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Decolourisation of textile waste water by electrocoagulation process - a review

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ABSTRACT

Textile industry waste water from dyeing and finishing processes constitute a substantial source of water pollution which imparts intense colour, high chemical oxygen demand, fluctuating pH and other suspended particles. This coloured waste water must be treated before final discharge to attain legal standards. Conventional methods for removing dyes from industrial waste water consist mainly of biological and physiochemical treatments and their various combinations. Biological methods are cheaper than other methods but dye toxicity usually inhibits bacterial growth and limits therefore the efficiency of decolourisation. Physical methods usually need additional chemicals which produce secondary pollution and a huge volume of sludge. Water treatment based on electro coagulation technique has been recently proving to evade most of the problems also being economically attractive. This review deals with better understanding of the decolourisation of the textile waste water through Electrocoagulation process. Although there are various electrochemical methods for the treatment of waste water Electrocoagulation has proved to be a clean, versatile, selective, flexible and a powerful process. Decolourisation of the dyeing and finishing waste is greatly affected by the important operating parameters such as the current density, pH, dye concentration, treatment time, type of electrode material used, electrolyte and its concentration. Upon survey it is found that Electrocoagulation combined with other processes also has proved good in the improvement of the decolourisation efficiency.

Introduction

Effluent with high colour and high COD are common in chemical process industries such as textile, paper, leather and mineral processing industries. Electro coagulation is an alternative technology for waste water treatment and recovery of valuable chemicals from the waste water. Successful electro coagulation treatment of various industrial effluents has been reported by various researchers as it is considered to be potentially an effective tool for treatment of waste waters with high removal efficiency. The main drawback of the other technologies is that they generally lack the broad scope treatment efficiency that is required in reduction of all the diverse pollutants present in the textile waste water Timothy R. et al., (1988)[1]. The main advantages of the electro coagulation technology over the other conventional methods are: in situ delivery of the coagulants, no generation of secondary pollution and compact equipment with the time required for the treatment being very less. Conventional methods for treating dyeing waste water from textile industries consist mainly of physiochemical and biological treatments and their various combinations. Biological treatments are cheaper than other methods, but dye toxicity usually inhibits bacterial growth and thereby limits the efficiency of the decolorization. Physical methods include adsorption, coagulation–flocculation, chemical oxidation and photo degradation. These technologies usually need additional chemicals which cause secondary pollution and a huge volume of sludge. Water treatments based on electro coagulation technique has recently proved to evade most of these problems, also being economically attractive. It is well known for its simplicity, efficiency, environmental compatibility, safety, flexibility and cost effectiveness. Dyes in the textile waste water undergo chemicals as well as biological changes, consume dissolved oxygen from stream and destroy aquatic life because of their toxicity. Many textile manufacturers use dyes that release aromatic amines (e.g. benzidine, toluidine). Dye bath effluents contain high colour, heavy metals, ammonia, alkali salts and large amount of other pigments which are toxic.

Dyes can be commonly classified according to the fibers to which they can be applied, and their chemical nature as: 1.Acid dyes, 2.Reactive dyes, 3.Dispersive dyes Chen-Lu Yang (2005)[3]

Why Electrochemical technology?

Electrochemical waste destruction shows several benefits in terms of costs and safety. Most of the process under this

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technology runs at high efficiency and operates at the same condition for a wide variety of wastes. .J.Grimm et al., (1998)[2]

What is Electrocoagulation?

It is a process in which coagulant is generated in situ through electrolytic oxidation at anode material and charged ionic species are removed from waste water by allowing it to react with coagulates of metallic hydroxide generated within effluent. The three major reactions in an Electrocoagulation process.

- Electrolytic reactions at electrode
- Formation of coagulants
- Adsorption of pollutants and removal

From the previous literature it is clear that the suitable electrode for treatment through this process is Iron electrode or Aluminium. This is because of its easy availability, low cost and high removal efficiency.

