Pollution, 3(3): 517-526, Summer 2017
DOI: 10.7508/pj.2017.03.015
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Assessment of effective operational parameters on dyeing wastewater treatment by electrocoagulation process

Shahriari, T.* and Saeb, B.

Faculty of Environment, University of Tehran, Tehran, Iran

Received: 22 Feb. 2017 Accepted: 8 Apr. 2017

ABSTRACT: A wide range of chemicals and dyes are being used in textile industry, and are often found in the wastewater produced. This study attempts to investigate the reduction of COD, TSS, and dye in effluents from the dyeing and washing unit of textile industry, using electrocoagulation process. The reactor is equipped with 10 iron electrodes, connected to a direct current (DC) source in a monopolar electrode configuration. In each stage of the experiment, 2.5 l of the effluent enters the reactor and the effects of a number of important operational parameters such as voltage, pH, and reaction time is studied on the removal of COD, TSS, and dye parameters. Results show that the optimum operational conditions are reaction time of 120 min, voltage of 30 V, and pH of 7, which reduces COD, TSS, and dye by 87%, 91%, and 98%, respectively. Therefore, it has been concluded that the efficiency of pollutants removal from the wastewater improves as voltage and reaction time are increased.

Keywords: dyeing wastewater, electrocoagulation, pH, time, voltage.

INTRODUCTION

The volume of water, used in textile industry, has increased with the expansion of this industry. It has been estimated that in order to produce one kilogram fabric, as much as 40-65 L of wastewater is generated, while this aftermath is one of the important sources to contaminate surface water and groundwater resources (Imran et al., 2015; Phalakornkule et al., 2010). The textile industry produces wastewater in very different quantities and qualities, for it employs various production methods, dyes, and chemicals. Large quantities of wastewater, produced in this industry, contain various dyes, potentially toxic to all forms of life (Daassi et al., 2013; Danwittayakul et al., 2015; Kabra et al., 2012; Manenti et al., 2014). Moreover, this wastewater includes heavy metals and organic pollutants, the amount of which depends on the type of the used dyes or chemicals (Shehzadi et al., 2014; Zaharia & Suteu, 2013). The use of various nano-materials for treatment of various wastewaters is under investigation (Fathi et al., 2016). Discharge of colored wastewater into receiving waters leads to reduced sunlight penetration into water, causing eutriphication phenomenon, and interfering with the ecology of these bodies of water. This can damage the environment in addition to influencing the photosynthesis rate of aquatic plants and algae in aqueous environments. Therefore, this type of wastewater must be desirably treated before being discharged into the environment (Dasgupta et al., 2015;

* Corresponding author Email: Tshshahriari@ut.ac.ir

Shamsnejati et al., 2015; Verma et al., 2012). Numerous processes have so far been used to treat this type of wastewater, including precipitation, adsorption by activated carbon, chemical oxidation, membrane processes, and biodegradation processes (Belkacem et al., 2008; Ellouze et al., 2012; Eren et al., 2012; Kobya & Demirbas., 2015; Silva et al., 2016). Electrocoagulation process is another method to remove pollutants from water and wastewater. It has attracted a substantial interest, thanks to its good performance when treating large volumes of water and wastewater at a low cost (Sahu et al., 2014). Electrocoagulation is used to treat the wastewater from pharmaceutical industry (Deshpand et al., 2010), landfill leachate (Kabuk et al., 2014), electroplating wastewater (Verma et al., 2013), and laundry wastewater (Janpoor et al., 2011). Along with these processes, bubbles of hydrogen gas produced at the cathode entrap the pollutants, bringing them up to the surface of the wastewater (Cerqueira et al., 2009; Un & Aytac, 2013). In the recent years some new views of environmental pollution prevention have been developed in Iran (Karbassi et al., 2016a; 2016b). We hope that the present investigation can meaningfully add more practical measures in this direction.

The effluents from the dyeing and washing unit of textile industry is used in this study to investigate the effect of electrocoagulation process on the removal of COD, TSS, and dye pollutants.

