Iranian J Publ Health, Vol. 36, No.4, 2007, pp.57-64 **Original Article**

Algae Removal by Electro-coagulation Process, Application for Treatment of the Effluent from an Industrial Wastewater Treatment Plant

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Abstract:
Background: Although stabilization ponds and lagoons are suitable treatment processes due to simplicity of operation and low per capital costs, the effluents of these systems have too high of a total suspended solids concentration to be discharged into receiving waters. This problem is mainly caused by algae. In this study, an electro-coagulation reactor was examined to remove algae from the final effluent of the wastewater treatment plant belong to Bu-Ali Industrial Estates (Hamadan City).
Methods: For the continuous flow electro-coagulation reactor used in these experiments three aluminum anodes were utilized. This type of metal was selected because it could introduce the flocculation agent into the effluent, thereby algae could be removed by both mechanisms of electro-flotation and electro-flocculation.
Results: The results of treatment were remarkably good and the efficiencies of total suspended solids (TSS) and chlorophyll a removal reached to as high as 99.5% and about 100% by applying a power input of about 550 W. In fact, this level of power input was needed for complete removal of algae in a low retention time of 15 minutes. Meanwhile, by applying less power input of about $100 Wdm^{-3}$, the required time for a relatively same treatment was reached to 30 minutes.
Conclusion: It is expected that this method which is also known as a multiple contaminants removal process will be considered as a suitable alternative for final polishing of effluents from lagoons and similar treatment systems.

Keywords: *Electro-coagulation, Algae, Industrial waste, Iran*

Introduction
Stabilization ponds and lagoons are advantageous wastewater treatment processes, especially for developing countries, since they usually demand low capital cost and present great simplicity for operation and maintenance. In addition, the climatic conditions of tropical countries are favorable to the installation of this type of treatment process and most natural wastewater treatment processes (1). Use of these processes is expected to grow for the most regions of our country because of suitable climatic conditions. Nevertheless, in spite of the well known advantages of the implementation of the stabilization ponds and lagoons, the effluent of this type of treatment system usually has high concentration of total suspended solids (TSS), mainly due to the significant amounts of algae in it. In order to solve this inconvenience which can be harmful to the receiving waters and can hinder the water reuse for a wide range of different applications, it is necessary to look for post-treatment processes that can provide significant removal of TSS and, at the same time, assure that the treatment system as a whole will maintain the primordial advantages of the pond treatment process (i.e. low cost and operational simplicity). With respect to TSS remained in wastewater ef-

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fluents, several methods can be recommended for treatment. Natural processes are specifically recommended for algae removal from the effluents of stabilization ponds and lagoons. Examples are: Rock filter, intermittent sand filter, floating aquatic plants (Eichhornia crassipes), constructed wetlands-subsurface flow system (Typha Sp.), overland flow and electrolytic method (1, 2). The use of electro-coagulation techniques is also developed for final polishing of effluents from these systems and it may be proposed for removal of algae too.
The major mechanisms for algae destruction or removal are as follows:
(a) electro-oxidation/disinfection (b) electro-flocculation or (c) electro-flotation, or any combination of these three mechanisms. For an inert (electrochemically non-dissolving) anode in the presence of chloride ions, the chlorine generated at the anode initiates the formation of oxidants which become the primary agents for algal destruction (electro-oxidation/disinfection) (3, 4). When active polyvalent metal anodes are used, flocculating agents (usually dissolved metal ions, such as Fe^{+3} and Al^{+3}) flocculate the algae to form algal clumps. Inactive metal cathodes generate hydrogen gas micro bubbles which entrap into the algae and float them up to the surface (electro-flotation) (5). For this purpose, a polyvalent metal anode was utilized to generate the flocculating agent and an electro-inactive metal cathode to generate the flotation agent (equations 1 and 2) (6, 7). Nevertheless, in every electrolytic treatment, gases needed for flotation is produced by water electrolysis. The overall reactions proceed as follows:

$$M \longrightarrow M^{n+} + ne^- \qquad (i)$$

$$2H_2O + 2e^- \longrightarrow 2OH^- + H_2 \qquad (ii)$$

The cation hydrolyzes in water forming a hydroxide with the dominant species determined by solution pH. Equations 3-6 illustrate this in the case of aluminum:

$$Al^{3+} + H_2O \longrightarrow Al(OH)^{2+} + H^+ \qquad (iii)$$

$$Al(OH)^{2+} + H_2O \longrightarrow Al(OH)_2^+ + H^+ \qquad (iv)$$

$$Al(OH)_2^+ + H_2O \longrightarrow Al(OH)_3 + H^+ \qquad (v)$$

$$Al(OH)_3 + H_2O \longrightarrow Al(OH)_4^- + H^+ \qquad (vi)$$

Highly charged cations destabilize any colloidal particles by the formation of polyvalent polyhydroxide estates (8, 9).
This experimental research has been performed in Wastewater Treatment Plant of Bu-Ali Industrial Estates in Hamadan City from April to September 2006. The system of treatment at this estate is based on aeration lagoons, so significant amounts of algae are always discharged with effluent especially in warm and mild seasons.

Materials and Methods

This research included a continuous treat ability analysis of the industrial effluent from Bu-Ali Estates by use of a laboratory-scale reactor for accomplishing the electrolytic process. The reactor used had two basic compartments for coagulation and sedimentation-flotation. The first compartment with 8 dm^3 volume was a monopolar plate in tank reactor in which flocs were formed and the second compartment of 16 dm^3 volume was a simple sedimentation tank for removal of flocs by both sedimentation and flotation processes at the specified detention times of 5 to 30 min. A drawing of the treat ability study continuous reactor is presented in Fig. 1. The main electrode plates used were made of aluminum and about 14×24 cm^2 with maximum and minimum spacing of 4 and 2 centimeters. These dimensions were adjusted in a manner so that the required electrical current for meeting the designed treatment efficiency was achievable. The power supply was direct current by use of an ordinary trans. The wastewater sampling from the effluent of sedimentation lagoon was performed on a complex basis and all the experiments had been repeated twice a week. There was no need to add the number of experiments since the detention time adopted for the sedimentation lagoon was two days and the changes of algae density was insignificant (it was mainly changed by season). The effluent samples in these experiments had a TSS concentrations of 30 to 400 mg/L and chlorophyll a concentrations of 100 to 1600 mg m^{-3} determined respectively by gravimetric and spectrophotometric methods [according to the Standard Methods, procedure No. 10200.H for chlorophyll a determination]. Aluminum concentration was also measured by a colorimetric method (spectrophotometer model DR2500 from the Hach Co.) and pH was determined by a lab pH-meter (from the Hach Co).

In this study, mechanical cleaning of electrodes had been used to face the problem of deposition on cathode and anode plates, since this method has proved to be a better process for prevention of passivation in continuous systems. The stage of mechanical cleaning during the experiments can be seen in Fig. 2. The action of cleaning was performed manually after the end of each treatment run. According to Peter's report (8), the most efficient and reliable method of electrode maintenance was to periodically mechanical cleaning of the electrodes which for large-scale, continuous processes is a nontrivial issue.