State-of-the-art:

Decolourisation of the waste water from the textile industry is achieved through

- Optimisation of the operating parameters for colour removal efficiency.
- Usage of different types of electrodes.
- Electrocoagulation combined with other processes.
- Modification in various parameters.

Optimisation of the operating parameters for colour removal efficiency

Chen-Lu Yang & Jared McGarrahan (2005)[3] has carried out an experimental investigation in which reactive acid and disperse dyes were used. Both Aluminium and Iron electrodes were used for the experiment. NaCl was used as the electrolyte to increase the electrical conductivity and that has helped to promote production of coagulant. The results showed that most of the colour removal was due to adsorption and complexation. The authors suggest that Iron Electrocoagulation process is more effective for the colour removal of textile effluents whereas the Al Electrocoagulation is more effective for disperse dyes. The experiments proved that the presence of NaCl reduces the power consumption.

Zaroual Z., et al., (2005)[5] has made an attempt to study the feasibility of Electrocoagulation in treating textile waste water. The author has reported the effects of electrolysis time and electrolysis potential and also has reported that time and potential are the important operational parameters for the treatment efficiency. The zeta potential measurement demonstrated that iron hydroxide $Fe(OH)_2$ was responsible for the Electrocoagulation process. It was found that the removal efficiency of COD and colour depends on the quantity of iron (electrode) generated. From the results it is seen that the pH of the effluent does not change with electrolysis time. The iron concentration was determined using atomic absorption spectroscopy and zeta potential analyzer for determining the zeta potential of flocs formed during electrolysis.

Daneshwar N., et al (2006)[7] has carried out experiments in C.I. Basic Red 46 (BR46) to study the effect of operating parameters such as current density , initial pH, time of electrolysis, initial dye concentration and solution conductivity for higher removal efficiency. It is found that the colour removal was high when the pH was maintained between 5.5-8.5. The electrolysis time determined the production rate of Fe^{2+} or Fe^{3+} ions from the iron electrodes. From the results there was a good relationship between the colour removal efficiency and the electrolysis time and hence the predicted that the colour removal efficiency directly depends on the concentration of hydroxyl and metal ions produced on the electrodes. The author has found that the solution conductivity affects the current efficiency, cell voltage and hence was adjusted using NaCl.

Yalcin Sevki Yildiz (2008)15 has worked to determine dye removal from aqueous solution by Electrocoagulation using Al electrodes. The effect of five important operating parameters such as initial dye concentration and pH. supporting electrolyte concentration and its type and current density. The author has undergone variance analysis after the experimental analysis to determine the optimum levels. Then the Tauguchis formula has been employed. Bomaplex Red dye was used for which the absorbance was measured at 450nm before and after Electrocoagulation. The author also proposed that orthogonal array technique for experimental design reduces the number of experiments required to investigate a set of parameters and thereby minimizes time and cost.

Aoudj et al (2010)[20] in this work, electro coagulation was applied for the colour removal of solutions containing Direct red 81. Experiments were performed for synthetic solutions in batch mode. The study focuses on the effect of following operational parameters electrolysis time -60mincurrent density - 1.875 mA/cm^2 initial pH - 6 inter-electrode distance 1.5cm initial dye concentration (and type of supporting electrolyte (NaCl). In best conditions, high decolouration efficiency was obtained, reaching more than 98% of colour removal. Fourier transform infrared spectroscopy (FTIR) analysis was used to characterize the residual EC by-product.

Senthilkumar et al (2010)[21] This paper deals with the batch removal of reactive red 120 dyes by electrocoagulation method using stainless steel electrodes. Electrocoagulation using stainless steel electrodes was found to be more effective particularly for the color removal. The effects of following parameters were identified initial pH -8 currentdensity-50A/m^2 electrolytes-Nacl electrolysis time – 15 minThe increase of current density up to 50 A/m^2 enhanced the color and COD removal. NaClelectrolyte was found to be the best suited electrolyte for the electrocoagulation process. The dominant mechanism of color and COD removal from the reactive red 120 dye by electrocoagulation process found to follow coagulation and adsorption at pH values from 6 to 8. It was found that EC process under the optimum conditions was able to attain a COD removal of nearly 74% and color removal of more than 98%.

