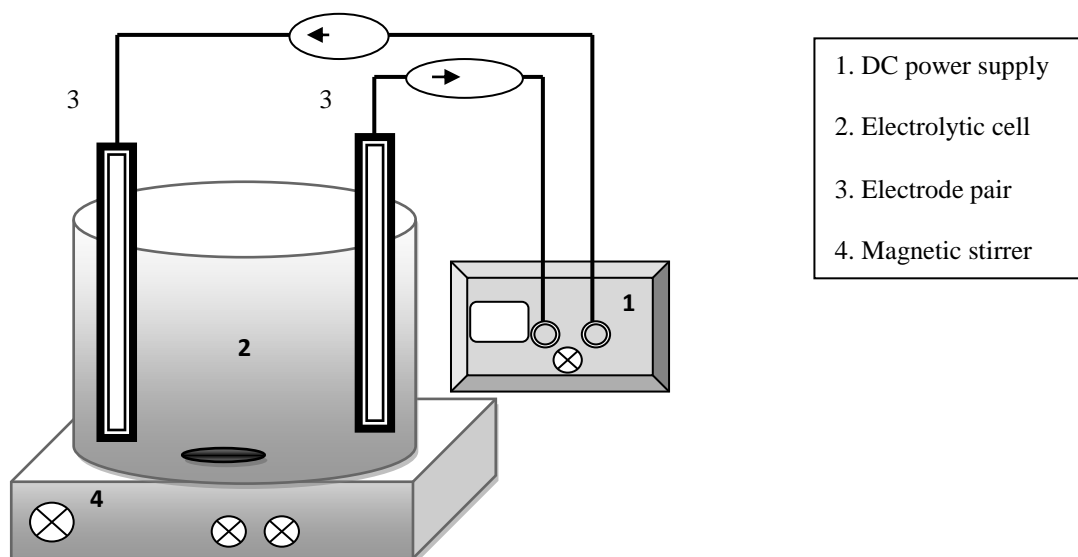


Fig. 1. Schematic figure of experimental set-up

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A UV-Vis spectrophotometer (Dr-LANGE CADAS 30 S) was used to determine the decolorization efficiency via the decrease in absorbance at the maximum wavelength ($\lambda_{max}= 420$ nm for JY) of the dye. The calculation of decolorization efficiency (DE%) after the operation was performed using this formula:

$$DE\% = \frac{[C_0 - C]}{C_0} \times 100 \tag{4}$$

where C_0 and C are dye concentrations before and after electrocoagulation process, respectively. The remnant dye concentration was determined from its absorbent characteristics in the UV-Vis range (200–800 nm) with the calibration method using Beer-Lambert’s law. The absorbance of the dye solution in the treated sample was recorded at 420 nm (λ_{max}) and the concentration was determined from the constructed calibration chart using Beer-Lambert’s law as seen in Fig. 2. A good linear relationship by plotting the absorbances versus known concentrations at λ_{max} was obtained. The Beer-Lambert’s law expresses the relationship between concentration and absorbance according to Eq. (5):

$$A = \epsilon b C \tag{5}$$

where A is absorbance, ϵ is the molar extinction coefficient, b is the path length of the sample in cm, C is the concentration of the compound in solution. Not to make a duplication and to facilitate the data displays, decolorization efficiency was just calculated for absorbance values at 420 nm which is the maximum value of the dye [19].

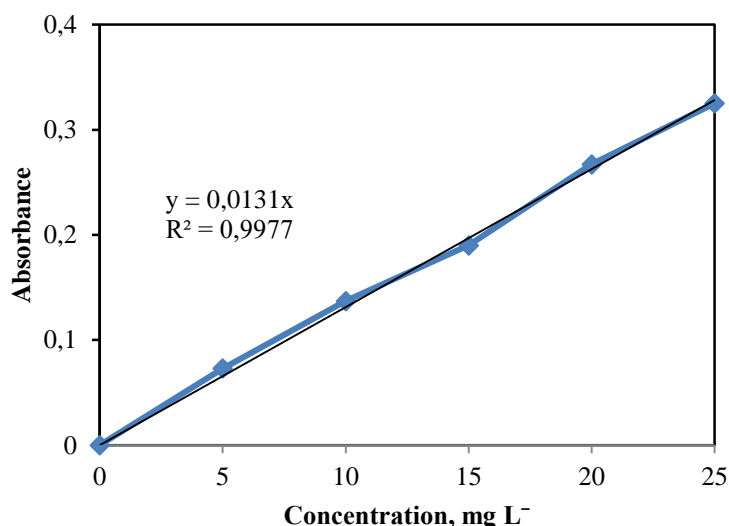


Fig. 2. Calibration chart of Jakofix Yellow dye.

