Evaluation of Using Photovoltaic Cell in the Electro-Fenton Oxidation for the Removal of Oil Content in Refinery Wastewater

Salwan Fadhil Alturki *a, Ahmed Hasan Ghareeb b, Raid T. Hadi a, Ali A. Hassan a

a College of Engineering, Al Muthanna University, Al Muthanna, Iraq.
b College of Engineering, University of Kirkuk, Kirkuk, Iraq.
*Corresponding author: salwan.fadil@mu.edu.iq

Abstract. In this study, the refinery wastewater treatment system by the photovoltaic electro-Fenton oxidation process was presented, which integrates the environmentally friendly photovoltaic and autonomous solar energy along with the capability of electro for oil content removing in the refinery wastewater. The direct connection between the photovoltaic panel and the electro-oxidation reactor can be accomplished without using batteries. This connection increases the sustainability of the system and eliminates the environment hazard resulted from the inappropriate disposal of the batteries. The photovoltaic electro-oxidation system is commonly made for multipurpose usage depending on the instantaneous solar irradiation by setting the volume of the wastewater to the supplied current intensity that provided by the photovoltaic array. The effect of several parameters that have critical impacts on the system efficiency of the presented process has studied by the Minitab-17 and the response surface methodology. Speed of agitation, solution electrolysis time, and the temperature have been presented and the optimal levels that corresponds to the optimal conditions were investigated and presented as well. Results of the experimental work showed that the working conditions of the agitation speed was 175 rpm, temperature was 70 °C and 15 min- reaction time, the concentration of oil in the treated refinery wastewater (RWW) was significantly decreased from 96.5 ppm (initial value) to specific values less than 2 ppm (the permissible limit), a removal percentage with an amount more that 98% and 20.4 kWh/m3 for the energy consumption were obtained. The suggested process is suitable for refinery wastewater remediation, especially for small amounts of oil content in RWW.

Keywords: Solar energy; photovoltaic cell; Refinery wastewater; Oil content; advanced oxidation processes.

1. Introduction
Throughout the refining process, the crude oil is typically transformed into several by-products and petroleum. A large volume of wastewater products is generated through the refinery process. [1], [2]. The average consumption of water to remedy one barrel of crude oil is estimated by 246–341 L. The refining petroleum process may produce about 0.4-1.6 times volume of oil as a wastewater [3]. Pollutants are mostly showing toxicity even at low micro levels [4]. The composition of polluted water is extremely complex and variable. Several groups of the hydrocarbon are presented throughout the RWW process, such as, alkynes, alkenes, aromatics, alkanes and polynuclear aromatics [5], [6]. These compounds are considered volatile and toxic. The materials are very toxic in their nature [7]. Practically, the organic compounds concentration was found within the range of 20–200 ppm [8]. In the operation of crude oil production, the brine handling is necessary. Indeed, the brine is produced with the crude oil.
Water separation process is critical to separate water from crude oil, and then disposed it out in a specific manner where assure no environment violation [9]. The bioremediation and the physical–chemical methods that usually used for compounds degradation have presented several operational shortcuts and problems. Such these operational methods and problems are production of toxic intermediates, effluent partial degradation, generation of secondary phases and energy consumption. Where these problems added extra costs for the process [10], [9]. Conservative treatment developments have been institute to be fewer active for removing approximately pollutants from wastewater due to their intractable and non-biodegradable natures and poisonous [12]. These useful reuses proportionally decreases the potable water withdrawal and highly valuable product for several regions of the world [13], [14]. Several common techniques have been adapted for oil removing from the wastewater, such as coagulant mixtures [15], the biological treatment [16], adsorption [17], [18], and membrane separation technique [19],[20]. However, no one of these treatments’ approaches were an active to treat the produced water. Extra treatment stage is optional which is considered as an advanced oxidation processes (AOPs) [21], [22]. AOP has become a widespread process for organic removing from the wastewaters [23], [24]. Furthermore, AOPs show the ability for intractable contaminants fast degradation in the environment of water. These procedures could completely degrade the contaminants into inoffensive inorganic materials below reasonable working conditions, such as H2O and CO2 [25]. Recently, people put more attention on developments of the chemical oxidation, which known by electro-Fenton [26]. The process includes in-situ generation of highly reactive oxidizing reagent, where hydroxyl radicals (•OH radicals) reacting with ferrous ions in the system, and then hydrogen peroxide (H2O2) is generated. The main limitations of this process are the narrow value of the working pH range (2.0–3.0), and also iron that is left over in the treated water [10]. Among them, the advanced electrochemical oxidation processes (AEOPs) have emerged over the last decade as novel smart techniques for a broad-range for the organic pollutants treatment that do not need reagent introduction. This is because its generation from the redox reactions [27]. The system of Electro-Fenton, which shows an environment friendly and efficient technique which was used for oxidized dye preparation by the adding (SC-Fe2+) as catalyst and different dosages of H2O2 as oxidizing agent. On the other side, fast oxidation process of Fe(II) can be avoided by the citrate ions, which could enhance the efficiency of reaction of the Electro-Fenton system [28],[29].