MATERIALS AND METHODS

Samples of wastewater were taken from the dyeing and washing unit of Alipoosh Textile Factory, which produces worsted fabric and uses disperse dye. Table 1 presents the characteristics of the initial tested wastewater.

A three-liter Plexiglas pilot was constructed with iron electrodes, having the following dimensions: $0.2\times8\times12$ cm^3. These were 2 cm apart and had a monopolar electrode configuration inside the reactor. A HUA ELECTRONICS converter (model DC POWER SUPPLY HY3003-F), capable of adjusting the voltage from zero to 40 V was used to apply the desired voltage to the electrocoagulation reactor. A magnetic stirrer (model RCT Basic made by the German company, IKA) was employed to mix the wastewater. Also the utilized products in this experiment were originated from the German company, Merck. They included 1N sulfuric acid and sodium hydroxide for adjusting the pH as well as hydrochloric acid for washing the blades. Figure 1 shows the schema of the used reactor.

Table 1. Summary of physico-chemical characterization of textile effluent

Characteristics	Value
Chemical Oxygen Demand (COD)	691 (mg/L)
Total Suspended Solids (TSS)	301 (mg/L)
Dye	922 (mg/L)
pH	7.55

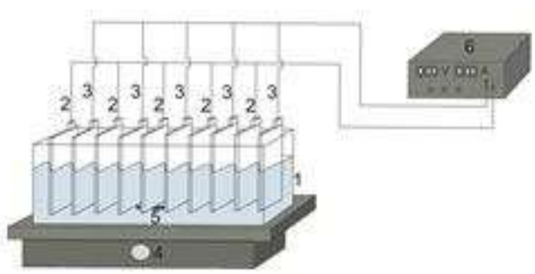

Fig. 1. Electrocoagulation reactor with monopolar electrodes
1- Electrical coagulation cell 2- Cathode 3- Anode4- Magnetic stirrer 5- Magnetic bar-stirrer 6- Direct current source

In each stage of the experiment, 2.5 L of the wastewater was poured into the reactor which was equipped with a discharge valve for taking samples during the treatment process. After performing each electrocoagulation experiment, the content of the reactor was given 45 min to settle and then the samples were taken, to be poured into 100cc containers and kept at 4˚C. Electrocoagulation processes were carried out in reaction time periods, which lasted 15-120 min, at voltages of 10-40 V, and with pH values of 3-9.

The Reactor Digestion Method (Franson, 2005) was employed and a HACH DR 5000 spectrophotometer was used to measure COD values in order that the effect of each mentioned parameter could be studied. Moreover, the dye was measured using the HACH DR 5000 spectrophotometer. Employing the standard platinum-cobalt (Pt-Co) method, pH values were determined, using a pH-meter (model Metrohm 691, made in Switzerland) (Franson, 2005), and TSS values were measured following the standard gravimetric method (Franson, 2005). To guarantee the accuracy of the obtained results, each experiment was performed three times. Furthermore, the standard deviation was in the range of 0.5 to 0.8. Excel 2010 was used to plot the related diagrams.

RESULTS AND DISCUSSION

The pH of about 7 was used to determine the optimum reaction time of the experiments at a voltage of 30 V. As shown in Tables 2-4, efficiencies of COD, TSS, and dye removal from the wastewater, obtained from the dyeing and washing unit of the textile factory improved as the reaction time rose. COD, TSS, and dye removal efficiencies improved from 42%, 55%, and 93% to 87%, 91%, and 98%, respectively, when the reaction time increased from 15 to 120 min.

