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TREATMENT OF A TEXTILE WASTEWATER USING AN ELECTROCOAGULATION REACTOR POWERED BY PHOTOVOLTAIC SOLAR ENERGY

Tratamento de efluente de indústria têxtil utilizando reator de eletrocoagulação tendo como fonte a energia solar fotovoltaica

Tratamiento de efluentes de la industria textil mediante un reactor de electrocoagulación con energía solar fotovoltaica como fuente

Traitement des effluents de l'industrie textile utilisant un réacteur d'électrocoagulation ayant l'énergie solaire photovoltaque comme source

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Abstract

The textil industry uses a variety of dyes in the stage of coloring. The liquid effluent resulting at the end of the process has high turbidity and a large chemical oxygen demand. If these byproducts are dumped into natural water bodies, even in small quantities, they may produce damage to the aquatic environment and to human health. Electrocoagulation is becoming an efficient technique for the removal of pollutants from industrial effluents, it is easy to operate, and produces little sludge at the end of the treatment. In the present study, the use of an electrocoagulation reactor with aluminum electrodes proved efficient for turbidity removal from synthetic industrial effluents. The use of a solar plate of photovoltaic electricity for the functioning of the reactor was evaluated. Ideal time of treatment was 20 minutes. The use of a conventional energy source removed 63% of the turbidity. Using the voltaic solar energy source, a removal of 72% of turbidity was attained. We conclude that it is possible to use the alternative solar energy source in order to minimize costs resulting from electrical energy consumption, and, at the same time, to obtain the best results in the removal of pollutants.

Keywords: Industrial Wastewater. Turbidity Removal. Aluminum Electrodes. Water pollutant. Environmental Conservation.

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Resumo

A indústria têxtil utiliza-se de uma variedade de corantes na etapa de tingimento, e ao final do processo é gerado um efluente líquido de elevada turbidez e demanda química de oxigênio. Se estes forem lançados em corpos hídricos, mesmo em pequenas quantidades, podem trazer danos ao meio aquático, bem como à saúde humana. A eletrocoagulação vem se apresentando como uma técnica eficaz na remoção de poluentes em efluentes industriais, é de fácil operação, e apresenta pouca geração de lodo ao final do tratamento. No presente estudo, foi verificada a eficiência de remoção de turbidez de um efluente sintético, utilizando um reator de eletrocoagulação com eletrodos de alumínio, e avaliação do emprego de uma fonte de energia elétrica oriunda de placa solar fotovoltaica para funcionamento do reator. O tempo ideal de tratamento foi de 20 minutos, com eficiência de remoção de turbidez de 63%, utilizando uma fonte de energia convencional, e de 72%, utilizando como fonte de energia o painel solar. Concluímos que é possível utilizar uma fonte de energia alternativa de forma a minimizar os custos com energia elétrica no processo de tratamento e obter bons resultados na remoção de poluentes.

Palavras-chave: Efluente Industrial. Remoção de Turbidez. Eletrodos de Alumínio. Poluente Aquático. Conservação Ambiental.

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Resumen

La industria textil utiliza una variedad de tintes en la etapa de tintura, y al final del proceso se genera un efluente líquido de alta turbidez y demanda química de oxígeno, y si estos se liberan en cuerpos de agua, incluso en pequeñas cantidades, pueden traer daños al medio ambiente acuático, así como a la salud humana. Se ha demostrado que la electrocoagulación es una técnica eficaz para eliminar los contaminantes en los efluentes industriales, es fácil de operar y tiene poca generación de lodos al final del tratamiento. En el presente estudio, se verificó la eficiencia de eliminar la turbidez de un efluente sintético, utilizando un reactor de electrocoagulación con electrodos de aluminio, y la evaluación del uso de una fuente de energía eléctrica de una placa solar fotovoltaica para el funcionamiento del reactor. El tiempo de tratamiento ideal fue de 20 minutos con una eficiencia de eliminación de turbidez del 63% utilizando una fuente de energía convencional y del 72% utilizando el panel solar como fuente de energía, concluyendo que es posible utilizar una fuente de energía alternativa para minimizar los costos de electricidad en el proceso de tratamiento y obtener buenos resultados en la eliminación de contaminantes.