\[
Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO^- + HO^+
\]  
\[
O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \]  
\[
O_2 + H_2O + 2e^- \rightarrow HO_2^- + HO^-
\]

This work concerned on using the photovoltaic Electro-Fenton Oxidation to remove oil from refinery wastewater, and also find the optimum level values of agitation speed, moreover investigation the effects of temperature and time of the electrolysis in photovoltaic Electro-Fenton Oxidation.

2. Materials and methods

2.1. Refinery wastewater

Refinery wastewater contaminated along with oil dews analyst was kindhearted provided through the native Iraqi refinery, located at Muthanna/Samawa. The RWW secondhand in these investigations are presence elated from refinery exposed to the atmosphere and formerly earmarked in a location analogous to their innate home that contains oxygen undecided the behavior process is appreciated. The refinery wastewater description is presumed in Table 1.
Table 1. Characteristics of RWW

| Parameter               | Value           |
|-------------------------|-----------------|
| Organic content         | 96.5 (mg/l)     |
| Turbidity               | 60.1 NTU        |
| pH                      | 6.85            |
| Solution oxygen content | 0.051 (mg/l)    |
| Specific gravity        | 0.994           |
| Conductivity            | 100151 μs/cm    |
| TDS                     | 64069.64 (mg/l) |
| Viscosity               | 1.104 m Pa/S    |
| Iron                    | 0.29 (mg/l)     |
| Sulphate                | 55.7 (mg/l)     |

2.2. Electrodes and photovoltaic cell

The electrodes utilized in this work were iron and stainless steel applied as cathode and anode, respectively. The iron electrode dimensions were (10 × 8 × 0.3) cm³. The electrode made from stainless-steel has dimensions of (10 × 8 × 0.1) cm³. In the Electro-Fenton process, the electrodes effective area was maintained at 30 cm², while the space of the inner electrode was maintained at 5 cm. The electrochemical cell (as presented in Fig. 1a) is made of four acrylic blocks. Gaskets that made from silicon rubber sheets were inserted between blocks in order to avoid leakages. This cell configuration allows two possible positions for the anode in the anolyte compartment: at the end-plate (between the acrylic blocks so the anode will be z1 cm far from the cathode, as shown in Fig. 1b).

Figure 1. a: flow-cell main parts. b: the hydraulic circuit, solar panel, and the flow-cell.

2.3. Adsorbate and analytical measurements

All substances used in this current study are a logical grade, hydrogen peroxide (45% wt. /wt.) from Germany , H₂SO₄ (98% purity) , sodium chloride (99 % purity ) and NaOH (98% purity) were bought from India. The oil content in the refinery wastewater was strong-minded at all-out absorption
wavelength (312 nm) by a UV–spectra meter (UV-1800 Shimadzu, manufactured in Japan) associated to a PC. The capacities of pH were made by means of pH meter (Model 2906, Jenway Ltd, manufactured in UK) and turbid meter (Lovibond, SN 10/1471, manufactured in Germany), respectively. The INO Lab device: this instrument stretches a straight interpretation for electrical conductivity and total dissolved solid concentration (TDS) in the petroleum wastewater in (ppm).

2.4. Electro oxidation procedure
In electro-Fenton process, the experiment was accomplished in a batch reactor consisting of a glass reactor of 1000 mL. 350 mL of RWW was placed and initial value of pH was adapted to 5 by 1N H2SO4 and NaOH. The used electrodes were associated to direct current power supply (RXN-305D) provided by the solar energy, and additional 0.25 gm of NaCl. DC voltage was kept as 29.6 v. The power supply was functioned for (5 min) to sweep the ions of the iron in the reactor and then added 15 ppm of H2O2 when the current was fixed at 1 amps for all experiments as shown in Fig.2. The resulted samples were reserved at unvarying time intervals, centrifuged at 3000 rpm (to distinct the sludge) for 5 min and the supernatant material was calm for oil approximation. Reduction of oil was defined as the residual organic ratio at the time t (Ct) to initial oil in refinery wastewater (Co). Several studies were approved out through varying the rpm, temperature and time. Before using the electrodes in E-Fenton process, they were thoroughly water gutted for elimination any extra debris. The electrodes were then soaked in 1N HCl for 1 hour and shadowed through 1M NaOH for the next hour. The electrodes were stored in distilled water, when they were not in use. Afterward each usage, the 1M NaOH and 1N HCl are used to erode electrodes to eliminate any possible pollution.