Table 2. COD removal efficiency in the electrocoagulation process at various reaction times

Time (min)	Voltage (V)	Initial pH	Initial COD (mg/L)	Removal Percentage (%)
15	30	7.09	691	42.69
30	30	7.15	691	68.5
45	30	6.89	691	71.15
60	30	7.05	691	74.19
75	30	7.18	691	77.42
90	30	7.35	691	79.59
105	30	7.34	691	83.88
120	30	7.22	691	87.79

Table 3. TSS removal efficiency in the electrocoagulation process at different reaction times

Time (min)	Voltage (V)	Initial pH	Initial TSS (mg/L)	Removal Percentage (%)
15	30	7.09	301	55.04
30	30	7.15	301	56.82
45	30	6.89	301	64.15
60	30	7.05	301	73.02
75	30	7.18	301	75.14
90	30	7.35	301	81.9
105	30	7.34	301	87.79
120	30	7.22	301	91.34

Table 4. Dye removal efficiency in the electrocoagulation process at different reaction times

Time (min)	Voltage (V)	Initial pH	Initial Dye (mg/L)	Removal Percentage (%)
15	30	7.09	922	93.66
30	30	7.15	922	94.23
45	30	6.89	922	94.95
60	30	7.05	922	95.82
75	30	7.18	922	96.97
90	30	7.35	922	97.69
105	30	7.34	922	98.05
120	30	7.22	922	98.88

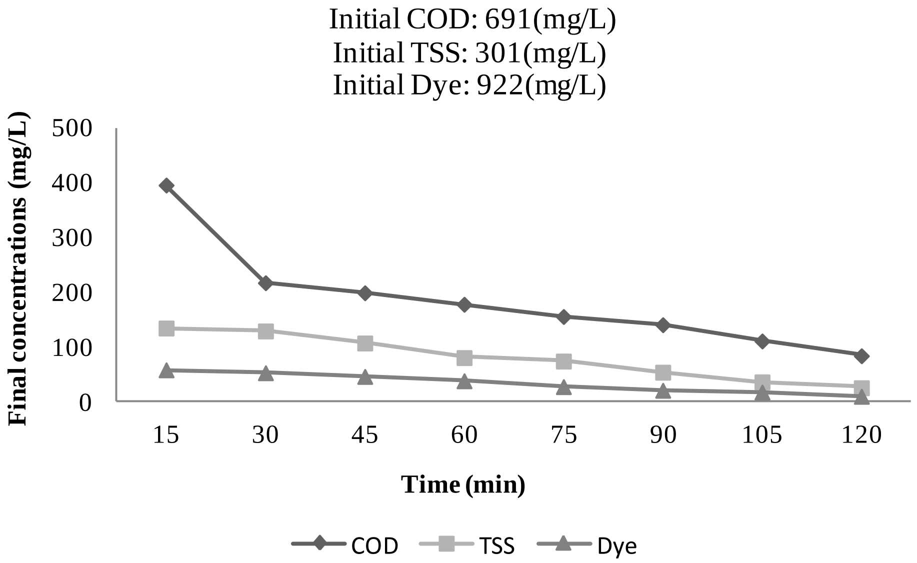

Fig. 2. Comparison of TSS, COD, and dye removal from the wastewater by electrocoagulation process at various reaction times

Figure 2 also shows that the removal efficiencies of COD, TSS, and the dye from the wastewater, obtained from the dyeing and washing unit, improved as the reaction time was increased, because the extent of oxidation rose as electrolysis duration became longer, thus increasing the concentration of the produced ions. This, in fact, induced the formation of metal hydroxide (iron hydroxide in this case) flocs, leading to higher efficiencies in the removal of the mentioned parameters. Al-Shannag et al. (2014) studied COD reduction in baker's yeast wastewater, using electrocoagulation method. They concluded that percentages of COD removal improved when the reaction time increased from 10 to 50 min. Furthermore, a study, conducted in 2014 on COD removal from tannery wastewater using aluminum and steel electrodes, showed that COD removal ascended by 82.2% for aluminum and by 67.4% for steel electrodes when reaction time rose from 5 to 45 min (Varank et al., 2014). Results from the above-mentioned studies, which indicated the improvement of removal percentages with the increases of electrolysis duration, confirm the results of the present study. Results of the experiments showed that the best reaction time for wastewater treatment was 120 min.