3. RESULTS AND DISCUSSION

Performance of the electrochemical treatment process was investigated working on the parameters of current density, initial pH, electrode type and electrolysis time to assign the optimum experimental conditions and to detect the maximum efficiency of decolorization for reactive JY dye.

3.1 Effect Of The Current Density

Current density (j) is orientated from current applied per unit surface area of the electrode employed in the process. As applied current density increases removal of solutes increases, but this may not be valid in pursuit of certain value of j . As known j parameter of electrocoagulation process adjusts the coagulant proportioning, bubble formation rate, size and growth of the flocs, therefore it can affect the efficiency of electrochemical treatment [20]. For this reason, the effect of current density on treatment efficiency was evaluated at three

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different j values, 98, 196 and 392 $A\ m^{-2}$ for concentration of JY solution of 1000 $mg\ L^{-1}$, using iron electrode and keeping constant other operation conditions. It can be seen from Fig.3 that decolorization efficiency is minimum for a current density of 98 $A\ m^{-2}$. Besides it increases rapidly up to 99.4% with a current density of 392 $A\ m^{-2}$ and just 10 min electrolysis is sufficient to catch up this efficiency value. In 5 min, the performance of efficiency reaches to 96.7% decreasing after 25 min to 45 min. For lower j value of 196 $A\ m^{-2}$, decolorization efficiency was 98.3% after 15 min treatment remaining almost constant until the end of the process. Keeping constant the treatment performance after 15 min till the end for lower j value of 196 $A\ m^{-2}$ means that it shows the superior performance compared to other j values of 98 and 392 $A\ m^{-2}$. When too large current is used, cell voltage increases and there is a potentiality of wasting electrical energy in heating up the water in the case of the use of excessive values of j . Remarkably, operating with excessive current density of process results in a significant decrease in current efficiency [21].

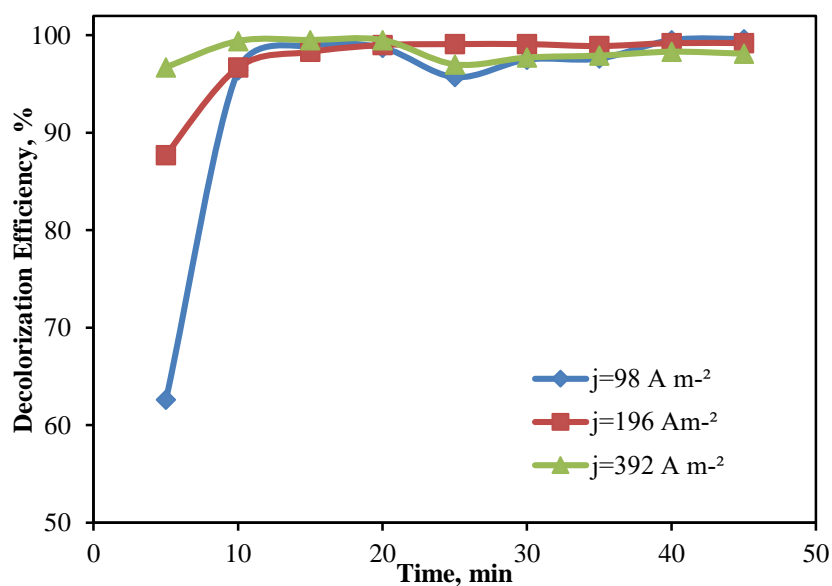


Fig. 3. Effect of the current density on decolorization efficiency over time (pH=5.5, Fe-electrode)

On the other hand, the situation in the solution can be explained as the j raise, more dissolution of the Al anode (or Fe, Zn) is promoted and consequently, a higher number of metal hydroxide flocs is formed to remove the pollutant as seen in Eq.(1) and Eq.(2) [18,22,23]. Dissolution of the Al anodes could accelerate owing to Cl^- ions present due to the corrosion in the EC medium. Additionally, electrogeneration of active chlorine species may proceed with the addition of NaCl to the system [24]. Consequently as j increases, both the formation of these species and the decolorization efficiency of the process will be improved [25].