![Figure2. Schematic of the electro oxidation reactor](image)

The consumption of the energy (kWh/m³) is very important feature in such type of treatment methods, so, it was intended by using Eq.4 as [30]:

$$E = \frac{(U.I.t)}{(1000V)}$$  \hspace{1cm} (4)

Where I refers to the applied current (Amps.), U refers to the applied voltage (volt), t refers to contact time (h), and V is the RWW volume (m³).

2.5. AOPS treatment
The change in the oil content concentration in RWW during the process of electro oxidation was measured using UV spectrophotometer (UV-1800 Shimadzu, Japan) at 312 nm and the consequences were rehabilitated into the conforming concentrations (C). The efficiency of oil removal could be calculated as per Eq. (5):

$$\eta = \frac{C_o - C_t}{C_o} \times 100$$  \hspace{1cm} (5)

Where $\eta$ refers to the percentage value of oil removal, $C_0$ refers to the concentration measured before the treatment process (mg/L), and $C_t$ refers to the value of concentration after treatment process (ppm).
2.6. Experimental design

In this work, experimental conditions for RWW mineralization via the process of electro-Fenton was optimized utilizing the technique of central composite design (CCD) under RSM. Minitab-17 was used as an experimental design software, analysis of data, extraction of quadratic model, and plotting of graphs. The independent variables such as the time of electrolysis (X1), rpm (X2) and temperature (X3) were coded with their high and low levels in the CCD as listed in Table 2. Table 3 lists the required operational variables (i.e. coded and natural) with the Minitab used for the experimental systems.

| Table 2. Operational parameters |
|---------------------------------|
| Parameters                      | levels  |
| X1: time of electrolysis (min)  | 5-15    |
| X2: rpm                         | 100-200 |
| X3: temperature(°C)             | 30-70   |

| Table 3. Operational variables (natural and coded) |
|---------------------------------------------------|
| Natural Variables (Xi)                            | Coded Variables |
|                                                  | -2 | -1 | 0  | 1  | 2  |
| X1: time of electrolysis (min.)                   | 5  | 7.5| 10 | 12.5| 15 |
| X2: rpm                                           | 100| 125| 150| 175 | 200|
| X3: temperature(°C)                              | 30 | 40 | 50 | 60  | 70 |

In this work, the correlation coefficients suitability and their accuracy were evaluated using Chi-square ($\chi^2$) in accordance with Eq. (6): where the magnitude of this indicator must be the minimum one. The higher coefficient of correlation (i.e. $R^2$) with the lower value of $\chi^2$ indicates the reliable application of the proposed model.

$$\chi^2 = \frac{(Y_{exp} - Y_{cod})^2}{Y_{cod}}$$ (6)

Where $Y_{exp}$ and $Y_{cod}$ represent the experimental and coded responses, respectively.

2.7. Measurement of organic content in RWW

NaCl with mass equal to 0.25 gm was added to 50 ml wastewater of petroleum in the separating funnel for breaking the organic emulsion. CCL4 with 5 ml was added and strongly shaken for two minutes. Once the solution has been separated into two distinctive types of coating (after 25 minutes), the lower (organic) layer was taken to measure the absorbance. Calibration curve was used to obtain the organic.

3. Results and discussion

3.1. Regression models

The relationship between responses versus independent variables could be acquired from using the second-order model with a least-squares method [10]:

$$Y = B_0 + \sum_{i=1}^{q} B_i X_i + \sum_{i=1}^{q} B_{ii} X_i^2 + \sum_{i} \sum_{j} B_{ij} X_i X_j + \varepsilon$$ (7)

Where the symbol Y denotes to the studied responses. Symbols $X_1, X_2, \ldots X_q$ represent the operational variables. Symbol $B_0$ refers to the constant of regression and $B_i$ is the coefficient of linear regression. While, $B_{ii}$ and $B_{ij}$ are the squared regression and the cross-product regression coefficients, respectively.
Symbol $\varepsilon$ refers to the random error. Table (4) lists the operational variables values, studied responses’ percentage removal (oil removal), final consumption of energy and pH.