The voltages, used to study the effect of voltage on the electrocoagulation process, ranged from 10 to 40 V. As shown in Tables 5-7, efficiencies of COD, TSS, and dye removal from the wastewater got better; similarly the removal percentages of COD, TSS, and dye improved from 40%, 65%, and 57% to 95%, 94%, and 99%, respectively, when the voltage was increased from 10 to 40 V.

Table 5. COD removal efficiency in the electrocoagulation process at different voltages

Time (min)	Voltage (V)	Initial pH	Initial COD (mg/L)	Removal Percentage (%)
120	10	6.85	691	40.23
120	20	7.13	691	66.42
120	30	7.22	691	87.79
120	40	7.05	691	95.03

Table 6. TSS removal efficiency in the electrocoagulation process at different voltages

Time (min)	Voltage (V)	Initial pH	Initial TSS (mg/L)	Removal Percentage (%)
120	10	6.85	301	65.37
120	20	7.13	301	80.46
120	30	7.22	301	92.78
120	40	7.05	301	94.77

Table 7. Dye removal efficiency in the electrocoagulation process at different voltages

Time (min)	Voltage (V)	Initial pH	Initial Dye (mg/L)	Removal Percentage (%)
120	10	6.85	922	57.31
120	20	7.13	922	79.71
120	30	7.22	922	98.91
120	40	7.05	922	99.49

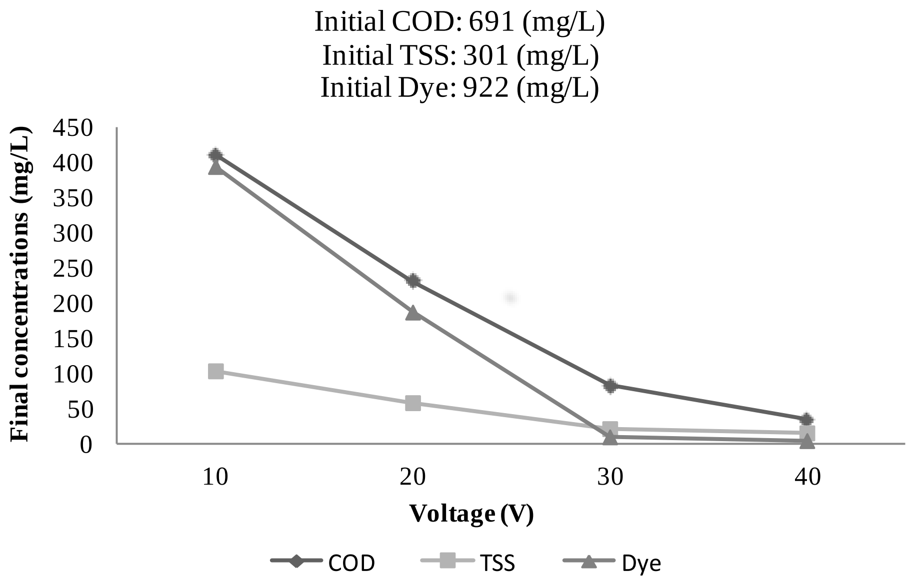

Fig. 3. Comparison of TSS, COD, and dye removal from the wastewater by electrocoagulation process at various voltages

In all electrochemical processes, the applied voltage is one of the important parameters to control reaction rate in electrochemical reactors. As shown in Figure 3, removal efficiencies of the studied pollutants improved with an increase in voltage. In fact, at low voltages, less iron hydroxides were produced, thus the lower removal efficiencies; however, production of iron hydroxides improved as the voltage increased, which raised the removal efficiencies. Furthermore, the number of bubbles produced on the surfaces of the electrodes increased and the bubbles became smaller as the current density rose. Consequently, the effective surfaces of the bubbles as well as their residence time increased, improving the pollutants' removal efficiencies. This variable determines the extent of coagulant production, also adjusting the number of hydrogen gas bubbles produced, hence influencing the removal percentages of the pollutants (Bazrafshan et al., 2007).