3.2 Effect Of The Initial Ph

The initial pH of the bulk is an essential parameter in the optimization of electrocoagulation process. As some researchers indicated and seen in Table 2, pH of the working solution gets regularly different values throughout the decolorization process [10, 26]. This variation is related with the type of electrode material and initial pH [27]. The effect of initial pH on color removal efficiencies for iron electrode is presented in Fig.4. It is clear that maximum removal efficiencies have been performed with iron electrode in acidic medium with pH of 4 and pH of 5.5. The lowest decolorization efficiencies have been obtained in neutral and basic effluents. As a conclusion low initial pH values are more productive from the view point of the best decolorization efficiencies. In agreement with this study, Werma et al. [28] also concluded that the pH of the synthetic solution after the EC process increased over electrolysis time due to the generation of OH^- in the EC process.

Table 2. Initial and final pH values of decolorization process

Time (min)	Initial pH	Final pH	Initial pH	Final pH	Initial pH	Final pH	Initial pH	Final pH
5	4.0	8.5	5.5	9.1	7.0	9.6	8.5	10.1
10	4.0	10.2	5.5	10.2	7.0	10.5	8.5	10.6
15	4.0	10.3	5.5	10.5	7.0	10.5	8.5	10.8
20	4.0	10.5	5.5	10.7	7.0	10.5	8.5	10.8
25	4.0	10.6	5.5	10.7	7.0	10.5	8.5	10.8
30	4.0	10.6	5.5	10.8	7.0	10.6	8.5	10.8
35	4.0	10.8	5.5	10.9	7.0	10.6	8.5	10.9
40	4.0	10.9	5.5	10.9	7.0	10.7	8.5	10.9
45	4.0	10.9	5.5	10.9	7.0	10.7	8.5	10.9

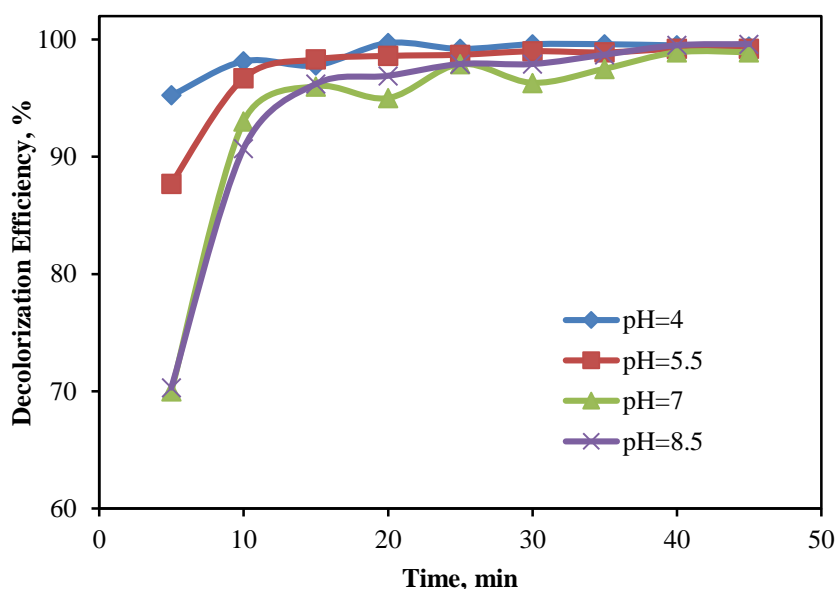


Fig. 4. Effect of initial pH on decolorization efficiency ($j=196 \text{ A m}^{-2}$, Fe-electrode)

