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# Optimal concentration and efficiency of the photo fenton system for the treatment of a synthetic textile effluent

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**Ana Paula Barrenechea Fernández[1]; Paola Vela Brandon[1*]; Armando Jesus Vélez Azañero[2]**

[1]Facultad de Ciencias Ambientales. Universidad Científica del Sur, Carretera Panamericana Sur, km 19, 15067, Villa El Salvador, Lima, Perú. E-mail: anapau072@gmail.com
[2]Facultad de Ciencias Naturales y Matemática. Universidad Nacional Federico Villarreal, Avenida Río Chepén, s/n, 15003, El Agustino, Lima, Perú. E-mail: fonia14@gmail.com
[*]Corresponding author. E-mail: paolavelabrandon.94@gmail.com

## ABSTRACT

The Photo Fenton process is an alternative process for the treatment of effluents from the textile industry, being a reagent-based chemical on $Fe^{2+}$ and $H_2O_2$ + UV light, whose mechanism consists of oxidizing the pollutants until they are suitable for discharge into bodies of water. This research seeks to determine the optimum concentration of $Fe^{2+}$ - $H_2O_2$ in the treatment of a synthetic textile effluent and, subsequently, to evaluate the efficiency of the system. The synthetic textile effluent was prepared under laboratory conditions, $FeSO_4$ and $H_2O_2$ were added at different concentrations, with exposure to UV-A light throughout the process, and it was determined that the optimum concentration of the Photo Fenton reagent was 400 mg L-1 of $FeSO_4$ and 12 ml L-1 of $H_2O_2$, a dosage that reduced initial turbidity, color, and COD by 100%, 99% and 83%, respectively, and increased the DO by 11%. Turbidity removal was obtained by carrying out the treatment in an acid medium (pH 3). The presence of $Fe^{2+}$ promoted the significant removal of COD. The increase in DO was obtained by the presence of $H_2O_2$ and UV-A light, and this in turn, had a considerable influence on the removal of effluent color. Regarding the efficiency of the system, it was determined that the Photo Fenton reagent is an excellent alternative for the treatment of textile effluents with high and low organic loads, reducing contaminants derived from industry processes.

**Keywords:** clean technology, $Fe^{2+}$-$H_2O_2$, organic, oxidation, pollution, water.

# Concentração e eficiência óptimas do sistema foto fenton para o tratamento de um efluente têxtil sintético

## RESUMO

O processo Foto Fenton é uma alternativa para o tratamento de efluentes da indústria têxtil, sendo um reagente à base de $Fe^{2+}$ e $H_2O_2$ + luz UV cujo mecanismo consiste em oxidar os contaminantes até que estejam aptos para lançamento em corpos d'água. O objetivo da pesquisa é determinar a concentração ótima de $Fe^{2+}$ - $H_2O_2$ no tratamento de um efluente têxtil sintético e avaliar a eficiência do sistema. Um efluente têxtil sintético foi preparado em condições de laboratório, $FeSO_4$ e $H_2O_2$ foram adicionados em diferentes concentrações com exposição à luz UV-A durante todo o processo. Daí se determinou a concentração ideal do reagente Foto Fenton era 400 mg L-1 $Fe^{2+}$ e 12 ml L-1de $H_2O_2$, dosagem que conseguiu reduzir a turbidez, cor e DQO inicial em 100%, 99% e 83%, respectivamente, e conseguiu aumentar a OD em 11%. A remoção da turbidez foi obtida realizando o tratamento em meio ácido (pH 3), a presença de $Fe^{+2}$ favoreceu a remoção significativa de DQO, o aumento de OD foi obtido com a presença de $H_2O_2$ e luz UV -A, resultando na remoção de cor do efluente. À eficiência do sistema, determinou que o reagente Foto Fenton é uma excelente alternativa para o tratamento de efluentes têxteis com altas e baixas cargas orgânicas, reduzindo contaminantes derivados de processos industriais.

**Palavras-chave:** água, $Fe^{2+}$-$H_2O_2$, orgânico, oxidação, poluição, tecnologia limpa.

## 1. INTRODUCTION

Industrial production of textile fibers requires a large amount of water consumption and discharge (Deng *et al.*, 2020). The wastewater generated contains a high number of pollutants such as NaCl and $Na_2SO_4$, phenols, heavy metals, chlorinated solvents, surfactants biocides such as pentachlorophenol and toxic anions such as sulfur (Cortazar *et al.*, 2014). When discharged into water bodies, they remain in the water and soil for long periods of time, reducing soil fertility and affecting the esthetic quality of the water by increasing chemical and biochemical oxygen demand, thereby impairing photosynthesis of aquatic plants (Al-Tohamy, *et al.*, 2022). In addition, the dyes used in this industry contain heavy metal ions in their structure, which can be assimilated by the gills of fish, accumulating in their tissues, and subsequently accumulating in human organs through the food chain (Mendoza Vazquez, 2021).

The advanced Oxidation Processes (AOPs) could be quite effective for the degradation of persistent contaminants. Their efficiency is based on the generation of highly reactive OH- radicals, which are capable of oxidizing many organic compounds (Arka *et al.*, 2022). OH- radicals are generated by the intervention of sunlight or other energy sources and are characterized by their great effectiveness in oxidizing organic matter (Litter, 2005) The versatility of AOPs lies in the different existing ways of producing free radicals, such as heterogeneous photocatalytic ozonation, anodic oxidation, ultraviolet/hydrogen peroxide (UV/$H_2O_2$), Fenton and Photo-Fenton, among others (Cruz-Gonzalez *et al.*, 2017).

One of the most effective AOPs for the generation of the hydroxyl radical is the Fenton process, based on $Fe^{2+}$ and $H_2O_2$, where the radicals are formed by catalytic decomposition of $H_2O_2$, with $Fe^{2+}$ being the catalyst (Cruz-Gonzalez *et al.*, 2017) at low pH conditions (pH of 2–4) (Yan *et al.*, 2022) (Equation 1). When $H_2O_2$ is combined with iron salts, the reaction is generated (Equations 1 and 2).

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \mathrm{HO-} \ + \mathrm{HO}\bullet \quad (1)$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + \mathrm{H} + + \mathrm{HO2}\bullet \quad (2)$$

In Equation 1, OH- radicals are generated, and in Equation 2 perhydroxyl radicals (-$HO_2$) are generated, thus oxidizing organic compounds (Equation 3), with the -$HO_2$ radical being the least reactive (Barliza and Torres, 2018). From the Fenton reagent, several processes derive, such as the Photo Fenton Process, which employs UV light to increase the production of -OH (Equations 4 and 5) (Núñez and Vergara, 2016).

$$\mathrm{RH} \ + \ \mathrm{OH}\bullet \ + H_2O \rightarrow \ \mathrm{ROH} \ + H_3O + \rightarrow \ \text{oxidized products} \quad (3)$$

$$H_2O_2 + Fe^{2+} \rightarrow \ \mathrm{Fe3+} \ + \mathrm{HO} \ - \ + \mathrm{OH}\ \cdot \quad (4)$$

$$Fe^{3+} + H_2O + hv \rightarrow Fe^{2+} + HO\cdot + H \quad (5)$$

UV light increases the generation rate of OH- radicals and enhances the regeneration of the ferrous catalyst by the reduction of $Fe^{3+}$ ions. There are three types of UV light wavelengths: UV-A (315- 400 nm), UV-B (280-315 nm) and UV-C (100-280 nm) (World Health Organization, 2003). The maximum absorbance of $Fe(OH)_2$ is at a wavelength of 300 nm, extending to approximately 400 nm (Medina Flores, 2019).