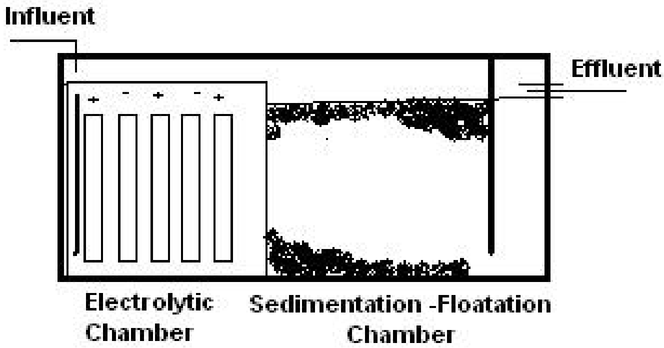

Fig. 1: Schematic diagram of the treatability study continuous reactor

Fig. 2: Manual cleaning of electrodes for preventing passivation

Results

For determining the optimum surface area of anode plates and spacing between plates as well as the required number of electrodes several treat ability experiments using a certain sample were first accomplished. Results obtained indicated that electro-coagulation was better accomplished by use of three aluminum plates in place of anode each with a surface area of 14×24 cm^2, and a maximum spacing of 2 cm. Cathode used was also of aluminum kind (two plates of aluminum instead of cathode). The best location for these electrodes was at the depth of the first chamber (above 2 cm of the bottom). This location was selected because this arrangement provided higher treatment efficiencies due to better contact of TSS and algae masses with micro bubbles of electrolysis gases.

This reactor was then operated at various flow rates, electrical power inputs, influent TSS and chlorophyll a concentrations. Electrical power input was adjusted in a range of 6-550 W dm^{-3} and wastewater flows were changed between 30 to 96 m^3h^{-1}. In experiments performed at these variable conditions the influent was a sample of wastewater with specified concentrations of TSS and chlorophyll a. The results of treatment were then compared to individualize conditions with best efficiencies. Fig. 3 shows the results of these experiments and it clearly indicates that better removal rates of TSS and chlorophyll a can be obtained by using higher electrical power inputs. Because of the effect of this parameter on retention time and removal efficiency, a higher power inputs (over than 100 Wdm^{-3}) was used. Results of wastewater treatment at various electrical power inputs can be seen in Fig. 4; and Fig. 5 shows the results of experiments accomplished for comparison the treatment experiments at a constant electrical power input of 375 W dm^{-3}. Finally, Fig. 6 shows the performance of the electro-coagulation system in algae removal at various conditions of treatment.

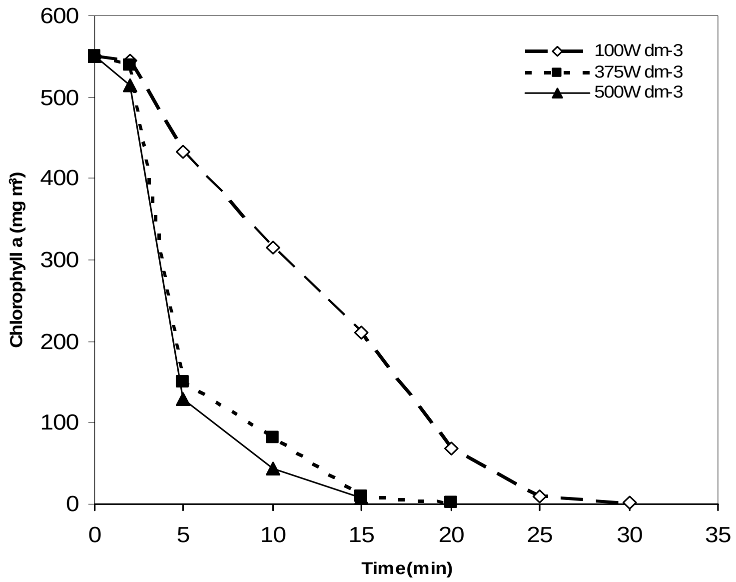

Fig. 3: Changes in chlorophyll a concentration during electro-coagulation treatment by applying different power inputs versus detention time