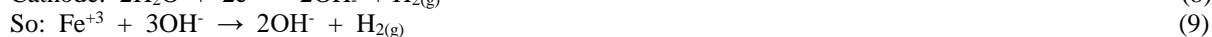
3.3 Effect Of The Electrode Type

One of the major operational parameters in EC process is the sacrificial electrode type since different electrode materials affect the performance of the treatment [28]. Furthermore the electrode material plays a significant role in the cost analysis of the electrocoagulation process. The well-known electrode materials are aluminum and iron because they are cheap, accessible and effective [29]. In addition to these familiar type of electrodes, zinc plate was also used as electrode in this study. As seen in Fig. 5, Fe electrodes displayed a better efficiency than Al and Zn electrodes did on account of decolorization performance. Performance of the treatment reaches to 88% in 5 min and increases to 97% after 10 min. Other electrode materials exhibited lower decolorization efficiency than Fe (<86%). Due to the fact that performance is maximum, it will be a good choice to select Fe electrodes for higher treatment efficiencies. Generated metal hydroxide forms takes in charge of removal the colloidal, suspended and dissolved contaminations from wastewater [30]. Current density, electrical current and treatment time promotes comparatively the amount of formed metal hydroxide sludge [31]. The amount and composition of the formed sludge changes with the type of electrode material and the results are consistent with other researchers' findings [17,32].

Two mechanisms are possible during EC by using iron as sacrificial anode:

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Mechanism I:



Mechanism II:



The green colour of bulk points to the formation of the $Fe(OH)_2$ and then $Fe(OH)_2$ is oxidized to advance the formation of $Fe(OH)_3$ [33].

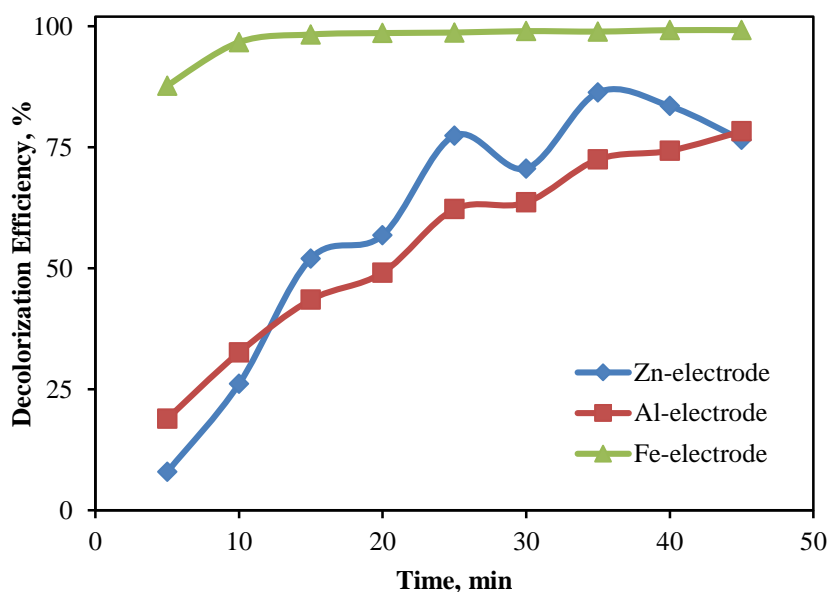


Fig. 5. Effect of the type of sacrificial electrode type on decolorization efficiency ($j=196 \text{ A m}^{-2}$, $\text{pH}=5.5$)

3.4 Effect Of The Electrolysis Time

Electrolysis time (contact time) influences the performance of the electrocoagulation process since it plays a role in the determination stage of rate of metal production and hydroxyl ions generated by the electrodes [34]. The effect of electrolysis time on colour removal efficiency was investigated maintaining the optimum pH of 5.5 and keeping constant the current density of 196 A m^{-2} . It can be observed from Fig.6 that concentration of dye is decreasing with increase in the reaction time up to 15 min and then become almost constant for Fe electrode. Also this means that decolorization efficiency increases over time. This situation is characterized as decreasing extent of cathodic reduction and production of nascent electro-coagulant flocs [35]. Optimum operating time is important from the view point of the economy of operation. As Bayramoğlu et al. [36] also highlighted that treatment cost increases by the time of progress.