The objective of this research was to determine the optimal concentration of $Fe^{2+}$ – $H_2O_2$ in the treatment of a synthetic textile effluent under the Photo-Fenton system, and to evaluate the efficiency of the Photo-Fenton system in five different treatments generated from a synthetic textile effluent sample. This study seeks to minimize the environmental impact caused by the discharge of effluents from the textile industry by determining the optimal concentration of $Fe^{2+}$ - $H_2O_2$. It will also bring this technology closer to the various stakeholders, providing the necessary information for replication and scaling in order to comply with applicable effluent-disposal regulations.

## 2. MATERIAL AND METHODS

### 2.1. Research design

**Optimal concentration of $Fe^{2+}/H_2O_2$**

To achieve this objective, the reduction of the pollutants in the synthetic textile effluent were analyzed based on two factors ($Fe^{2+}$ and $H_2O_2$), with three levels each. For this, a completely randomized 2x3 factorial design was worked using three repetitions (Table 1).

**Table 1.** Design to Determine the Optimal Concentration of $Fe^{2+}$ - $H_2O_2$.

| Treatments* | Independent Variables | | | Coded Independent Variables | Dependent Variable ** | | |
|---|---|---|---|---|---|---|---|
| | $FeSO_4$ (mg $L^{-1}$) | $H_2O_2$ (ml $L^{-1}$) | $\tau$ (x1) | $\beta$ (x2) | $y_{ij1}$ | $y_{ij2}$ | $y_{ij3}$ |
| **T1** | 200 | 10 | -1 | -1 | . | . | . |
| **T2** | 400 | 10 | 0 | -1 | . | . | . |
| **T3** | 600 | 10 | 1 | -1 | . | . | . |
| **T4** | 200 | 12 | -1 | 0 | . | . | . |
| **T5** | 400 | 12 | 0 | 0 | . | . | . |
| **T6** | 600 | 12 | 1 | 0 | . | . | . |
| **T7** | 200 | 14 | -1 | 1 | . | . | . |
| **T8** | 400 | 14 | 0 | 1 | . | . | . |
| **T9** | 600 | 14 | 1 | 1 | . | . | . |

**Source:** Reduction of colorant content in textile industry effluents using the Fenton Process (Rosales Palomino, 2017).
*3 replicates were performed for each of the 9 treatments (27 repetitions)
**Reduction of the contaminant (color among others physicochemical parameters)

**Efficiency of the Photo-Fenton system**

The optimal concentration of $H_2O_2$ – $Fe^{2+}$ obtained in the first part of the study was used as a basis and the efficiency of the Photo-Fenton System was evaluated, for which a completely randomized design of five treatments with three repetitions was structured (Table 2).

**Table 2.** Treatments to Determine the Efficiency of the Photo-Fenton System at Five Different Contaminant Concentrations.

| Treatments* | Synthetic textile effluent (concentration %v/v) | $H_2O_2 – Fe^{2+}$ (mg $L^{-1}$) |
|---|---|---|
| **T1** | 100% | |
| **T2** | 80% | |
| **T3** | 60% | $H_2O_2 – Fe^{2+}$ Optimal concentration |
| **T4** | 40% | |
| **T5** | 20% | |

*3 replicates were made for each of the 5 treatments (15 repetitions).

## 2.2. Methods

### 2.2.1. Preparation of the synthetic textile effluent (Hanela *et al.*, 2018)

A clothing item that weighs 400 g, was placed in a metal container, 4 L of deionized water, 8g of moisturizer and 20g of $Na_2CO_3$ was added for the scouring process. The container was heated on a stove until the water started to boil, then it was left to cool off for a few minutes. Afterwards, the clothing item was rinsed with 4 L of deionized water. The residual water from the scouring process and the rinsed water were stored in a plastic container.

The next step was to dye the clothing item. To do this, 4g of moisturizer with 4 ml of detergent, 320g of NaCl (sea salt) and 20g of aniline previously dissolved in water were added to a metal container. It was heated on a stove, where 2 doses of $Na_2CO_3$ and NaOH (6g and 2g, respectively, dissolved in water) and 4L of deionized water were added. Then the excess water was drained and stored in the plastic container.

The last step was the rinsing process, for which 4 ml of fabric softener and 2g of glacial acetic acid were used. It was left to rest for a few minutes and a series of rinses were conducted. The residual water produced during this procedure was stored in the same plastic container. At the end of this process, approximately 30 L of residual water was obtained, which resulted in the synthetic textile effluent. Finally, the physicochemical parameters of the contaminant such as pH, color, turbidity, COD and DO were measured.

### 2.2.2. Optimal concentration of $Fe^{2+}/H_2O_2$

Prior to the start of the treatment, and in order to obtain the best decontamination results, the 30 L of synthetic textile effluent were acidified with concentrated Hydrochloric Acid (Medina Valderrama *et al.*, 2016) to obtain a pH of 3. This was done because it has been shown that the highest decontamination values with the Photo-Fenton System are obtained with a pH level between 2 – 4 (Kiruthiga and Sampath Kumar, 2015; Patil and Raut, 2014).

A volume of 1 L of the synthetic textile effluent was added in each of the twenty seven repetitions (1 L beaker), the $FeSO_4$ (Table 1) was added, and it was taken to the magnetic stirrer for five minutes at 50 rpm. Each sample was exposed to 400 nm UV-A light (Medina Flores, 2019) throughout the process. Finally, the $H_2O_2$ was added, and it was kept under constant stirring for one hour at 300 rpm, and then the samples were left to rest for 48 hours (Rosales Palomino, 2017), all exposed to UV-A light. After rest time, the samples were filtered with the use of filter paper, to separate the possible sediments. The pH, color, turbidity, COD and DO were measured to verify the effectiveness of the removal of the contaminant. Likewise, the spectrophotometer was used to measure the absorbance of each repetition (Chaparro *et al.*, 2014; Muñoz *et al.*, 2016), with the objective of figuring out the concentrations of each problem sample, using a calibration curve.

#### 2.2.3. Photo-Fenton System's efficiency

The optimal concentration of $H_2O_2$ – $Fe^{2+}$ obtained in the first part of the study was used as a basis and the efficiency of the Photo-Fenton Method was evaluated, for which a 15 L sample of synthetic textile effluent was prepared, as described in Item a.; then the concentration of the contaminant in each treatment was altered by diluting it with distilled water (Table 2) and 1 L of this sample was added to each of the 15 beakers.