Palabras clave: Efluentes Industriales. Eliminación de Turbidez. Electrodos de Alumínio. Poluente Acuático. Conservacion Ambiental.

Résumé

L'industrie textile utilise une variété de colorants au stade de la teinture et, à la fin du processus, un effluent liquide avec une turbidité élevée et une demande chimique en oxygène est généré. Si ceux-ci sont rejetés dans les plans d'eau, même en petites quantités, ils peuvent nuire à l'environnement aquatique, ainsi qu'à la santé humaine. L'électrocoagulation a été présentée comme une technique efficace pour éliminer les polluants des effluents industriels, est facile à opérer et génère peu de boues en fin de traitement. Dans la présente étude, l'efficacité de l'élimination de la turbidité d'un effluent synthétique a été vérifiée, en utilisant un réacteur d'électrocoagulation avec des électrodes en aluminium, et l'évaluation de l'utilisation d'une source d'énergie électrique à partir d'une plaque solaire photovoltaïque pour faire fonctionner le réacteur. Le temps de traitement idéal était de 20 minutes, avec une efficacité d'élimination de la turbidité de 63 %, en utilisant une source d'énergie conventionnelle, et de 72 %, en utilisant le panneau solaire comme source d'énergie. Nous concluons qu'il est possible d'utiliser une source d'énergie alternative afin de minimiser les coûts d'électricité dans le processus de traitement et d'obtenir de bons résultats dans l'élimination des polluants.

Mots-clés: Effluents industriels. Élimination de la turbidité. Électrodes en aluminium. Polluant de l'eau. Protection de l'environnement.

1 INTRODUCTION

The dyeing fabric is a millenar technique. With technological development, several chemical components have been synthesized and produced with the aim of enhancing color fixation on the fabric. The main groups of dyes are classified according to the mode of fixation onto the fabric. All dyes have high water solubility, thus being easily detectable even in concentrations below 1 ppm (1 mg/L) (ZANONI and GUARATINI, 2000). The textil industry is responsible for producing great volumes of residual waters, containing not only dyes, but also surfactants, inorganic ions, humectant agents, among others. These substances alter the quality of superficial water, producing increases in turbidity. This turbidity reduces solar incidence and interfers with the biogeochemical cycles of life in the water (QUEIROZ, 2019).

In the face of more strict regulations and increased environmental awareness, companies strive to reinforce an environmentally more favorable image. They search for efficient and economically viable solutions to contemplate the parameters established by these resolutions. According to Resolution CONAMA N. 430 of May 13, 2011, industrial effluents contaminated by pollutants must be treated before being released into water bodies. They must be subject to adequate treatment, in order to attain minimally acceptable conditions for their discarding into the environment. Industrial effluents are classified in order to avoid their excessive contamination and their potential for causing disorders and eventual environmental disasters.

To improve the quality indexes for textil industry effluents, several techniques are being studied and applied. Physical treatments are characterized by methods acting on distinct phases: sedimentation, decantation, filtration, centrifugation and flotation of residues. There are also treatments using biological processes, adsorption, ionic change, and chemical oxidation, including advanced oxidation processes (DIAS et al., 2018; CUNHA et al., 2019). Yet these conventional processes require expertise, high investment and operational costs, and produce large quantities of secondary pollutors such as sludge.

Among existing technologies for the removal of pollutants from liquid effluents, electroflocculation, also known as electrocoagulation or electrocoagulation/flotation, is a technique used in the treatment of industrial effluents since the close of the nineteenth century. It has become increasingly used since then for the treatment of a diversity of types of effluents, from polluted subterranean waters to residual waters in highly contaminated dystilleries (MOUSSA, et al., 2017). Basically, this technique consists in using a low-cost reactor that is simple to operate, powered by electric energy to initiate reactions of oxidation/reduction on its electrodes. The metallic ions detached from the plates react with the contaminants present in the liquid medium and promote the destabilization of the particles (CRESPILHO and REZENDE, 2004; EZECHI et al., 2020). The energy normally used comes from hydroelectrical power plants and is converted into a continuous energy flow by an AC/DC source.

Because this procedure consumes a relatively large amount of energy, research has been conducted in order to make this process more viable economically. The challenge then becomes to find a technology that uses an alternative source of energy to feed the system.