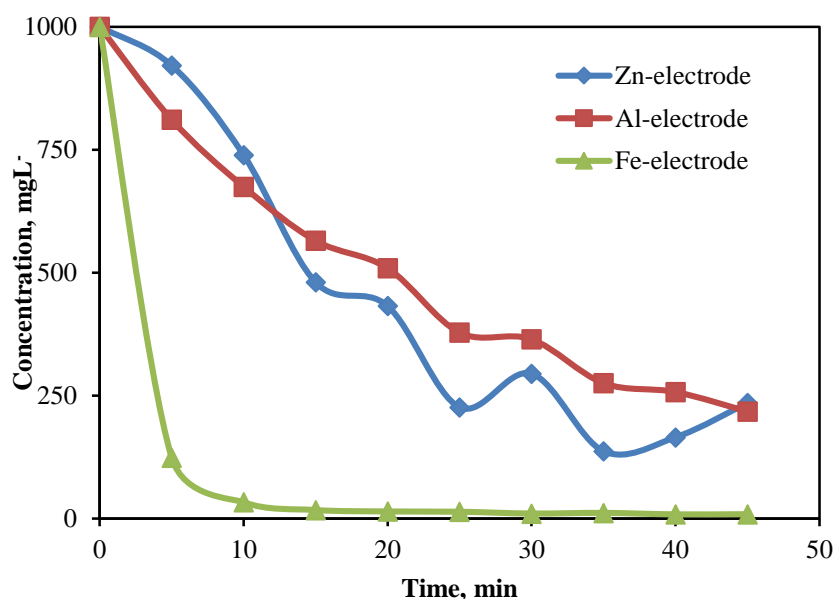


Fig. 6. The change of the concentration over time ($j=196 \text{ A m}^{-2}$, $\text{pH}=5.5$)

3.5 Effect Of The Addition Of Some Clay Minerals

Clay minerals could be employed as adsorbents in the treatment of heavy metals and organic pollutants, or as coagulant aids since investigations on their specific surface chemical properties, e.g. cations exchange capacity, and adsorptive affinity for some organic and inorganic compounds led to the potential use of clays [37,38]. The effects of some clay minerals' addition consisted of kaolinite and colemanite were investigated at a constant dose, 2 g L^{-1} . All runs were performed by the direct addition of clay minerals to the dye solution in the EC system. Fig. 7 shows that clay particles exhibit a significant role in removing the color of the dye solutions. In 5 min at first decolorization efficiency were: 88% without clay, 96% with kaolinite and 97% with colemanite. As a result adding the clay minerals enhances the treatment and accelerates the depurate of organic pollutants by electrocoagulation. It can also be said that the most efficient clay mineral is colemanite. This phenomena could be explained that the increase in surface area by involving the clays to the bulk causes the increase the adsorption of pollutants, ultimately the decolorization performance increases.

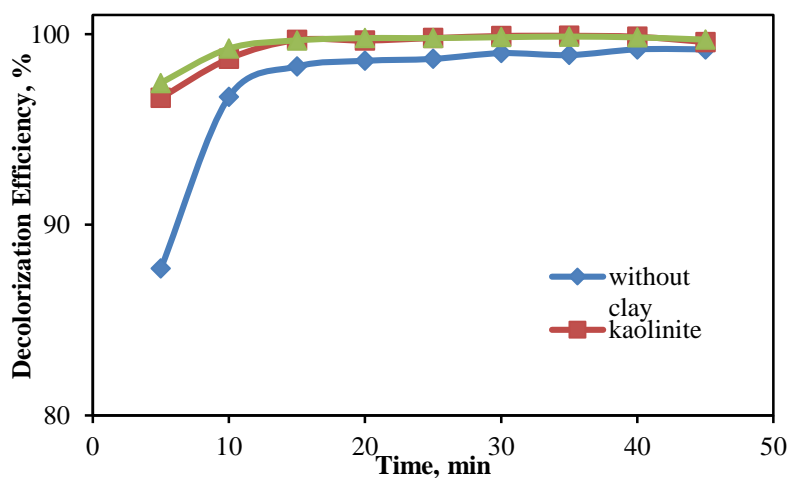


Fig. 7. Effect of the addition of clay minerals on decolorization efficiency ($j=196 \text{ A m}^{-2}$, $\text{pH}=5.5$, Fe-electrode, clay dose= 2 g L^{-1})

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4. CONCLUSION

The electrochemical treatment method (EC) was employed in the present study to investigate the effectiveness of treatment of solutions containing reactive Jakofix Yellow dye. From our present study, it was clearly concluded that:

- i. the removal of textile dye by electrocoagulation process using three types of electrode (aluminum, zinc and iron) can be a viable technique.
- ii. best decolorization efficiency values have been performed employing iron electrode material.
- iii. optimum pH of the dye solution was 5.5 which is dye's natural pH value.
- iv. the most economical current density value was 196 A m⁻² consuming the electric energy at optimum rating.
- v. clay minerals produce more effective flocs in the bulk improving and fastening the performance of the treatment by electrocoagulation.

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