Durango, et al (2010)[25] An experimental design methodology has been applied to evaluate the decolourization of crystal violet (CV) dye by electrocoagulation using iron or aluminium electrodes. The effects and interactions of four parameters initial pH (3-9), current density (6-28 A /m^2), substrate concentration (50-200 mg/L) supporting electrolyte concentration (284-1420 mg/ l of Na2SO4), were optimized and evaluated. Although the results using iron anodes were better than for aluminium, the effects and interactions of the studied parameters were quite similar. With a confidence level of 95%, initial pH and supporting electrolyte concentration showed limited effects on the removal rate of CV, whereas current density, pollutant concentration and the interaction of both were significant. Under optimal conditions, almost complete removal of CV and chemical oxygen demand were obtained after electrocoagulation for 5 and 30 min, using iron and aluminium electrodes, respectively. These results indicate that electrocoagulation with iron anodes is a rapid, economical and effective alternative to the complete removal of CV in waters.

Kobya et al (2010)[23] The paper demonstrated the applicability of the electrocoagulation method for the removal of reactive dye, Remazol Red 3B, in a batch study. Iron electrode material was used as a sacrificial electrode in monopolar parallel mode in this study. The effects of the following operating parameters has been investigated initial pH – 6 current density - 15 mA cm^{-2} initial concentration of dye - and 500 mg l-1 electrolysis time - 10 min High decolorisation efficiency (> 99%) for Remazol 3B dye solution was obtained with the above optimal value of process parameters. The energy consumption, electrode consumption and operating costs under optimum operating conditions were calculated as 3.3 kW h/ kg dye, 1.2 kg Fe/ kg dye and 0.6 euro/ m^3, respectively.

Ahlawat et al (2008)[26] This study was performed to investigate the variables that influence the removal efficiency of an acid dye, i.e., cotton blue (CB) (chemical name: aniline blue WS) dye, from aqueous solution by an electrocoagulation (EC) technique. Batch EC studies were performed using aluminum electrodes to evaluate the influences of various experimental parameters, i.e., initial pH (pH(0)): 3-11, electrolysis time (t): 0-30 min, initial concentration (C-0): 100-1000 mg/L, electrode gap (g): 0.5-1.3 cm, number of electrodes (N): 4 - 10, and applied voltage (V-ap): 7-11 V, on the removal of CB dye. The optimum values of pH (0), V-ap and t for CB removal were found to be 6.0, 11 V and 15 min, respectively. The removal efficiency increased with decreasing values of C-0 and g. For a CB solution having C-0 = 100 mg/L, 97% removal efficiency was obtained at the optimized conditions. It was found that the EC sludge can be dried and thermally degraded. The bottom ash obtained after its combustion can be blended with cementitious mixtures. This approach for EC sludge disposal ensures energy recovery along with safe disposal of the EC sludge.

Saravanan, et al (2010)[24] The electrocoagulation (EC) treatment of Acid Blue 113 (AB 113) was performed on the basis of chemical oxygen demand (COD) removal efficiency using an iron anode. The process variables including current density -3 A/dm^2 pH -6.5 electrolyte concentration -2 g/L were investigated. Under the optimum operating conditions, more than 91% COD removal efficiency was found. COD removal rates obtained during the EC process can be described using a pseudo-kinetic model. The experimental kinetic data fit well with pseudo first-order kinetic model, with no significant change on the rate constant after 3 A/dm^2 of current density. The absorption spectra and Fourier transform infra red analysis were also performed to characterize the mechanism and nature of dye cleavage.