In 2016, results of a study, conducted to determine the effects of voltage parameter on percentages of COD and TSS removal from dairy wastewater by means of electrocoagulation method, indicated that the removal percentages of these two parameters improved as the voltage ascended up to 25 V (Kandasamy et al., 2016). Bazrafshan et al. (2016) carried out a study, using a combination of chemical coagulation, electrocoagulation, and adsorption, with their results showing that the removal percentages of pollutants from textile wastewater improved as the applied voltage rose, reaching 93%, 88%, and 98% for COD, BOD, and dye, respectively (Bazrafshan et al., 2016). These studies on the effects of voltage confirm the results obtained in the present study. Comparing the experiments' results showed that the optimum voltage was 30 V.

Considering the results of the previous experiments, in order to determine the effect of pH parameter, the experiments were carried out at a reaction time of 120 min, a voltage of 30 V, and solution pH values of 3, 5, 7 (the approximate initial pH value of the wastewater), and 9. As it can be seen in Tables 8-10, removal percentages of COD, TSS, and dye were higher at pH= 7 (the initial pH of the wastewater) because more iron hydroxide was produced at this pH and operations of charge neutralization took place, raising the COD, TSS, and dye removal from 41%, 86%, and 74% to 87%, 91%, and 99%, respectively, when the pH increased from 3 to 7. Removal efficiencies declined at higher pH values and percentages of COD, TSS, and dye removal, dropping from 87%, 91%, and 99% to 9%, 86%, and 35%, respectively, when the pH was raised from 7 to 9.

Table 8. COD removal efficiency in the electrocoagulation process at different pH values

Time (min)	Voltage (V)	Initial pH	Initial COD (mg/L)	Removal Percentage (%)
120	30	2.85	691	41.82
120	30	5.13	691	69.36
120	30	7.22	691	87.36
120	30	9.08	691	9.98

Table 9. TSS removal efficiency in the electrocoagulation process at different pH values

Time (min)	Voltage (V)	Initial pH	Initial TSS (mg/L)	Removal Percentage (%)
120	30	2.85	301	86.79
120	30	5.13	301	89.67
120	30	7.22	301	91.89
120	30	9.08	301	86.57

Table 10. Dye removal efficiency in the electrocoagulation process at different pH values

Time (min)	Voltage (V)	Initial pH	Initial Dye (mg/L)	Removal Percentage (%)
120	30	2.85	922	74.74
120	30	5.13	922	88.56
120	30	7.22	922	99.02
120	30	9.08	922	35.95

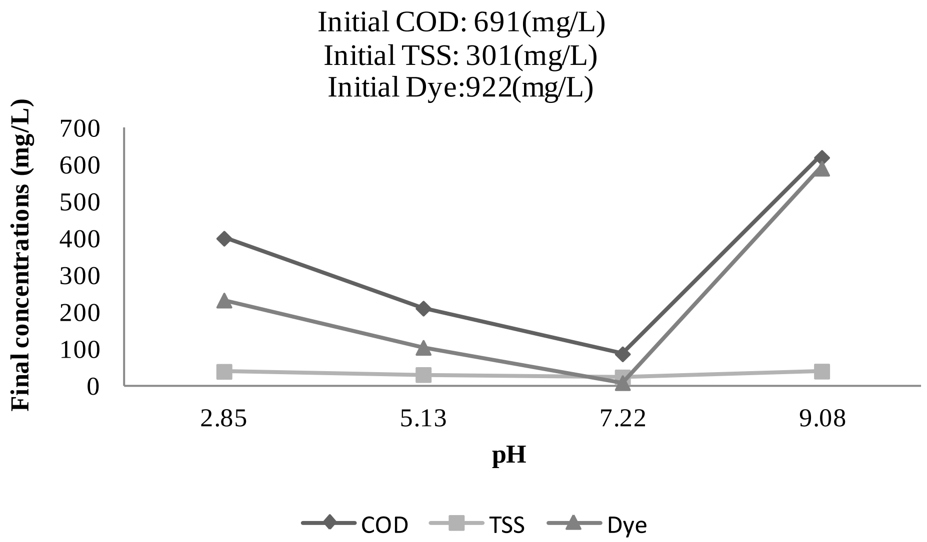

Fig. 4. Comparison of TSS, COD, and dye removal from the wastewater by electrocoagulation process at various pH values