A commonly used alternative source of energy is photovoltaic energy, in which the transformation of solar radiation into electricity occurs directly. The device used to convert solar energy into electricity is the photovoltaic cell. When associated with other similar cells, a photovoltaic panel is produced. Its capacity for the production of electric energy is proportional to the number of such panels connected in tandem or in parallel series, is a function of the incidence of solar radiation onto these panels (LOPEZ, 2012).

Regarding the efficiency of using photovoltaic cells as sources of electrical energy, reserchers such as Valero et al. (2003) corroborated the viability of this method for removing the reactive contaminant Remazed Red 133 from a textil effluent. They were able to remove more than 90% of this contaminant. Zhang et al. (2013) used photovoltaic cells to remove phosphate from natural water and confirmed the reduction of the original concentration of phosphates. Palácio et al. (2013) aimed at reducing ions of chrome present in effluents from electroplating, and were able to eliminate 99% of the chrome during a treatment of 58 minutes.

The aim of this work was to evaluate the applicability and efficiency of the process of electrocoagulation with the use of aluminum electrodes powered by photovoltaic energy, as an alternative energy source for the treatment of textile wastewater, and for the removal of turbidity.

2 MATERIALS AND METHODS

2.1 Wastewater

In this study, a model wastewater was prepared to simulate an industrial textile wastewater. In our experiment, we introduced Eriochrome T dye, diluted in water in the proportion of 20g/l. Turbidity, color, conductivity, and pH were measured with Standard Methods for Examination of Water & Wasterwater (APHA, 2005). Both untreated wastewater and water after the electrocoagulation process were analyzed in duplicate, the average values being reported.

2.2 Experimental Procedure

The experimental studies were carried out at the bach mode, using a 1L acrylic monopolar reactor with four aluminum electrodes (measuring 5x10 cm in width x length, and 4 mm in thickness). Experiments were divided into two parts. In the first, a conventional source of energy was used (Fig. 1a). In the second, a solar photovoltaic plate (Si, potency of 50W, maximum tension of 17,5 V, current of 2,3 A) was used as the source of energy (Fig. 1b). The connection of the solar plate to the reactor was made using wires of 1,5 mm, isolated with PVC, and connected to a stationary battery of 12 V, followed by a digital multimeter connected in series for the measurement of the current in the system. A further connection was made to the aluminum electrodes within the reactor. The photovoltaic plate was installed in the system in parallel to the ground, in order to obtain an optimal use of the local solar radiation.



(a) (b)

Figure 1 – Assembly of the system of electrocoagulation using (a) a conventional source of energy, and (b) a photovoltaic source of energy.

Auxiliary equipments used in the experimental studies were: multimeter, pH meter, WTW Cond 720 conductivity meter, and a magnetic stirrer. The following parameters were maintained constant in both experiments: pH of effluent, 6,5; conductivity of untreated effluent, 1,870 mS; distance among electrodes, 4mm; agitation during experimental time, 300 rpm; and tension, 12 V. In order to test the efficiency for the removal of turbidity, durations of 10, 20, and 30 min were tested. The value of the current during the time of testing was measured in order to calculate the energetic cost of the procedure.

3 RESULTS AND DISCUSSION

3.1 Effects of pH and Turbidity Removal

A recent publication (EZECHI, et al., 2020) indicates that the pH of the environment changes during the process of electrocoagulation, depending on the type of electrode and on the initial pH.

It is observed in electrocoagulation works such as in the work of Ezechi et al. (2020), that the pH of the medium changes during the electrocoagulation process depending on the type of electrode and the initial pH, according to that, in our study the initial pH of the effluent to be treated was fixed at 6.5, because a pH in the range between 6 and 7 leads to chemical coagulation effective maintained constant at 6.5, because it is known that an effective chemical coagulation occurs between 6 and 7, due to the formation of amorphous Al(OH)3(s) (equations 1 and 2). Such large surface areas are beneficial for rapid adsorption of organic compounds and for the imprisonment of colloidal particles (MOHOUEDHEN at al., 2008; HAKIZIMANA et al., 2017). The production of such stable compounds may

be predicted using the diagram E-pH for aluminum in different conditions.