Next, hydrochloric acid was added until a pH of 3 was obtained. Once these conditions were met, the optimal dose of $Fe^{2+}$ obtained in the first part of the study was added to each treatment and constant stirring was done for 5 minutes at 50 rpm using a Magnetic stirrer. After 5 minutes, the stirring speed was decreased to 30 rpm (Medina Valderrama *et al.*, 2016). Finally, $H_2O_2$ was added according to the optimal dose obtained in the first part of the study. The mixture was kept under constant stirring for 1 hour at 300 rpm. Afterwards, it was left to rest for 48 hours (Rosales Palomino, 2017). Each sample was exposed to 400 nm UV-A light throughout the process. Once the rest time had passed, each sample was filtered using filter paper, to separate the possible sediments that could have formed and the pH, Color, Turbidity, COD and DO were measured. Likewise, the spectrophotometer was used to measure the absorbance of each repetition, to figure out the concentrations of each problem sample.

### 2.3. Statistical analysis

#### 2.3.1. Optimal concentration of $Fe^{2+}/H_2O_2$

The results were analyzed through a factorial analysis of variance, where the individual effect of $Fe^{2+}$ and $H_2O_2$ was evaluated, as well as the interactions, and the Dunet statistical test was used, which was applied to see which treatments were different from the control, allowing to determine the treatment or treatments (Table 1) that best reduced the contaminants in the synthetic textile effluent.

### 2.4. Efficiency of the Photo-Fenton system

One-way analysis of variance was applied and the Dunet statistical test was performed with a 95% confidence level.

### 2.5. Ethical aspects

This research did not affect the harmony or balance of the ecosystem (animals, plants, or the soil) since the study was conducted in a controlled environment. The final water samples were placed in plastic containers and the filter papers with the sediments were placed in red bags, where the correct handling of these residues was subsequently carried out.

## 3. RESULTS AND DISCUSSION

### 3.1. Results

#### 3.1.1. Optimal concentration of $Fe^{2+}/H_2O_2$

In the first part of the study, the variables pH, COD, turbidity, and color showed values lower than the control, while the DO variable showed values higher than the control in all the Photo-Fenton treatments (Annex 1), conforming to significance per the Dunnett Test (Figure 1). Based on these differences, the controls were removed from the graph to better demonstrate the effect of each treatment (Figure 2).

Sufficient statistical evidence was not found to indicate differences between the treatments of the variables of color, DO, and turbidity. However, the analysis for the COD variable revealed that T5 was significantly lower than the rest of the treatments (Figure 3); and for the turbidity variable, differences were found between treatments T5, T8 and T9 (Figure 4). The results indicate that T5 represents the optimal dose, showing significant differences in at least two variables.

