An environmental impact assessment of a pilot solar photoelectro-Fenton technology inside the integral basin management of the Turbio-Palote and Guanajuato rivers

Roberto Acero Rueda[1]
Juan Manuel Peralta Hernández[2]

Summary

The use of solar technologies is increasing worldwide. For this study an environmental assessment of a pilot plant with photoelectro-Fenton technology for the treatment of domestic and industrial wastewaters was performed. The results show that the technology can help in the solution of several severe water pollution problems in the Turbio-Palote and Guanajuato river basins, which are some of the most important areas of México with at least the 2.5% of the total country population. The water pollution problems are mainly a result of a dense, urban population and the activity of the local leather and shoe industries. The solar plant was able to achieve an 80% reduction in organic water pollution. The environmental impact assessment of this alternative demonstrates a minimum number of significant impacts as well as a high feasibility in terms of economic and environmental implementation.

Introduction

In recent years, an increasing need and interest to preserve environment has arisen, mainly by eliminating chemical compounds produced by many human activities. In this context, electrochemical advance oxidation processes (EAOPs) capable of destroying several organic compounds in wastewater are being developed. The basis for these methods is the production of free hydroxyl radicals (•OH) as a primary oxidant. In these systems, the •OH is generated by water discharge over the anode of a high oxygen overvoltage material, and by the electro-Fenton type reaction. This last creates a mixture of iron ions (Fe^{2+}) and hydrogen peroxide (H_2O_2), electrochemically generated at the cathode by oxygen reduction via two electrons in acidic media. UVA irradiation improves the regeneration of Fe^{2+} ions, enhancing the •OH production, generating the solar photolectro-Fenton process.

This pilot plat is been implementing in the Turbio Palote and Guanajuato Basins region, with a surface near to 500,000 ha. and one of the most important zones of the central part of México, where the industrializing process, mainly shoe and leather industries, jointly with the urban grown, causes a several pollution problem that need to be resolved.

This region with a population in 2010 near to 2.8 million of persons[1], has as a principal city León, Guanajuato generates the pollution by waste water of the turbio river, considered like highly contaminated according to the national water quality index and not suitable for any kind of activity. The electro fenton process can help to reduce the pollution level, removing the organic material.

Electro Fenton process (EF)

The EF process involves the *in-situ* electrochemical generation of H_2O_2 [2] [3] [4] as previously mentioned, which readily decomposes in aqueous medium catalyzed with iron ions to produce the hydroxyl radical species. The relevant electrochemical reaction, described by

[1] Titular resercher of the Mexican public reserch center CIATEC A.C.
[2] Titular resercher of the Mexican public reserch center CIATEC A.C

Eq. 1, corresponds to the $2e^-$ reduction of dissolved oxygen (O_2) under slightly acidic conditions[5]:

$$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \quad 1)$$

It results from a complex system involving the formation of the superoxide anionic species $O^{\bullet}_2$ and the hydroperoxide radical $^{\bullet}OH_2$. This selective reaction takes place on the surface of a variety of carbonaceous materials such as graphite, carbon cloth, reticulated vitreous carbon, oxygen diffusion cathodes[6] and recently were tested BDD surfaces[7] following the Damjanovic mechanism, as evidenced by rotating ring disk experiments[8]. In the EF process, the presence of iron ions, which are usually introduced to the system as ferrous sulphate ($FeSO_4$), accelerates the production of •OH radicals[9], by Eq. 2:

$$Fe^{2+} + H_2O_2 \rightarrow Fe(OH)^{2+} + {}^{\bullet}OH \quad 2)$$

This catalytic reaction is propagated from Fe^{2+} regeneration, which mainly takes place by the reduction of Fe^{3+} ions with the H_2O_2.

Solar Photoelectro Fenton process (SFPF)

When the EF process (1) is irradiated by means of solar light, this can accelerate the degradation of organic compounds by two principal pathways: a) the photolysis of Fe^{3+} -oxidation products complexes, and b) improving the Fe^{2+} regeneration from the photoreduction of Fe^{3+} ions according to the equation[10 11 12 13]:

$$Fe(OH)^{2+} + hv \rightarrow Fe^{2+} + {}^{\bullet}OH \quad 3)$$

Results

The capacity of the system to electrochemically generated H_2O_2 by O_2 reduction (reaction 1) on the BDD cathode at different current densities (j = 8 mA/cm^2, 15 mA/cm^2 and 23 mA/cm^2) was spectrophotometrically estimated. The accumulation of H_2O_2 during the first 30 min of electrolysis increased. For the evaluated, H_2O_2 concentrations were 25 mg/L, 32 mg/L and 45 mg/L, respectively.