According to the results of Fig. 4, the highest removal efficiencies of COD, TSS, and dye were achieved at pH of about 7. One of the most important parameters and indices, affecting the trend of electrocoagulation process is pH of the wastewater, entering the reactor, whose effect on pollutants removal depends on the formation of complexes along with the production of various metal hydroxides, such as $Fe(OH)^{+}_{2}$ and $Fe(OH)_3$, produced under acidic and neutral conditions, not to mention $Fe(OH)^{-}_{4}$, produced under alkaline conditions (Akyol, 2012; Akyol et al., 2013). $Fe(OH)_3$ performs better in adsorbing pollutants. That is why pollutants removal efficiencies decline under alkaline pH as $Fe(OH)^{-}_{4}$ negatively influences the removal efficiency in electrocoagulation, thanks to its electrical repulsion (Pirkarami et al., 2013; Thirugnanasambandham et al., 2014). Al-Shannag et al. (2014) studied reduced levels of COD in baker's yeast wastewater, using electrocoagulation method, and concluded that the COD removal percentage improved up to pH=4, then remained almost constant from pH value of 4 to 8, eventually to decline at higher pH values. In a review study on industrial wastewater treatment using the electrocoagulation method, one of the results indicated that, when treating textile wastewater by this method, the removal percentage of disperse red dye improved and reached 85% when pH increased from 6 to 9, while COD removal percentage also rose to 80% (Kabdasli et al., 2012). This indicated that removal of COD and dye took place in a parallel operation. Moreover, the removal percentages of these pollutants declined at pH>9 (Kabdasli et al., 2012). Ghanbari et al. (2014) studied textile wastewater treatment and noticed that dye removal percentage improved when pH of the solution increased from 4 to 7. They also concluded that increasing pH values from 7 to 9 at a constant reaction time, reduced the efficiency of dye removal. In their study, they found out that simultaneous use of iron and aluminum electrodes led to optimum flocculation at pH=7. In the present study too, the pollutant removal efficiency was at its maximum level at pH=7, and the reduction of removal efficiency occurred under alkaline conditions.

CONCLUSION

This study investigated the removal of COD, TSS, and dye parameters from the dyeing and washing unit of a textile factory. Studying the effects of some parameters such as reaction time, voltage, and pH showed that removal percentages improved as the reaction time and voltage rose, which was due to increased anode corrosion as well as higher production rate of metal hydroxide ions that result from anodes' ionization. Moreover, it was found that the best pH for the pollutants removal was 7, because at this pH value, iron oxide was in the form of $Fe(OH)_3$, a gelatinous hydroxide, playing an effective role in pollutants removal; therefore, it was concluded that the use of electrocoagulation process is a suitable method to treat dyeing wastewater.

Acknowledgements

The authors would like to express their deep gratitude to the directors of Alipoosh Textile Factory for their cooperation in conducting this research.

References

Akyol, A. (2012). Treatment of paint manufacturing wastewater by electrocoagulation. Desalination, 285, 91-99.

Akyol, A., Can, O.T., Demirbas, E. and Kobya, M. (2013). A comparative study of electrocoagulation and electro-Fenton for treatment of wastewater from liquid organic fertilizer plant. Sep. Purif. Technol., 112, 11-19.

Al-Shannag, M., Al-Qodah, Z., Alananbeh, K., Bouqellah, N., Assirey, E. and Bani-Melhem, K. (2014). COD reduction of baker's yeast wastewater using batch electrocoagulation. Environ. Eng. Manage. J., 13(12), 3153-3160.

Bazrafshan, E., Alipour, M.R. and Mahvi, A.H. (2016). Textile wastewater treatment by application of combined chemical coagulation, electrocoagulation, and adsorption processes. Desalin. Water. Treat., 57(20), 9203-9215.