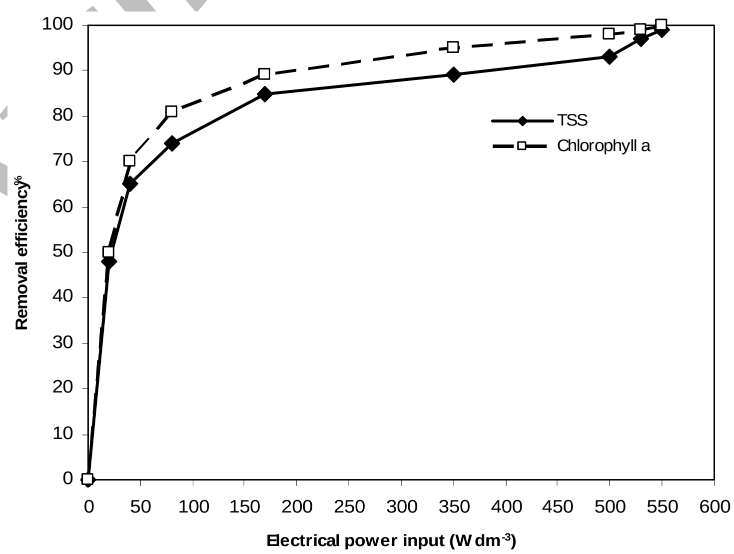

Fig. 4: Algae (as chlorophyll a) and suspended solids removal efficiencies at different electrical power inputs (retention time= 10 min)

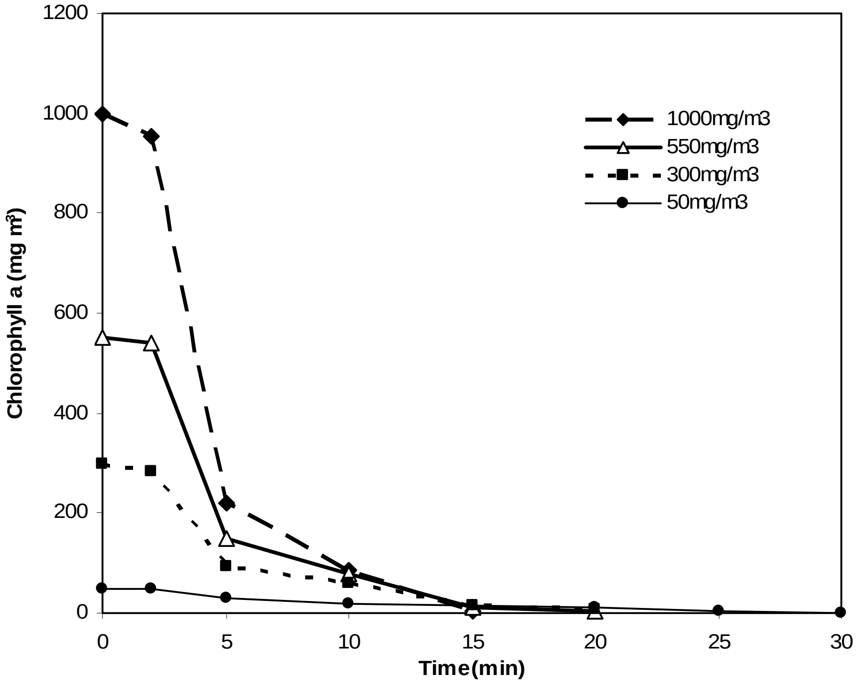

Fig. 5: Comparison of algae treatment results at constant 375 Wdm^{-3} electrical power input