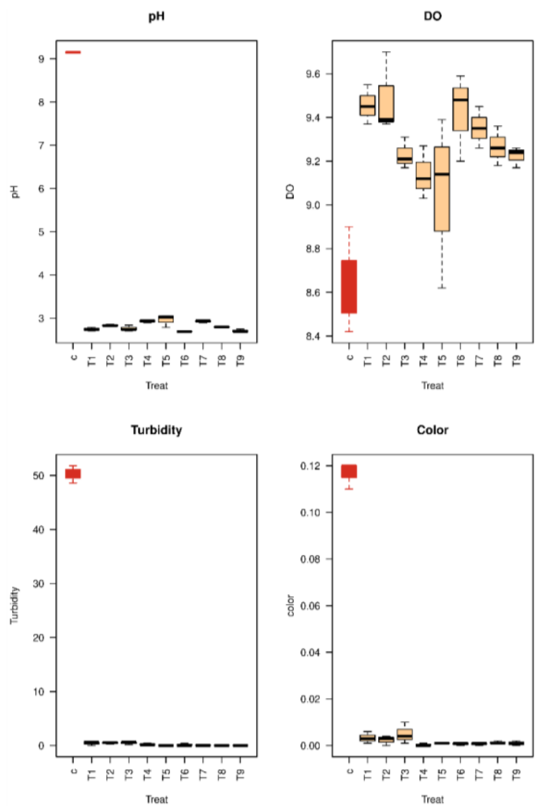


**Figure 1.** Box plot of pH, DO, COD, turbidity, and color as a function of nine treatments and the control (red box).

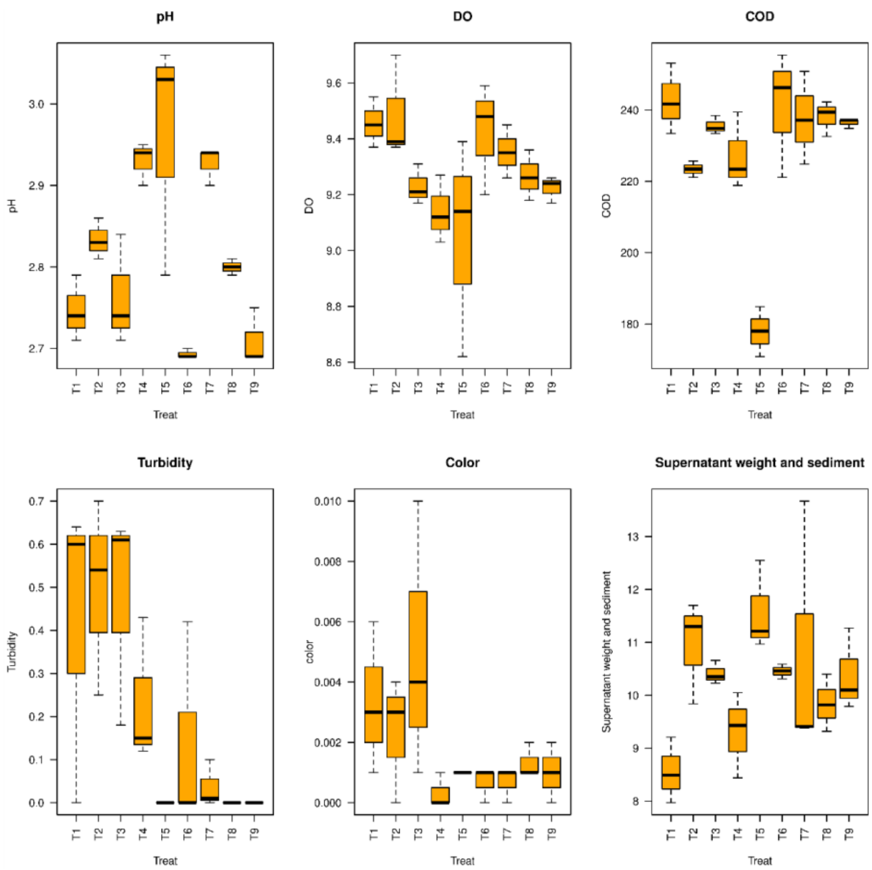


**Figure 2.** Box plot of pH, DO, COD, turbidity, and color as a function of nine treatments.

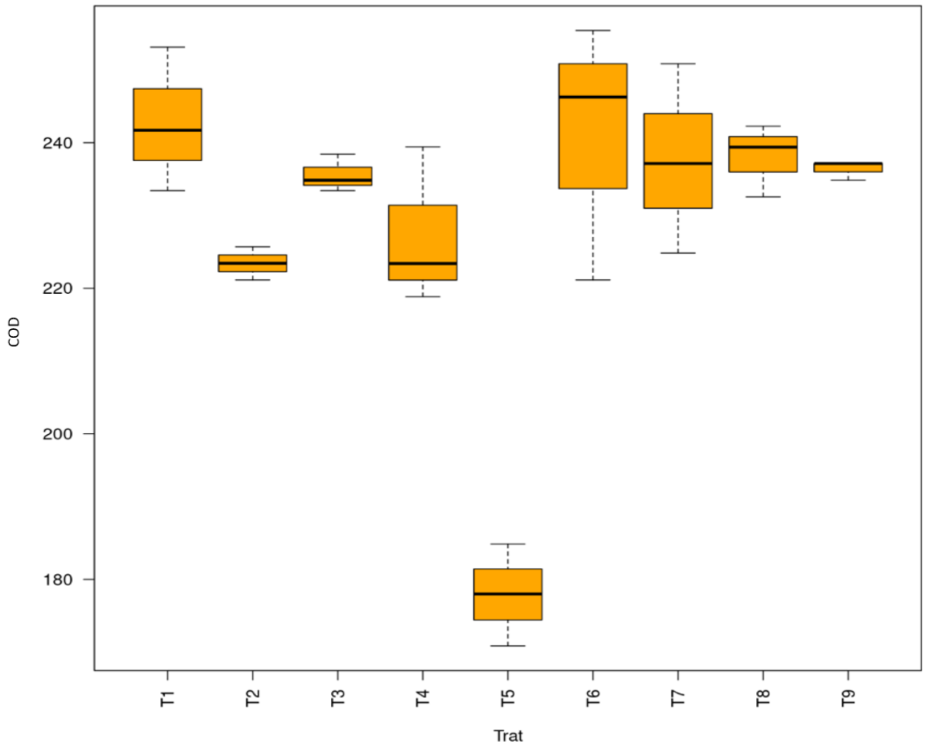


**Figure 3.** Box plot of COD as a function of nine treatments.

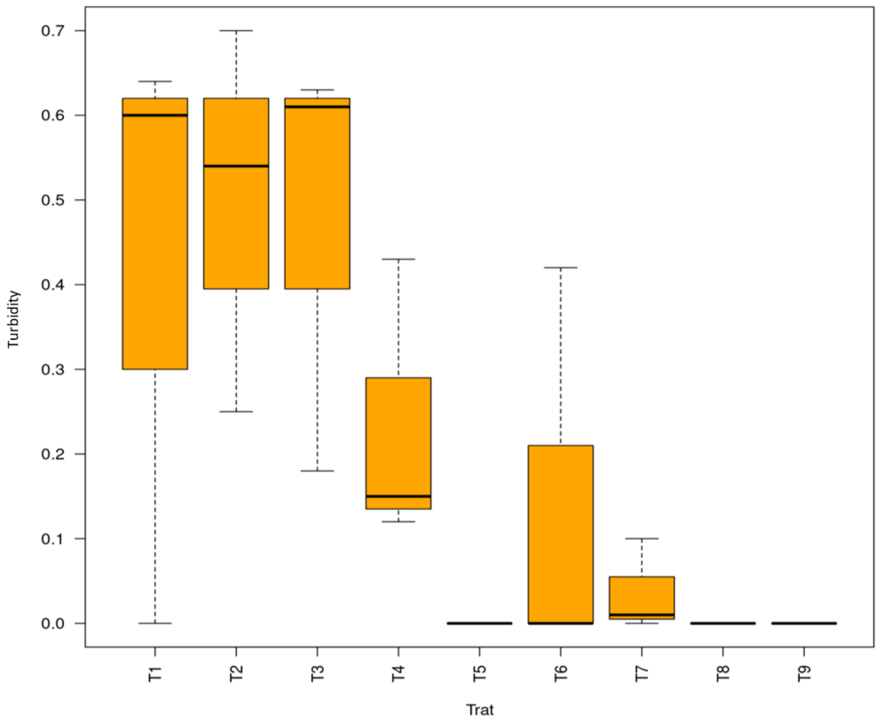


**Figure 4.** Box plot of Turbidity as a function of nine treatments.

### 3.1.2. Efficiency of the Photo-Fenton System

In the second part of the investigation, the variables pH, COD, turbidity, and color, showed lower values than the control (Annex 2) in all treatments, while in the DO variable, it was observed that Treatment 5 presented a higher value to the control (Figure 5). Based on these differences, the controls were removed from the graph to better demonstrate the effect of each treatment (Figure 6).