Bazrafshan, E., Mahvi, A.H., Nasseri, S. and Shaieghi, M. (2007). Performance evaluation of electrocoagulation process for diazinon removal from aqueous environments by using iron electrodes. J. Environ. Health. Sci. Eng., 4(2), 127-132.

Belkacem, M., Khodir, M. and Abdelkrim, S. (2008). Treatment characteristics of textile wastewater and removal of heavy metals using the electroflotation technique. Desalination, 228(1), 245-254.

Cerqueira, A., Russo, C. and Marques, M.R.C. (2009). Electroflocculation for textile wastewater treatment. Braz. J. Chem. Eng., 26(4), 659-668.

Daassi, D., Mechichi, T., Nasri, M. and Rodriguez-Couto, S. (2013). Decolorization of the metal textile dye Lanaset Grey G by immobilized white-rot fungi. J. Environ. Manage., 129, 324-332.

Danwittayakul, S., Jaisai, M. and Dutta, J. (2015). Efficient solar photocatalytic degradation of textile wastewater using ZnO/ZTO composites. Appl. Catal. B: Environ., 163, 1-8.

Dasgupta, J., Sikder, J., Chakraborty, S., Curcio, S. and Drioli, E. (2015). Remediation of textile effluents by membrane based treatment techniques: a state of the art review. J. environ. Manage., 147, 55-72.

Deshpande, A.M., Satyanarayan, S. and Ramakant, S. (2010). Treatment of high-strength pharmaceutical wastewater by electrocoagulation combined with anaerobic process. Water. Sci. Technol., 61(2), 463-472.

Ellouze, E., Tahri, N. and Amar, R.B. (2012). Enhancement of textile wastewater treatment process using nanofiltration. Desalination, 286, 16-23.

Eren, B., Ileri, R., Dogan, E., Caglar, N. and Koyuncu, I. (2012). Development of artificial neural network for prediction of salt recovery by nanofiltration from textile industry wastewaters. Desalin. Water. Treat., 50(1-3), 317-328.

Fathi, S., Rezaei Kalantary, R., Rashidi, A. and Karbassi, A. (2016). Hexavalent chromium adsorption from aqueous solutions using nanoporous graphene/Fe3O4 (NPG/Fe_3O_4: modeling and optimization). Desalination and Water Treatment, 57(58), 28284-28293.

Franson, M.A. (2005). Standard methods for the examination of water and wastewater. 21st edn., USA: American Public Health Association.

Ghanbari, F., Moradi, M., Eslami, A. and Emamjomeh, M.M. (2014). Electrocoagulation/flotation of textile wastewater with simultaneous application of aluminum and iron as anode. Environ. Proc., 1(4), 447-457.

Imran, M., Crowley, D.E., Khalid, A., Hussain, S., Mumtaz, M.W. and Arshad, M. (2015). Microbial biotechnology for decolorization of textile wastewaters. Rev. Environ. Sci. Bio/Technol., 14(1), 73-92.

Janpoor, F., Torabian, A. and Khatibikamal, V. (2011). Treatment of laundry wastewater by electrocoagulation. J. Chem. Technol. Biotechnol., 86(8), 1113-1120.

Karbassi, S., Malek, M., Shahriari, T. and Zahed, M. A. (2016a). Uptake of metals by plants in urban areas. Int. J. Environ. Sci. Technol., 13(12), 2847-2854.

Karbassi, S., Nasrabadi, T. and Shahriari, T. (2016b). Metallic pollution of soil in the vicinity of National Iranian Lead and Zinc (NILZ) Company. Environ. Earth Sci., 75(22), 1433.

Kabdasli, I., Arslan-Alaton, I., Olmez-Hancı, T. and Tunay, O. (2012). Electrocoagulation applications for industrial wastewaters: a critical review. Environ. Technol. Rev., 1(1), 2-45.