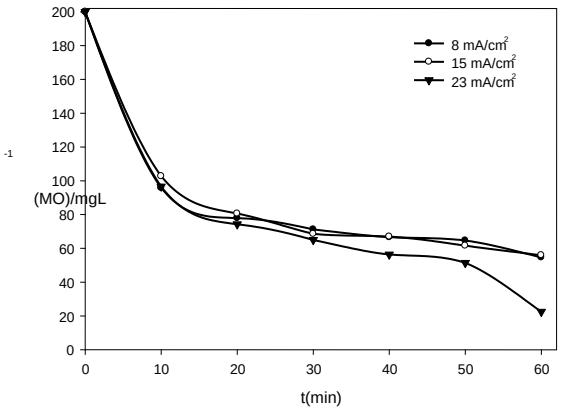

Figure 1. Influence of current density on TOC removal during the SPEF treatment of 60L of 200 mgL^{-1} AY-36 in 0.1 M Na_2SO_4 with 0.3 mM Fe^{2+} in the recirculation solar flow plant Applied current density: (•) 8 mAcm^{-2}, (o) 15 mAcm^{-2}and (▲) 23 mAcm^{-2}.

The abatement of Total Organic Carbon (TOC) of 200 mg/L of AY-36 was evaluated as a function of electrolysis time. The decay of azo dyes compound exhibited an exponential behavior, indicating a first-order reaction. In the SPEF process treatment were evaluated different iron (Fe^{2+}) concentrations in the solution (0.1 mM, 0.2 mM, and 0.3 mM). Treatment was more effective using the SPEF combined process, where Ay-36 degradation occurred after 60 min with efficiency closely of 80%, as can be shown in figure1.

Impact assessment methodology

The methodology was based on Mexico regulations for environmental impact assessment that establishes 3 different steps (identification, valuation and description of environmental impacts), including the use of check lists and matrices that describe the attributes of each impact. Specifically, the methodological development considered the following parameters for each impact: character, duration, extent, intensity, synergy, reversibility and mitigability; for both direct and indirect impacts. The first phase developed was the elaboration of a specific list of environmental factors and the project impact agents or components (Modak. 19914)[9] (Canter 1977)[15].

For the evaluation of environmental impacts, we used the methodology known as Leopold matrix (1971)[16], which was modified to match with the particular features of each project component. This matrix was developed based on the results of the check list and the table that included a double entry with the interactions environment-project, choosing those environmental factors that may be impacted, qualify them according to the parameters, on a scale from 1 up to 4. The score was awarded based on pre-established criteria matrix.

As a second step in order to determine the impact magnitude regarding the surface or affected volume, permanence and intensity, the following equation was used to determine the magnitude level.

$$\text{Magnitude} = \left(\frac{E + D + I}{12} \right) S$$

Where:

E = impact extension
D = Impact time
I = impact strength
S = synergy
12 = is the sum of the maximum values of E, D and I
In order with the assessment criteria, the possible values established in the equation means that the domain of the magnitude variable (M) could be from 0.25 up 2. All the impacts, according to their value were classified inside three different categories high, medium and low.

These values were matched with the critical ecosystem environmental factors aimed to determine the significance of the impact as well and only those considered impacts of high significance were selected.

The impact assessment results

The researcher results show that the impact assessment has a low significance as follows:

Firstly, the solar photoelectro fenton pilot plant, is considered like a project environmentally feasible because it does not cause or increase the ecosystem fragmentation and that does not exceed the basin load capacity where it intends to locate,

The main natural resource that will be used as raw but the waste water is the Sun and there is no way that the project will surpass its rate of renewal. In this framework, these pilot plants projects can help to combat the phenomenon of global warming when it removes the organic material and have any kind of emissions of methane. So the technological development is beneficial to the environment and with the climate change. It is appropriate to mention that the prevailing insolation in the area is adequate and sufficient for the development of a pilot plant which generates its own hydrogen peroxide..

The settlement of the project is highly altered by anthropic activities, the region is major consider like an urban environment, with a fragmented ecosystem, even it keeps some reminiscences of native vegetation.