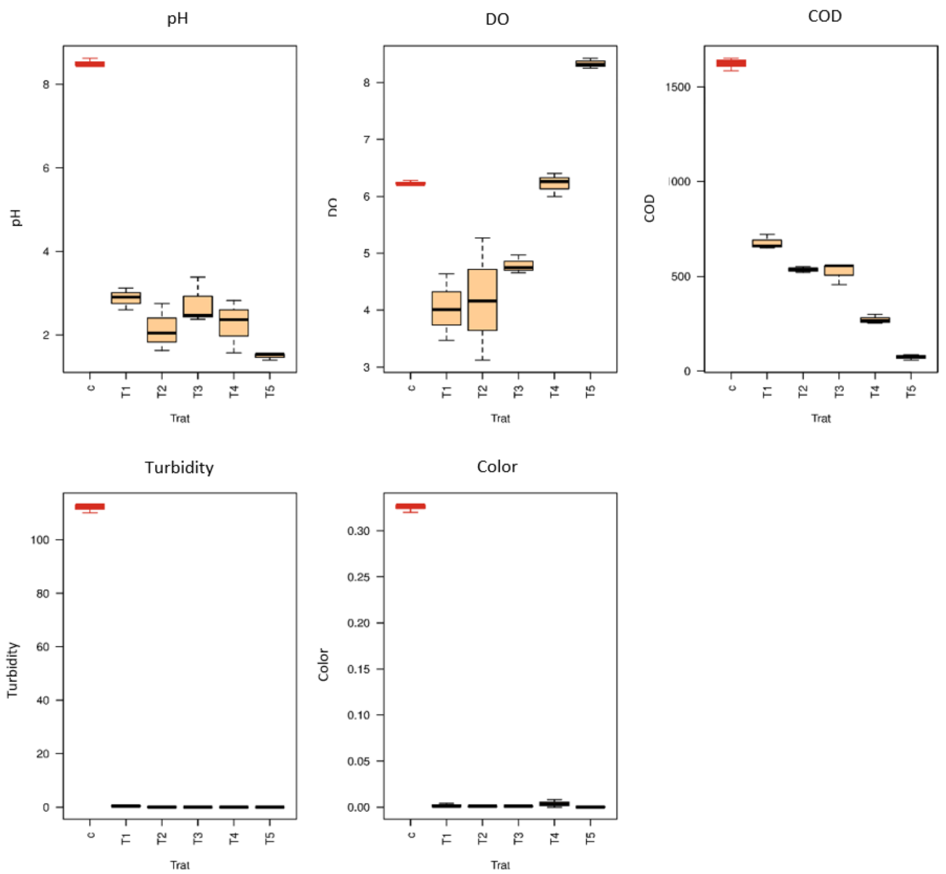


**Figure 5.** Box plot of pH, DO, COD, turbidity, and color as a function of five treatments and the control (red box).

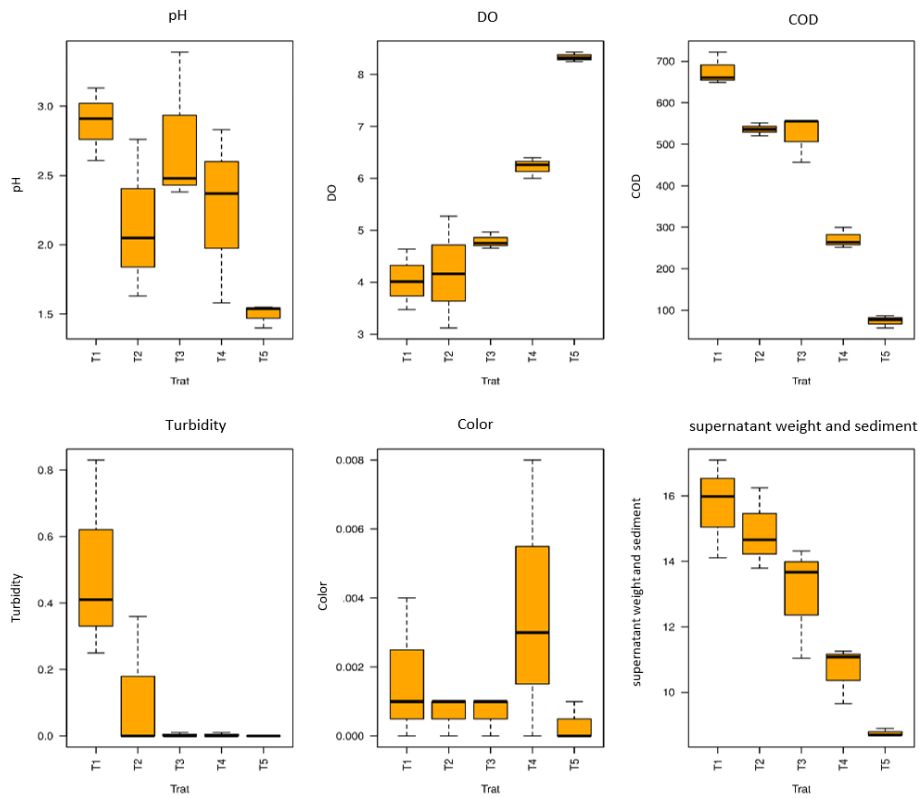


**Figure 6.** Box plot of pH, DO, COD, turbidity, and color as a function of five treatments.

No significant differences were found between the treatments of the variables pH, color and turbidity. However, the variables DO and COD presented statistical evidence of differences between at least two treatments. In this sense, regarding the DO variable, the assumption of normal distribution of the residuals are met, but not for the homogeneity of variances, for which the non-parametric Kruskal-Wallis Test was applied, showing that Treatments T5 and T4 are significantly higher than treatments T1, T2 and T3 (Figure 7). For the COD variable, it was found that both the assumptions of normal distribution of residuals and homogeneity of variances are met, so the analysis of variances was used, finding that T5 presented the least value (Figure 8).

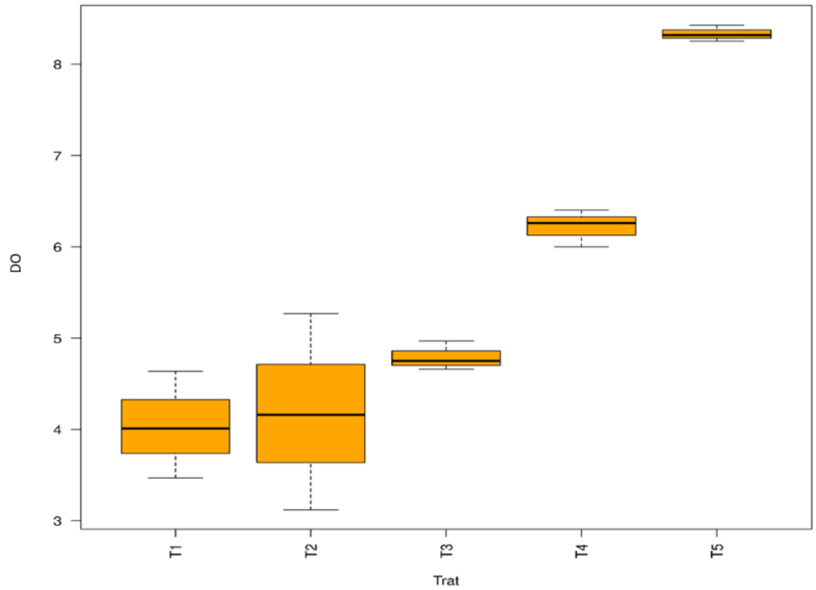


**Figure 7.** Box plot of DO as a function of five treatments.

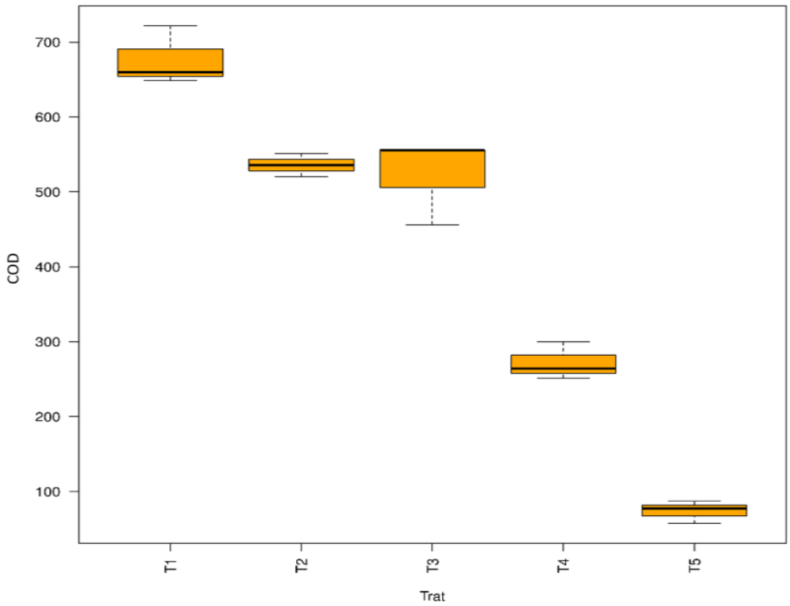


**Figure 8.** Box plot of COD as a function of five treatments.

### 3.2. Discussion

Since the pH of all the samples was homogenized at the beginning of the process, no significant changes in pH were observed between one repetition and another. This is due to the fact that the pH, despite being an important factor in the Fenton Process, should be considered only as a variable to carry out the reaction, and not for purposes of evaluating the efficiency of the Photo-Fenton System, since it is evaluated according to the percentage of contaminant removal (Leon *et al.*, 2020). The pH has a significant effect on the oxidation potential of OH- radicals, where at a pH value of 3 the production of these radicals in the reaction is greater than at higher pH values (Calderon and Olortico, 2019). Likewise, for the optimization of the Photo Fenton Process, the pH of the solution is highly significant as it generates a great impact on the removal of COD, as long as the pH value is 3 (Castrillon and Rubio, 2020).