Fig. 2 indicates that the pH at the end of the treatment increases in both the experiments with conventional electricity and with solar energy. This increase may be attributed to the evolution of hydrogen on the cathode, together with ions OH-, as expressed by equation 3 (MOUSSA et al., 2017), and observed in Fig. 3b.

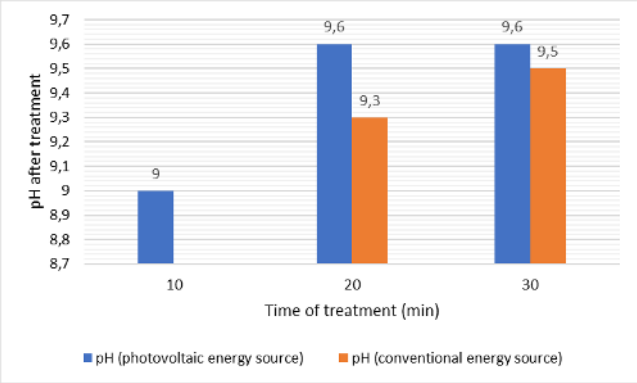
$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^{-1}$ Equation 1

$Al^{3+}_{(aq)} + nH_2O \rightarrow Al(OH)^{3-n}_{n} + nH^{+}$ Equation 2

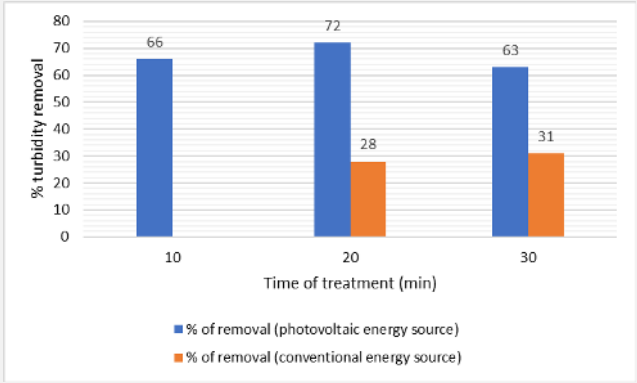
$2e^{-} + 2H_2O \rightarrow H_2 + 2OH^{-}$ Equation 3

According to Resolution CONAMA 430/11, conditions for the dumping of residual effluents into water bodies in the environment should have a pH between 5 and 9. As observed in this study, the untreated effluent lies outside this standard, and would have to be corrected with the addition of acids.

Figure 2 - Effect of pH (a) and efficiency of turbidity removal (b).



(a)



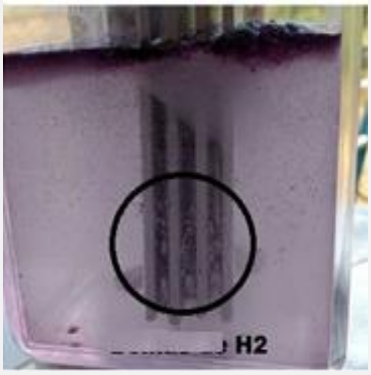
(b)

The synthetic effluent prepared with the dye Eriocrome T has a strong dark-red color (Fig. 3a). The turbidity analysis showed a value in the order of 1,92 NTU. We observed that the most efficient results of treatment, under both experimental designs, were obtained using the experimental time of 20 m (Fig. 2b).

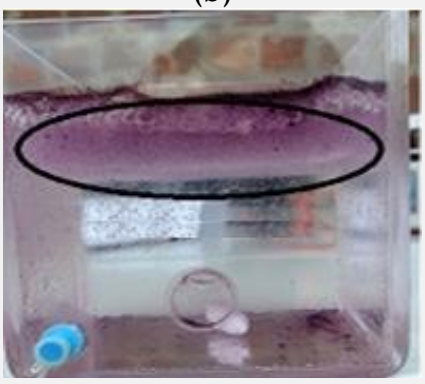
Figure 3 - Color of untreated effluent (a) and production of bubbles of H_2 during effluent treatment (b and c).



(a)



(b)



(c)

When using a time of 30 min for the experiments, we observed the appearance of flakes of gel in the treated suspension (Fig. 3c), for both experimental procedures (conventional electricity and solar energy). This indicates that shorter times are more efficient in removing turbidity. We were able to

establish an optimal time of 20 min for effluent treatments under both experimental procedures (Fig. 2b).