The project will not cause significant changes in the trend of environmental development of negative character that occurs in the environmental system and even expected that project area will be absorbed by the urban growth of the municipal seat in the medium term

The pilot plant when it is been located in natural soils will generate erosion in the area of solar cells and visual impact, but these impacts could be reduced if the project promotes to cultivate some shadow vegetation in the zone of installation. Without doubt the main effects could happen in the solar modules build and then in the shadow that will be reflected by the solar panels on the environmental factor soil.

The elimination of organic material by the pilot plant will not produce any sludge or other type of substance that could be considered as toxic or dangerous. In this case this pilot plant reduces to cero the waste management and it does not almost require any kind of maintenance. These topics also decrease the project operation costs

Other item that it is important to mention lies in the fact that the average cost of a solar photoelectro fenton pilot plant installation is already 40% lesser than the cost of installation of water waste management plants with the same capacity.

It is important to emphases the social benefits which will take place. The project promotes the use of energy clean alternatives to oil, which will result in a reduction in the emission of greenhouse gases. Also its expected to impact positively on the population of the area throughout the jobs creation of and the increases of the water quality.

References

[1] INEGI; “Censo de población y vivienda 2010”; México 2011.
[2] Martínez-Huitle, C.A. and E. Brillas, Decontamination of wastewaters containing synthetic organic dyes by electrochemical methods. A general review. Appl. Catal. BEnviron., 87(3-4), 105-145 (2009
[3] Brillas, E., M.A. Baños, S. Campos, C. Arias, P.-L. Cabot, J.A. Garrido and R.M. Rodríguez, Catalytic effect of Fe2+, Cu2+ and UVA light on the electrochemical degradation of nitrobenzene using an oxygen-diffusion cathode. New J. Chem., 28(2), 314-322 (2004).
[4] Da Pozzo, A., P. Ferrantelli, C. Merli and E. Petrucci, Oxidation efficiency in the electro-Fenton process. J. Appl. Electrochem., 35(4), 391- 398 (2005).
[5] Yeager, E., Electrocatalysts for O2 reduction. Electrochim. Acta, 29(11), 1527-1537 (1984).
[6] Friedrich, J.M., C. Ponce-de-León, G.W. Reade and F.C. Walsh, Reticulated vitreous carbon as an electrode material. J. Electroanal. Chem., 561(1-2), 203-217 (2004).
[7] Karla Cruz-González , Omar Torres-Lopez , Azucena M. García-León , Enric Brillas , Aracely Hernández-Ramírez , Juan M. Peralta-Hernández. Optimization of electro-Fenton/BDD process for decolorization of a model azo dye wastewater by means of response surface methodology. Desalination 286 (2012) 63–68
[8] Yeager, E., Electrocatalysts for O2 reduction. Electrochim. Acta, 29(11), 1527-1537 (1984).
[9] Sirés, I., J.A. Garrido, R.M. Rodríguez, E. Brillas, N. Oturan and M. Oturan, Catalytic behavior of the Fe3+/Fe2+ system in the electro-Fenton degradation of antimicrobial chlorophene. Appl. Catal. B-Environ., 72(3-4), 382-394 (2007).
[10] Martínez-Huitle, C.A. et al Op cit.
[11] Brillas, E., M.A. et al Op cit.
[12] Brillas, E., M.A. Baños, and J.A. Garrido, Mineralization of herbicide 3,6-dichloro-2- methoxybenzoic acid in aqueous medium by anodic oxidation, electro-Fenton and photoelectro- Fenton. Electrochim. Acta, 48(12), 1697-1705 (2003).
[13] Edgar J. Ruiz, Aracely Hernández-Ramírez, Juan M. Peralta-Hernández,

Conchita Arias, Enric Brillas. Application of solar photoelectro-Fenton technology to azo dyes mineralization: Effect of current density, Fe2+ and dye concentrations. Chemical Engineering Journal 171 (2011) 385– 392

[14]Modak, P. &A.K. Biswas. Conducting environmental impact assessment for developing countries. United Nations University Press. Tokyo, New York, Paris. 364pp.

[15]Canter, W. L. "Manual de evaluación de impacto ambiental. técnicas para la elaboración de estudios de impacto". Ed. McGraw Hill. México. 1998 841pp

16 Leopold, L. B., F. E. Clarke, B. B. Hanshaw, and J. E. Balsley; A procedure for evaluating environmental impact; U.S. Geological Survey Circular 645, Washington, D.C. 1971