In the matter of the COD variable, the total number of treatments showed lower values than the control samples, with the highest COD removal being 83% (Treatment 5). Similar results were obtained in a POPs removal study, where the Photo-Fenton treatment managed to reduce the initial COD of the synthetic textile effluent by 86% (Gutierrez and Pilco, 2020). The effectiveness of the process is attributed to the presence of $Fe^{2+}$ in the reagent that favors the formation of OH- radicals and these, at the same time, significantly remove COD (Agudelo Valencia *et al.*, 2020). Treatment 5, having intermediate concentrations of $Fe^{2+}$ and $H_2O_2$, achieved the highest COD removal. This result is similar to the one obtained in a petrochemical effluent treatment study, where a $Fe^{2+}$ concentration of 0.06M generated a COD reduction of 97.5%, while increasing the $Fe^{2+}$ concentration the efficiency of the process was reduced, removing only 80% of COD (Ghosh *et al.*, 2010).

Depending on the turbidity variable, the treatments showed lower values than the control samples, mostly achieving a removal effectiveness of 100% of the initial turbidity. Similar results were obtained in a vinasse treatment study using Electro-Fenton, in which turbidity removal in all trials was greater than 95% and the maximum removal was 98.95% (Marin and Gonzales, 2018). The positive behavior of this variable is directly related to the effectiveness of the chemical (Photo-Fenton Treatment) and physical (filtration) process (Villota *et al.*, 2021) and to the initial acidification process that the samples went through, where the change in pH promoted the formation of flocs and the precipitation of organic matter (Medina Valderrama *et al.*, 2020) which is removed by the post-treatment filtration process (Blanco *et al.*, 2014), achieving total turbidity removal. Another influencing factor is the correctly administered concentration of the reagent, since an excess would have caused the inhibition of oxidation reactions, limiting the precipitation of organic matter (Segovia Obando, 2020).

Regarding the DO, the entirety of the treatments showed higher values than the control samples. This result is attributed to the considerable decrease in COD in the samples, since this allows an improvement in the amount of DO to be observed (Medina Valderrama *et al.*, 2020). In a contaminant treatment study of organic pollutants by Photo-Fenton, it was determined that the increase in DO is related to the concentration of $H_2O_2$, which should not be present in excess. Otherwise, a competitive reaction will be generated between the excess of $H_2O_2$ and OH- radicals and the self-decomposition of $H_2O_2$ into oxygen and water, inhibiting degradation (Silva *et al.*, 2009). In the same way, a high generation of oxygen is an indicator that there is an inefficient consumption of $H_2O_2$, and this would generate inadequate operating conditions (Rodriguez Suarez, 2018).

Furthermore, regarding the color variable, the total number of treatments showed lower values than the control samples. The color removal effect with the Photo-Fenton System may be due to the oxidation, coagulation and adsorption processes caused by the suspension of $Fe^{2+}$ (Calderon and Olortico, 2019). Likewise, by having an adequate concentration of $Fe^{2+}$, maximum color removal will be achieved, since according to a study carried out with $Fe^{2+}$, at concentrations between 100 ppm and 500 ppm it was determined that the concentration of 250 ppm obtained maximum color removal, with a value of 74.23% (Kaya and Asci, 2019). Likewise, another important factor that influences the discoloration of the synthetic textile effluent is the presence of UV rays during the treatment, since it accelerates the formation of OH- radicals, and these, at the same time, react rapidly with the color of the contaminant and lead to a rapid breakdown of the compound's chromophores (Kumar and Ameta, 2013).

Regarding the results of the efficiency of the Photo-Fenton system, it was discovered that Treatment 5 (lower concentration of contaminant) was the only one with higher DO values compared to the other treatments. This is due to the fact that the synthetic colorants present toxic compounds with high molecular weight, causing a decrease in DO. Meanwhile, having a lower concentration of colorants, there is a greater amount of DO (Brañez *et al.*, 2018). Likewise, another factor that influences the increase in DO is having an adequate concentration of $H_2O_2$ in the reagent (Santos *et al.*, 2011). In the same way, there is an inverse relationship between the DO and COD values obtained, mainly attributed to the influence of temperature, in this case UV rays, which generate quite low COD values, and which give rise to high DO values (Rincón and Sanabria, 2020).

# 4. CONCLUSIONS

The Photo-Fenton System, under an optimal concentration of 400 mg/L $Fe^{2+}$ and 12 ml/L $H_2O_2$, achieves the highest removal of contaminants in the synthetic textile effluent, where the presence of $Fe^{+2}$ favors the significant removal of COD and the increase in DO is related to the presence of $H_2O_2$ and UV-A light, which, in turn, considerably influences the removal of color from the effluent. Likewise, the removal of turbidity is obtained by carrying out the treatment in an acid medium (pH 3) which promotes the formation of flocs and precipitates organic matter. This is how it turns out to be an effective procedure for the treatment of textile effluents. Regarding the efficiency of the Photo-Fenton System, it is capable of decontaminating effluents with high and low organic load (100% - 20% physical concentration), reducing parameters such as turbidity, COD and color, and increasing the OD in the samples.

# 5. REFERENCES

AGUDELO VALENCIA, R. N.; OVALLE GONZÁLEZ, D. P.; RODRIGUEZ RODRIGUEZ, L. F. Aplicación de foto fenton (VIS) para la remoción de sulfuros y DQO en aguas residuales de curtiembre. **Luna Azul**, n. 50, 2020. https://doi.org/10.17151/luaz.2020.50.11

AL-TOHAMY, R.; SAMEH, S. A.; FANGHUA, L.; OKASHA, K. M.; MAHMOUD, Y. A.-G.; ELSAMAHY, T. *et al.* A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety. **Ecotoxicology and Environmental Safety**, v. 231, 2022. https://doi.org/10.1016/j.ecoenv.2021.113160

ARKA, A.; ASAITHAMBI, P.; KEBEDE, S. Development of Solar Photo-Fenton Process for the Removal of Color, COD, and Turbidity from Institutional Wastewater. **Journal of Energy, Environmental & Chemical Engineering**, v. 7, n. 2, p. 26-35, 2022. https://dx.doi.org/10.11648/j.jeece.20220702.12

BARLIZA, V.; TORRES, D. **Evaluación de los procesos de oxidación avanzada**: Fenton, UV/H2O2. y Foto-Fenton para la degradación de clorpirifós en aguas residuales a nivel laboratorio en la Universidad de Cartagena. Bogotá: Fundación Universidad de América, 2018.