**Table 4. Studied variables results**

| Run | $X_1$: Electrolysis time (min) | $X_2$: rpm | $X_3$: Temperature ($^\circ$C) | Oil removal (%) | Final pH | $E$ (kWh/m$^3$) |
|-----|-------------------------------|------------|---------------------------------|-----------------|---------|-----------------|
| 1   | 7.5                           | 125        | 40.00                           | 78.5            | 3.41    | 12.20833        |
| 2   | 12.5                          | 125        | 40.00                           | 91.3            | 3.89    | 20.34722        |
| 3   | 7.5                           | 175        | 40.00                           | 88.6            | 3.5     | 12.20833        |
| 4   | 12.5                          | 175        | 40.00                           | 95.6            | 3.75    | 20.34722        |
| 5   | 7.5                           | 125        | 60.00                           | 90.5            | 3.17    | 12.20833        |
| 6   | 12.5                          | 125        | 60.00                           | 94.9            | 3.77    | 20.34722        |
| 7   | 7.5                           | 175        | 60.00                           | 93.6            | 3.22    | 12.20833        |
| 8   | 12.5                          | 175        | 60.00                           | 98.07196        | 3.85    | 20.34722        |
| 9   | 5                             | 150        | 50.00                           | 88.9            | 3.16    | 8.13889         |
| 10  | 15                            | 150        | 50.00                           | 96.5            | 4.15    | 24.41667        |
| 11  | 10                            | 100        | 50.00                           | 85.6            | 3.52    | 16.27778        |
| 12  | 10                            | 200        | 50.00                           | 95.4            | 3.43    | 16.27778        |
| 13  | 10                            | 150        | 30.00                           | 82.45           | 3.28    | 16.27778        |
| 14  | 10                            | 150        | 70.00                           | 98.07196        | 3.31    | 16.27778        |
| 15  | 10                            | 150        | 50.00                           | 92.5            | 3.58    | 16.27778        |
| 16  | 10                            | 150        | 50.00                           | 93.05           | 3.46    | 16.27778        |
| 17  | 10                            | 150        | 50.00                           | 92.89           | 3.47    | 16.27778        |
| 18  | 10                            | 150        | 50.00                           | 91.9            | 3.52    | 16.27778        |
| 19  | 10                            | 150        | 50.00                           | 92              | 3.59    | 16.27778        |
| 20  | 10                            | 150        | 50.00                           | 92.4            | 3.44    | 16.27778        |

3.1.1 Agitation speed effect

Electro-Fenton oxidation of organic content in RWW was investigated using different agitation degrees. The results showed that increasing the speed of stirrer led to increase oil removal in a linear trend, which reached a maximum of 95.6 % for 175 rpm with 12.5 min, 15 ppm hydrogen peroxide, temperature 40 $^\circ$C and pH of 6 as shown in (Fig. 3). Lower oil removals were attained for speed $\leq 100$ rpm, which were 85.6 % in the same condition. The mass transfer was found to be higher when the agitation was higher [31]. Treatment of wastewater and synthetic liquid waste from the tanning and textile industries were investigated and it was found that stirring speed has a great impact on the electrochemical process [32]. Therefore, the oxidation improvement could be ascribed to higher mass transfer offered by agitation.

![Figure 3. Influence of agitation speed on the removal efficiencies of RWW.](image-url)
3.1.2 Electrolysis time effect
Experiments with operating treatment conditions of 96.5 ppm organic content in RWW and pH 3 were conducted to evaluate the effect of electrolysis time. Maximum removal was achieved using 175 rpm and 1 Am at least for 15 minutes, the removal efficiency of organic from RWW was increased as electrolysis time has been increased as shown in Fig. 4. This results is in agreement with that of previous study which was stated in Ref. [33]. Higher electrolysis time resulted in higher removal efficiencies of organic contents from the wastewater solution. This could be ascribed to the existence of a considerable activity of the adsorption throughout the electrochemical process as the electrolysis time has been prolonged [34]. In addition, long oxidation times led to a step-by-step detoxification before inorganic tin and CO2 were formed [35], thus obtaining completed mineralization.

![Figure 4. Influence of electrolysis time on the removal efficiencies of RWW.](image)

3.1.3 Temperature effect
Fig. 5 exhibited the temperature effect in the range between 25 to 70 °C on the electro-Fenton oxidation of organic content in RWW. It was found that the oil removal reached 98.07 % for 150 rpm with 10 min, 15 ppm hydrogen peroxide and temperature value is 60 °C. The oil removal at 70 °C was 1.15 times higher than that at 25° C. It was observed that the rate of reaction could be increased with increasing the temperature for both electrolytes. The findings were justified in terms of temperature influence on the reaction intermediates’ adsorption, anions, and poisons [36]. Increasing the temperature resulted in increasing the efficiency of electro-oxidation process for all organic. This suggests that rising the temperature will increase the electro-oxidation rate of organic materials existed in the wastewater [37].