Bayramoglu M et al., (2007)[10] presented results of a comparative study made for economic performance by Electrocoagulation process with reference to the electrode configurations. In the study Al and Fe electrodes were used in both parallel and serial mode. The results has clearly depicted that a monopolar- parallel connection is the most effective for both Al and Fe electrodes. Also the highest electrode consumption was with the bipolar electrode connection. It was found through the results that operating cost of chemical coagulation is 3.2 times higher than Electrocoagulation. The author has also suggested that slightly acidic medium (pH 5) is required for Al electrode and that for Fe electrode was a neutral medium (pH 7).

Usage of Different Electrodes

Aluminium

Kobya M et al., (2006)[8] has made an attempt for the decolourisation of the levafix orange dye solution using aluminium electrode. The important operating parameters considered were the electrolysis time, initial pH, current density, dye concentration for maximum decolourisation of the reactive dye. It was found that pH is an important operating parameter that affects the efficiency of the process. As the pH increased greater than 9 the efficiency of the process decreased. It is also found that both the energy and electrode consumption increased with increasing the operating time.

Idil Arslan et al (2008)[16] has experimented for the treatment of real reactive dye bath effluent by electrocoagulation using Al and stainless steel electrodes. Results indicated that treatment efficiency was enhanced by increasing the applied current density using Al electrodes whereas there was no correlation existed using stainless steel electrodes. Also the author has pointed out that Electrocoagulation with stainless steel was superior for decolourisation than aluminium whereas aluminium was found good for COD removal with respect to electrical energy consumption.

Kabdasli et al (2009)[29] In this paper, application of electrocoagulation using common electrode materials (aluminum and stainless steel) to a simulated reactive dyebath effluent was investigated. A single dyestuff was employed to reflect actual reactive dyeing conditions. Experimental study focused on the effect of individual reactive dye bath components on color and COD removal rates and efficiencies by electrocoagulation. Electrocoagulation using stainless steel electrodes was found to be more effective particularly for color abatement. Na_2CO_3 significantly reduced the process efficiency both in terms of color and COD removals. An adverse effect on COD removal efficiency was also observed for the sequestering agent. On the other hand, increasing the NaCl concentration not only enhanced color and COD removal efficiencies. The dominant mechanism of color and COD removals from reactive dyebath effluent by electrocoagulation seemed to be coagulation and adsorption at pH values above 11.

Modification of various parameters

pH

Kashefialasi M et al., (2007)[9] reported the results of decolourisation of dye solution (Acid Yellow 36) by electrcoagulation. According to the results with increase in the dye concentration the colour removal percent decreases. The author predicted that when the pH is less than 6, $Fe(OH)_3$ is in soluble form and when the pH is greater than 9 $Fe(OH)_3$ is in soluble form. Hence it is found that $Fe(OH)_3$ has the major role in the removal of colour. Therefore when the pH is maintained between 6- 8 the colour removal is high.

Saez et al (2010)[28] The aim of this work has been to study the influence of small changes in the pH of kaolin suspensions on the efficiency of batch coagulation with aluminum. From the results obtained, it seems clear that the raw pH conditions of the wastewater are important to explain the results of batch coagulation processes because they influence on the speciation and coagulation mechanisms, and thus on the efficiency of the coagulation process. In the particular case studied, the small differences in the initial pH are enough to explain a change in the primary mechanisms from a very cost-effective precipitation-charge-neutralization to a less efficient floc-enmeshment mechanism. Thus, a change of 1 unit of pH in the raw wastewater is enough to decrease the dose of aluminum necessary to obtain similar removal efficiencies (around 85%) from 12 to 2 mg Al $/dm^3$. Hence a good knowledge of the system could allow optimizing the performance of operation processes.