BLANCO, J.; TORRADES, F.; MORÓN, M.; BROUTA-AGNESA, M.; GARCÍA-MONTAÑO, J. **Photo-Fenton, Coupled biological-Photo Phenton and reverse osmosis processes for textile wastewater reclamation**: Feasibility of use in dying processes. LEITAT Technological Center, Environment R&D Department, 2014.

BRAÑEZ, M.; GUTIERREZ, R.; PEREZ, R.; URIBE, C.; VALLE, P. **Contaminación de los ambientes acuáticos generados por la industria textil**. Escuela Universitaria de Postgrado UNFV N° 26, 2018. p. 129-144.

CALDERON, F.; OLORTICO, S. **Proceso Foto-Fenton para la degradación de color del efluente de industria textil**. Huancayo: Universidad Nacional del Centro del Perú, 2019.

CASTRILLON, M.; RUBIO, A. Optimización del proceso sono-foto-Fenton para el tratamiento de aguas residuales usando un diseño central compuesto. **Producción+ limpia**, v. 15, n. 2, p. 24-45, 2020. https://doi.org/10.22507/pml.v15n2a2

CHAPARRO, C.; CABANZO, R.; MEJÍA OSPINO, E. Estudio de la Adsorción de Azul de Metileno sobre Óxido de Grafeno. **Revista Colombiana de Materiales,** n. 5, p. 131-139, 2014. https://doi.org/10.17533/udea.rcm.19442

CORTAZAR, A.; CORONEL, C.; ESCALANTE, A.; GONZALEZ, C. Contaminación generada por colorantes de la industria textil. **Vida Científica Boletín Científico de la Escuela Preparatoria**, v. 2, n. 3 , 2014.

CRUZ-GONZALEZ, G.; JULCOUR, C.; JÁUREGUI-HAZA, U. El Estado actual y perspectivas de la degradación de pesticidas por procesos avanzados de oxidación. **Revista Cubana de Química**, v. 29, n. 3, p. 492-516, 2017.

DENG, H.; WEI, R.; LUO, W.; HU, L.; LI, B.; DI, Y. *et al.* Microplastic pollution in water and sediment in a textile industrial area. **Environmental Pollution**, v. 258, 2020. https://doi.org/10.1016/j.envpol.2019.113658

GHOSH, P.; SAMANTA, A.; RAY, S. COD reduction of petrochemical industry wastewater using Fenton's oxidation. **The Canadian Journal of Chemical Engineering**, v. 6, p. 1021–1026, 2010. https://doi.org/10.1002/cjce.20353

GUTIERREZ, C.; PILCO, A. Optimization of the removal of persistent organic compounds through the photo-fenton process. **Revista de la Sociedad Química del Perú**, 2020.

HANELA, S.; FANTONI, S.; ROMERO, E.; DÍAZ, S.; CAINZOS, V.; POLLA, G. *et al.* **Procedimiento de elaboración y caracterización de un efluente textil**. Buenos Aires: Universidad Nacional de San Martín, 2018.

KAYA, S.; ASCI, Y. Evaluation of Color and COD Removal by Fenton and Photo-Fenton Processes from Industrial Paper Wastewater. **Journal of the Institute of Science and Technology**, v. 9, n. 3, p. 1539-1550, 2019. https://dx.doi.org/10.21597/jist.507181

KIRUTHIGA, R.; SAMPATH KUMAR, V. Treatment Of Textile Dyeing Wastewater By Applying Photo-Fenton Oxidation Technology. **International Journal of Science and Engineering Research**, v. 3, n. 6, 2015.

KUMAR, D.; AMETA, R. Use of photo-fenton reagent for the degradation of Basic orange 2 in aqueous medium. **Journal of Chemical and Pharmaceutical Research**, v. 5, n. 1, p. 68-74, 2013.

LEON, J.; MEDINA, C.; SEGOVIA, E. Aplicación del método Foto-fenton para el tratamiento de aguas residuales en la industria láctea. **Dominio de las ciencias**, v. 6, n. 3, p. 785-801, 2020.

LITTER, M. Tecnologías avanzadas de oxidación: Tecnologías solares. *In:* BLESA, M.; BLANCO, J. (eds.). **Solar Safe Water**. Buenos Aires: Universidad Nacional de General San Martín, 2005. p. 73-90.

MARIN, E.; GONZALES, F. **Influencia de la concentración de H2O2 y densidad de corriente en la remoción de color y DQO de la vinaza mediante Electro-Fenton**. Trujillo: Universidad Nacional de Trujillo, 2018.

MEDINA FLORES, C. **Degradación de metomilo mediante el proceso de oxidación Foto Fenton en aguas simuladas y aguas reales presente en drenes del Río Majes Sector De Uraca-Corire**. Arequipa: Universidad Nacional De San Agustín de Arequipa, 2019.

MEDINA VALDERRAMA, C.; URIARTE, W.; CARDENAS, E.; SALVADOR, O. Treatment wastewater of slaughterhouses through technology advanced oxidation: fenton process. **Revista Ingeniería UC**, v. 27, n. 2, p. 165-174, 2020.

MEDINA VALDERRAMA, C. J.; MONTERO DEL ÁGUILA, E. M.; CRUZ PIO, L. E. Optimización del Proceso Fenton en el Tratamiento de Lixiviados de Rellenos Sanitarios. **Revista de la Sociedad Química del Perú**, v. 82, n. 4, 2016.

MENDOZA VÁZQUEZ, V. **Sistema híbrido de eliminación de azul de metileno en agua mediante fotocatálisis con catalizador**. Puebla: Universidad Autónoma de Puebla, 2021.

MUÑOZ, A.; ADAME, R.; LIMÓN, P.; SANDOVAL, I. Determinación del valor de sorción de azul de metileno para fillers mediante la técnica de espectrofotometría visible. **Revista Ingeniería de Obras Civiles**, v. 6, p. 16-21, 2016.

NÚÑEZ, Z.; VERGARA, J. Tratamiento de agua residual textil con colorante negro acido empleando procesos avanzados de oxidacion: Fenton y Foto - Fenton. **Jóvenes en la Ciencia**, v. 2, p. 30-34, 2016.

PATIL, A. D.; RAUT, P. D. Treatment of Textile Wastewater by Fenton's Process as an Advance Oxidation Process. **IOSR Journal of Environmental Science, Toxicology and Food Technology**, v. 8, n. 10, p. 29–32, 2014.

RINCÓN, D.; SANABRIA, J. **Estudio comparativo de evaluación del ciclo de vida de procesos de tratamiento de aguas residuales**. Bogotá: Universidad Católica de Colombia, 2020.

RODRIGUEZ SUAREZ, E. **Degradación de genoal a escala piloto por el proceso Foto-Fenton empleando un irradiador UV**. Estado de México: Instituto Tecnologico de Toluca, 2018.