Kabra, A.N., Khandare, R.V., Waghmode, T.R. and Govindwar, S.P. (2012). Phytoremediation of textile effluent and mixture of structurally different dyes by Glandularia pulchella (Sweet) Tronc. Chemosphere, 87(3), 265-272.

Kabuk, H.A., Ilhan, F., Avsar, Y., Kurt, U., Apaydin, O. and Gonullu, M.T. (2014). Investigation of leachate treatment with electrocoagulation and optimization by response surface methodology. Clean. Soil. Air. Water, 42(5), 571-577.

Kandasamy, S., Apitha, C., Logarajan, V., Chandru, M. and Thirugnanasambandham, K. (2016). Optimization of treatment of dairy wastewater by electrocoagulation technique. Environ. Sci.: Indian J., 12(1), 30-40.

Kobya, M. and Demirbas, E. (2015). Evaluations of operating parameters on treatment of can manufacturing wastewater by electrocoagulation. J. Water. Proc. Eng., 8, 64-74.

Manenti, D.R., Modenes, A.N., Soares, P.A., Espinoza-Quinones, F.R., Boaventura, R.A., Bergamasco, R. and Vilar, V.J. (2014). Assessment of a multistage system based on electrocoagulation, solar photo-Fenton and biological oxidation processes for real textile wastewater treatment. Chem. Eng. J., 252, 120-130.

Phalakornkule, C., Polgumhang, S., Tongdaung, W., Karakat, B. and Nuyut, T. (2010). Electrocoagulation of blue reactive, red disperse and mixed dyes, and application in treating textile effluent. J. Environ. Manage., 91(4), 918-926.

Pirkarami, A., Olya, M.E. and Tabibian, S. (2013). Treatment of colored and real industrial effluents through electrocoagulation using solar energy. J. Environ. Sci. Health.: Part A, 48(10), 1243-1252.

Sahu, O., Mazumdar, B. and Chaudhari, P.K. (2014). Treatment of wastewater by electrocoagulation: a review. Environ. Sci. Pollut. R., 21(4), 2397-2413.

Shamsnejati, S., Chaibakhsh, N., Pendashteh, A.R. and Hayeripour, S. (2015). Mucilaginous seed of Ocimum basilicum as a natural coagulant for textile wastewater treatment. Ind. Crop. Prod., 69, 40-47.

Shehzadi, M., Afzal, M., Khan, M.U., Islam, E., Mobin, A., Anwar, S. and Khan, Q.M. (2014). Enhanced degradation of textile effluent in constructed wetland system using Typha domingensis and textile effluent-degrading endophytic bacteria. Water. Res., 58, 152-159.

Silva, K.K.O., Paskocimas, C.A., Oliveira, F.R., Nascimento, J.H. and Zille, A. (2016). Development of porous alumina membranes for treatment of textile effluent. Desalin. Water. Treat., 57(6), 2640-2648.

Thirugnanasambandham, K., Sivakumar, V. and Prakash, M.J. (2014). Optimization of electrocoagulation process to treat biologically pretreated bagasse effluent. J. Serb. Chem. Soc., 79(5), 613-626.

Un, U.T. and Aytac, E. (2013). Electrocoagulation in a packed bed reactor-complete treatment of color and cod from real textile wastewater. J. Environ. Manage., 123, 113-119.

Varank, G., Erkan, H., Yazycy, S., Demir, A. and Engin, G. (2014). Electrocoagulation of tannery wastewater using monopolar electrodes: process optimization by response surface methodology. Int. J. Environ. R., 8(1), 165-180.

Verma, S.K., Khandegar, V. and Saroha, A.K. (2013). Removal of chromium from electroplating industry effluent using electrocoagulation. J. Hazard. Tox. Radioact. Waste., 17(2), 146-152.

Verma, A.K., Dash, R.R. and Bhunia, P. (2012). A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. J. Environ. Manage., 93(1), 154-168.

Zaharia, C. and Suteu, D. (2013). Coal fly ash as adsorptive material for treatment of a real textile effluent: operating parameters and treatment efficiency. Environ. Sci. Pollut. R., 20(4), 2226-2235.