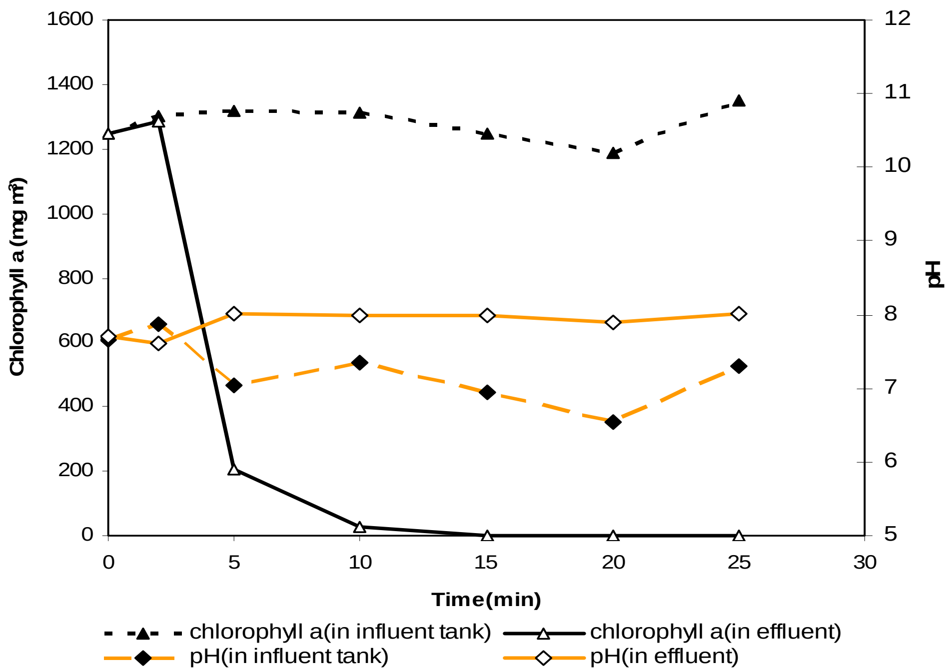

Fig. 6: Typical steady state profile in the continuous electrolysis system.

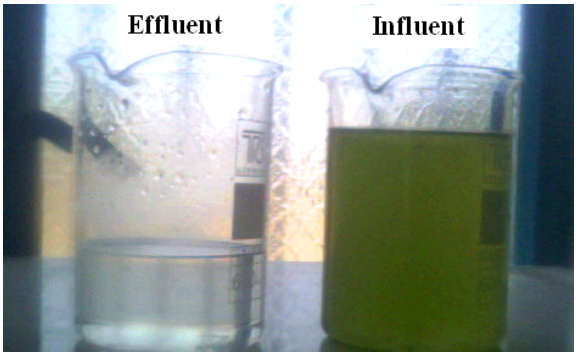

Fig. 7: Comparison of the wastewater appearance before and after electro-coagulation treatment

Discussion

Results of these experiments clearly indicated that better removal rates of algae can be expected by applying higher power inputs and as is shown in Fig. 3 it is possible to have complete reduction of algae at optimum conditions. Furthermore, by applying higher power input, the required detention time for this treatment would be reduced. It should be noted that for electrolytic treatment, the amount of flocculating and floating agents (needed for algae removal) is also dependent to the intensity of the applied power according to Faraday's law in physics. Although high efficiencies of TSS and chlorophyll a treatment would be achievable by applying higher power inputs but there was the problem of temperature increase. This problem often limits the potential of electrolytic treatment at desired currents. In this study, the increase of temperature at 550 W dm^{-3} power input was recorded to be about up to 50° C and not too severe to damage the process. At higher temperature of course much better disinfection of effluent would be accomplished. pH change was insignificant and it was not more than one unit.

According to Fig. 4 it should be concluded that the major fractions of TSS and chlorophyll a had been removed at low power input of 31 W dm^{-3}, but much higher input of about 550W dm^{-3} was required for removing the remained 10-15% of these pollutants. Results of a comparative study of electrolytic treatment at deferent concentrations of influent algae which can be seen in Fig. 5 also revealed that higher efficiencies of treatment were obtained when the initial concentration of chlorophyll a was high in the influent. The reason is that at low concentrations of TSS and chlorophyll, the amount of colloids present in the effluent is not sufficient for formation of enough settleable solids. According to literature, even if surface charges are neutralized, the flocculation process cannot occur unless some additional coagulants are added in order to precede the sweep coagulation (10). When the chlorophyll a and TSS concentrations were high, the destabilization of colloids could also performed by surface adsorption thus the precipitation of these solids would be accomplished in a short time. Besides, higher concentrations of algae and TSS increase the possibility of interactions between particles, thereupon a better coagulation would result at these conditions. Since, this study was established based on constant power input, the "removal time" of chlorophyll a in all concentrations are same (Fig. 5). This can be related to different applied current density.