Electrocoagulation assisted by other processes

Shuang Song et al (2007)[13] evaluated the variables that influence the efficiency of colour removal for an azo dye (CI Reactive Black 5). The author has obtained results by the combination of the ozonation and electrocoagulation process using iron electrodes. Important working parameters such as initial pH (5.5), current density ($10mA/cm^2$), salt (K_2SO_4) concentration (5000mg/l), ozone flow rate20ml/min), distance between the electrodes (1cm) and initial dye concentration (100mg/l) were studied for high colour removal efficiency. Iron electrodes immersed in dilute H_2SO_4 washed thoroughly with pure water and finally polished with sand to remove oxide. After reaction the sample were centrifuged at 2000rpm and then analysed at 597nm. The author has compared the results of three process ozonation, electrocoagulation and combined ozonation electrocoagulation. The results indicated that ozone could accelerate the rate of colour removal by Electrocoagulation process. The author suggested that the kinetics of Fe^{2+} conversion to Fe^{3+} is affected by pH. Current density could be limited to certain extent to avoid excessive oxygen evolution and heat generation.

Zodi et al (2009)[27] This paper deals with treatment of industrial wastewaters by electrocoagulation technique, with emphasis on settling process. The influence of electrode material, current density, pH, treatment period on the sludge settling characteristics has been investigated. The wastewater issued from textile industry is characterized by its high suspended solids content (SS), its high turbidity (NTU) and a fair chemical oxygen demand (COD). The wastewater treatment process consisted in a preliminary electrocoagulation step, followed by a settling step conducted without addition of flocculating agents. Sludge settling velocity after electrocoagulation was measured depending on the operating conditions. The sludge settling data were utilized to compare the efficiency of various empirical models for estimation of sludge settling velocity. Finally, the sludge aptitude to settling was studied in terms of sludge volume index (SVI) to determine the best operating conditions.

Ashtoukhy E.S, Amin (2010)[30] In this study acid green dye 50 is used for investigation. A comparative study of the electro oxidation process and electrocoagulation in a batch mode has been carried out. Effect of the operating parameters such as has been investigated. Electrocoagulation is found to be more economic compared to electro oxidation. The energy consumption for electrocoagulation is 2.8 – 12.8 KWh/kg and for electrooxidation is 3.31-16.97KWh/kg. The first order rate equation was exhibited for both the process.

Chang, Shih- Hsien et al (2010)[31] Treatment of an azo dye Reactive Black RB5 by a combined electrocoagulation- activated carbon adsorption was evaluated. The toxicity was monitored by the Vibrio fischeri light inhibition test.GAC adsorbed 82% of the RB5 within 4 hrs. Electro coagulation showed high decolourisation of RB5 within 8 min with current density- $277A/m^2$, pH – 7, NaCl - 1g/l

Conclusion

In this paper from the earlier days till the recent developments in the field of electrocoagulation process for the decolourisation of textile waste water has been discussed. The research work carried out by various investigators so far in this area are categorized as (i) Optimisation of the operating parameters for colour removal efficiency (ii) Usage of different types of electrodes (iii) Electrocoagulation combined with other processes (iv)Modification of various parameters. The results showed that for different conditions such as the process time, pH, and different value of current the removal efficiency varied. With increase in the current there is a high removal rate. Also the pH had influence on the removal efficiency. At pH from 6 the efficiency started increasing and at high pH greater than 8 the removal efficiency started decreasing. Only at an optimum pH of approximately 8 there is high removal efficiency for most categories of the dyes. The literature reveals that at different increased process time the rate of removal is higher. Finally it can be concluded that electro coagulation method is a safe, reliable, efficient and cost effective method for removal of color. Also the results showed that electrocoagulation is a faster and more effective process than other methods.

The major operating parameters influencing the EC process includes pH, current density, treatment time, type of electrode etc

- ✓ pH is to maintained at an optimum level between 4-8 for effective colour removal.(Chen etal 2005)
- ✓ Current density when increased to a certain level the RE increases after which it starts decreasing.(Zaroaul etal 2006)
- ✓ Al is more effective for reactive and disperse dyes whereas Fe or other electrodes may be suitable for other dye.

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