Gel formation is common in chemical treatments when coagulants are combined mainly with aluminum sulfates (Al2(SO4)3). Viana (2014) explains the phenomenon as a destabilization of particles by aluminum hydroxide. As pH and dosages of added flocculants increase, the hydroxide becomes insoluble. This insoluble substance takes the form of a gel in standing water. During the process of flocculation, the particles of this gel collides with the particles we wish to remove, adsorbing them.

Notwithstanding, Resolution CONAMA 430/11 does not establish a pattern of turbidity that should be adequate for dumping effluents into water bodies in the environment. It only recommends that turbitity should not exceed 100 NUT (nelephometric turbidity unit). Macedo (2002) indicates that dumping effluents of high turbidity into natural water bodies lowers light absorption and photosynthesis, interfering with the ecological equilibrium of the natural system, with the possible consequence of producing eutrophication of the environment.

3.2 Conductividy and Energy Consuption

According to Cerqueira (2006), the capacity for conducting electrical energy is proportional to the quantity of conductor ions present in the solution. Larger concentrations of ions increase the capacity for electric energy conduction. Possibilities for reactions among substances present in the solution are increased, and the requirement for energy input is reduced.

In this study, the conductivity in the untreated effluent was 1,870 mS, which is considered low for chemical reactions to occur in the reactor. Thus 20mg/L of sodium chloride were added during the effluent treatment before the beginning of the process of electrocoagulation/flotation.

Energy consumption is influenced by many factors, such as conductivity of the solution, the tension applied to the electrodes, the time of treatment, the distance among the electrodes, and others. Energy consumption is a parameter that directly influences costs. The longer the time of treatment, the higher the costs of the operation. In this study, we observed that, to treat 800 ml of effluents during 20 minutes, we have an energy consumption in the order of 6,623 kWh/m3. Taking into account a value of R$ 0,44026 as the cost of energy, the total cost for this time of treatment is R$ 2,915. For 30min of treatment, the consumption rises to 9,257 kWh/m3, at a cost of R$ 4,075.

On the other hand, feeding the reactor system with a source of photovoltaic energy, we observed that, for a time of 10 min, the consumption was in the order of 3,415 kWh/m3, and the cost was reduced to R$ 1,503 for the treatment of 800 ml. Increasing the testing time to 20 min, consumption was 6,374 kWh/m3, and the cost became R$ 2,806. At 30 min, consumption rose to 9,043 kWh/m3, at a cost of R$ 3,981. From these results, we conclude that the values of energy consumption are close, and the small difference observed occurred due to the stabilization of the application of tension in the photovoltaic source. This later source of energy feeds a battery that then feeds the system without variations in tension. On the other hand, the levels of tension when using a source of public electricity depends on the dealership. Furthermore, using photovoltaic energy avoids the public energy fee entirely. Studies still need to be conducted to evaluate the economic viability of the implementation of a project of electrocoagulation/flotation at an industrial scale.

In the process of electrocoagulation, costs are mainly the result of the use of electrodes, the consumption of energy, and of maintainance of the reactor. Yet, to calculate costs, only the material and energy need to be taken into account. To apply the process at an industrial scale, it is necessary to arrive at a realistic and viable alternative. Presently, consumption of electical energy is the factor that weights most on operational costs (KOBYA et al., 2011).

We are thus convinced that, proposing alternatives for reducing the costs of energy, we may stimulate new attempts to reduce pollution by industrial effluents. At the same time, we are contributing to the impacts that these sources of pollution are causing on our aquatic environments.

4 CONCLUSIONS

A solar powered electrocoagulation system was applied successfully in the treatment of a synthetic wastewater using aluminium electrodes. The following conclusions are drawn:

- The system of electrocoagulation/flotation proved to be adequate for the treatment of industrial textil effluents. Turbidity was reduced in 72%, the resulting effluents becoming almost transparent.

- Effluent conductivity is an important fator for the treatment system, because it is associated with a reduction in the costs of energy.

- A source of photovoltaic energy proved more efficient than traditional energy sources and, thus, economically more viable.

- The ideal time of treatment is 20 min with the tested parameters.

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