In Fig. 6 the typical steady state profile of the reactor used can be seen. As shown, the pH values were higher than the initial pH but the difference was not significant (only about 0.8-1.1 pH unit). This slight pH change is not considered a problem and even it would be beneficial when acidic wastes are discharged from industries. Another point of concern is the possibility of remaining aluminum in the final effluent. In this study, aluminum measurement results showed that the concentration of this metal had never exceeded 2mg/L in electrolytic reactor and it was reduced to as low as 0.1mg/L after final clarification. The latter figure is indeed less than the common concentrations in drinking water and the reason is that metal precipitation is often better accomplished in wastewater. Also, it should be noted that aluminum release into solution is dependent to the power input applied. In this study, the amount of this release was not much greater than the treatment demand even at high power input applied. Although this study was mainly limited to determine conditions for better removal of algae from the wastewater, other concurrent treatments were also detected at all conditions and this was obvious by the good appearance of the final effluent. This being the case, this type of treatment could have an application for overall polishing of the effluents. A comparison of the influent and effluent for the electro-coagulation system can be seen in Fig. 7.

A study conducted by the university of Tsukuha City for algae removal from the water of an eutrificated lake by using the electro chemical technique has showed the superiority of this method in comparison to many other suggested processes for algae removal (3). But for algae removal from wastewaters by this technique limited research has been accomplished. One study has demonstrated high algae removal efficiency by using polyvalent metal anodes and inert metal cathodes (5). However, electrolytic treatment application for other purposes is continued (11). Authors recommend more attention to be concentrated for developing the use of this process in this respect.

In the electrolytic treatment of algae in a continuous system, consideration for a balanced operation to achieve high algae removal efficiency and minimum release of excess aluminum should be considered. The scope and limitations of this process, especially the analysis of Al salts in sludge is under investigation in our laboratory.

In conclusion, the process of electro-coagulation which is also known as a multi-contaminant process can be used as an applicable method for final polishing of effluents from lagoons and similar treatment systems. Using this method could make the treatment plants capable in providing a good effluent for meeting the current requirements of discharge and/or reuse and decrease the need for resorting to high cost advanced wastewater treatment processes.

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The authors declare that they have no Conflict of Interests

References

1. Neder KD, Carneiro GA, Queiroz TR, De Souza MAA (2002). Selection of natural treatment processes for algae removal from stabilization ponds effluents in Brasilia, using multicriterion methods. *J Water Science and Technology*, 46(4-5): 347-54.
2. Tarr MA (2003). *Chemical degradation methods for wastes and pollutants, Environmental and industrial applications*. Marcel Dekker, pp.235-96.
3. Sugizaki K, Iwata T, Takeuchi Y (2000). Effect of electrolytic oxidation treatment on disinfection of algae in lake and marsh water. *Mizu Kankyou Gakkaishi*, 23:285-91.
4. Tsuzuki K, Tanaka T, Takagi T, Shimomura M (1999). Effect of electrochemical treatment on Microcystis extinction. *Mizu Kankyou Gakkaishi*, 22:228-31.
5. Catalino GA, Kazunori N, Nakao N, Takeshi I, Masatoshi M (2002). Operating and scale-up factors for the electrolytic removal of algae from eutrophied lakewater. *J Chem Technol Biotechnol,* 77:871-6.
6. Bustos Aragon A, Borja Padilla R, Fiestas Ros de Ursinos AJ (1992). Experimental study of the recovery of algae cultured in effluents from the anaerobic biological treatment urban wastewater. *Res Conserv Recyc*, 6:292-302.
7. Poelman E, De pauw N, Jeurissen B (1997). Potential of electrolytic flocculation for recovery of microalgae. *Res Conserv Recyc*, 9:1-10.

8. Peter H, Geoffrey B, Cynthia M (2006). Electrocoagulation as a wastewater treatment. *The third annual Australian Environmental Engineering Research Event*. 23-26 November Castlemaine, Victoria.
9. Nikolaev NV, Kozlovskii AS, Utkin II (1982). Treating natural waters in small water systems by filtration with electrocoagulation, *Soviet Journal of Water Chemistry and Technology*, 4(3):244-47.
10. Holt PK, Barton GW, Mitchell CA (2005). The future for electrocoagulation as a localised water treatment technology. *Chemosphere*, 59(3):355-67.
11. Edwards FG, Fendley DL, Lunsford JV (2006). Electrolytic Treatment of an industrial wastewater from a Hosiery plant. *Water Environment Research*, 78(4):435-41.