ROSALES PALOMINO, R. **Reducción del contenido de colorantes en efluentes de la industria textil usando el proceso Fenton**. Lima: Universidad César Vallejo, 2017.

SILVA, S.; TRUJILLO, J.; AGUILAR, L.; HINCAPIÉ, M. Tratamiento de contaminantes organicos por Foto Fenton con luz artificial. **Revista Ingenierias Universidad de Medellin**, v. 8, n. 15, p. 53-62, 2009.

SANTOS, L.; GARCÍA, J.; CASAS, J.; OLLER, I.; MALATO, S. Dissolved oxygen concentration: A key parameter in monitoring the photo-Fenton process. **Applied Catalysis B: Environmental,** v. 104, n. 3-4, p. 316-323, 2011. https://doi.org/10.1016/j.apcatb.2011.03.013

SEGOVIA OBANDO, E. **Evaluación de la eficiencia de Foto-Fenton con luz artificial para el tratamiento de aguas residuales de la industria láctea**. Riobamba: Escuela Superior Politécnica de Chimborazo, 2020.

VILLOTA, N.; FERREIRO, C.; QULATEIN, H.; LOMAS, J.; LOMBRAÑA, J. Turbidity Changes during Carbamazepine Oxidation by Photo-Fenton. **Catalysts,** v. 11, n. 8, 2021. https://doi.org/10.3390/catal11080894

WORLD HEALTH ORGANIZATION. **Artificial tanning sunbeds risks and guidance**. Geneva, 2003.

YAN, X.; LI, H.; FENG, J.; HOU, B.; YAN, W.; ZHOU, M. Activated Carbon Assisted Fenton-like Treatment of Wastewater Containing Acid Red G. **Catalysts**, v. 12, n. 11, 2022. https://doi.org/10.3390/catal12111358

## ANNEXES

**Appendix 1.** Results obtained in the laboratory to determine the optimal concentration of Fe2+/H2O2.

| SAMPLES | PARAMETERS | | | | |
|---|---|---|---|---|---|
| | pH | DO | COD | Turbidity | Absorbance |
| **Control Sample 1** | 9.13 | 8.90 | 1018.50 | 50.50 | 0.12 |
| **Control Sample 2** | 9.15 | 8.59 | 1018.00 | 48.60 | 0.11 |
| **Control Sample 3** | 9.16 | 8.42 | 1020.39 | 51.80 | 0.12 |
| **T1.1** | 2.79 | 9.55 | 253.14 | 0.60 | 0.006 |
| **T1.2** | 2.74 | 9.37 | 241.71 | 0.00 | 0.001 |
| **T1.3** | 2.71 | 9.45 | 233.43 | 0.64 | 0.003 |
| **T2.1** | 2.86 | 9.37 | 225.71 | 0.25 | 0.004 |
| **T2.2** | 2.83 | 9.39 | 221.14 | 0.54 | 0.000 |
| **T2.3** | 2.81 | 9.70 | 223.43 | 0.70 | 0.003 |
| **T3.1** | 2.74 | 9.31 | 234.85 | 0.63 | 0.001 |
| **T3.2** | 2.84 | 9.17 | 238.43 | 0.61 | 0.004 |
| **T3.3** | 2.71 | 9.21 | 233.43 | 0.18 | 0.010 |
| **T4.1** | 2.95 | 9.03 | 218.85 | 0.43 | 0.001 |
| **T4.2** | 2.90 | 9.12 | 239.43 | 0.12 | 0.000 |
| **T4.3** | 2.94 | 9.27 | 223.40 | 0.15 | 0.000 |
| **T5.1** | 2.79 | 9.14 | 170.85 | 0.00 | 0.001 |
| **T5.2** | 3.03 | 8.62 | 178.00 | 0.00 | 0.001 |
| **T5.3** | 3.06 | 9.39 | 184.86 | 0.00 | 0.001 |
| **T6.1** | 2.70 | 9.59 | 246.28 | 0.00 | 0.001 |
| **T6.2** | 2.69 | 9.48 | 255.42 | 0.42 | 0.001 |
| **T6.3** | 2.69 | 9.20 | 221.14 | 0.00 | 0.000 |
| **T7.1** | 2.94 | 9.26 | 250.85 | 0.00 | 0.000 |
| **T7.2** | 2.94 | 9.45 | 237.14 | 0.10 | 0.001 |
| **T7.3** | 2.90 | 9.35 | 224.85 | 0.01 | 0.001 |
| **T8.1** | 2.80 | 9.18 | 232.57 | 0.00 | 0.001 |
| **T8.2** | 2.79 | 9.26 | 242.28 | 0.00 | 0.001 |
| **T8.3** | 2.81 | 9.36 | 239.40 | 0.00 | 0.002 |
| **T9.1** | 2.75 | 9.17 | 234.85 | 0.00 | 0.000 |
| **T9.2** | 2.69 | 9.26 | 237.14 | 0.00 | 0.001 |
| **T9.3** | 2.69 | 9.24 | 237.14 | 0.00 | 0.002 |

**Appendix 2.** Results obtained in the laboratory to determine the efficiency of the Photo-Fenton system.

| SAMPLES | PARAMETERS | | | | |
|---|---|---|---|---|---|
| | **pH** | **DO** | **COD** | **Turbidity** | **Absorbance** |
| **Control Sample 1** | 8.45 | 6.21 | 1651.53 | 113.00 | 0.328 |
| **Control Sample 2** | 8.63 | 6.28 | 1629.38 | 110.00 | 0.320 |
| **Control Sample 3** | 8.45 | 6.21 | 1585.09 | 113.00 | 0.328 |
| **T1.1** | 2.91 | 4.64 | 722.02 | 0.41 | 0.001 |
| **T1.2** | 3.13 | 3.47 | 660.01 | 0.25 | 0.000 |
| **T1.3** | 2.61 | 4.01 | 649.08 | 0.83 | 0.004 |
| **T2.1** | 2.76 | 4.16 | 536.00 | 0.00 | 0.001 |
| **T2.2** | 2.05 | 3.12 | 520.49 | 0.00 | 0.000 |
| **T2.3** | 1.63 | 5.27 | 551.50 | 0.36 | 0.001 |
| **T3.1** | 2.48 | 4.75 | 555.44 | 0.00 | 0.001 |
| **T3.2** | 2.38 | 4.66 | 456.23 | 0.00 | 0.000 |
| **T3.3** | 3.39 | 4.97 | 555.44 | 0.01 | 0.001 |
| **T4.1** | 2.37 | 6.40 | 251.60 | 0.01 | 0.000 |
| **T4.2** | 1.58 | 6.26 | 264.00 | 0.00 | 0.003 |
| **T4.3** | 2.83 | 6.00 | 299.63 | 0.00 | 0.008 |
| **T5.1** | 1.54 | 8.43 | 77.13 | 0.00 | 0.001 |
| **T5.2** | 1.55 | 8.25 | 57.24 | 0.00 | 0.000 |
| **T5.3** | 1.40 | 8.32 | 86.80 | 0.00 | 0.000 |