![Figure 5. Influence of temperature (in °C) on the removal efficiencies of RWW.](image)
3.2 Optimizing the operational variables
Optimum values of operational variables such as electrolysis time, rpm and temperature were obtained utilizing Minitab-17. Fig. 6 describes the measurements results of the D-optimization. Optimum removal efficiencies of organic compounds were greater than 98 %.

![Figure 6. Optimum operational variables and the validated studied responses of RWW treatment](image)

3.3 Mathematical correlation of the studied responses
The second-order relationship (Eq. 7) was used for the evaluation of mathematical correlations of the removal organic content responses that related to the operational variables. Table 5 lists the real and coded coefficients of the oil removal and their quadratic relationships.

| Responses | terms | Mathematical correlations |
|-----------|-------|--------------------------|
| Y^{OCR}   | \( Y_{\text{exp}}^{OCR} \) % = -56.6 + 5.38X_1 + 0.657 X_2 + 2.053X_3 + 0.0083X_1^2 + 0.000797X_2^2 - 0.00558 X_3^2 - 0.001146 X_1 X_2 - 0.0546X_1X_3 - 0.0046 X_2X_3 |
| Oil Removal: | \( Y_{\text{cod}}^{OCR} \) % = -56.6 + 5.38X_1 + 0.657 X_2 + 2.053X_3 + 0.0083X_1^2 + 0.000797X_2^2 - 0.00558 X_3^2 + 0.001146 X_1 X_2 - 0.0546X_1X_3 - 0.0046 X_2X_3 |
| R^2      | R^2 (adjusted) | R^2 (predicted) |
| 0.9551   | 0.9146      | 0.970               |

Table 5 shows high values of the R^2 for real and coded responses which are highly needed for confident correlations and the predicted R^2 values were almost in agreement with adjusted ones. In order to examine the accuracy and suitability of correlation coefficients, the Chi-square (\( \chi^2 \)) test was applied as listed in Table (6). Higher values of R^2 with lower values of \( \chi^2 \) indicated that the model was applicable.
Table 6. Chi-square ($\chi^2$) test for the studied responses

| Run | $Y_{exp}$% | $Y_{cod}$% | $\chi^2$ |
|-----|-----------|-----------|---------|
| 1   | 78.5      | 76.417    | 0.05679107 |
| 2   | 91.3      | 85.7045   | 0.36532061 |
| 3   | 88.6      | 83.8145   | 0.273234467 |
| 4   | 95.6      | 90.237    | 0.318735873 |
| 5   | 90.5      | 86.357    | 0.198761525 |
| 6   | 94.9      | 90.0045   | 0.266274689 |
| 7   | 93.6      | 89.1545   | 0.221665426 |
| 8   | 98.07196  | 89.937    | 0.735821455 |
| 9   | 88.9      | 82.63     | 0.475770301 |
| 10  | 96.5      | 92.7      | 0.155771305 |
| 11  | 85.6      | 81.8      | 0.176528117 |
| 12  | 95.4      | 89.13     | 0.441073713 |
| 13  | 82.45     | 80.4055   | 0.051986248 |
| 14  | 98.07196  | 90.0455   | 0.715461185 |
| 15  | 92.5      | 87.4575   | 0.290733285 |
| 16  | 93.05     | 87.4575   | 0.357614341 |
| 17  | 92.89     | 87.4575   | 0.337444544 |
| 18  | 91.9      | 87.4575   | 0.225661679 |
| 19  | 92        | 87.4575   | 0.235935224 |
| 20  | 92.4      | 87.4575   | 0.279316311 |

3.4 Estimation of energy consumption

Adopting of electrochemical technology to treat the effluent should take some aspects in the consideration for making its application feasible (i.e. anode material performance, consumption of energy and cost of operation). Fig. 7 shows the consumption of energy in terms of electrolysis time and current during the electro-Fenton treatment of organic in RWW. Clearly, the energy consumption values were linearly proportional to the applied time during electrochemical treatment for all types of water [11].

Figure 7. Influence of electrolysis time on the consumption of energy for the treatment of RWW
Depending on the optimum value of electrolysis time that was obtained before (i.e. 12.5 min), the energy consumption is equal to 20.4 kWh/m³. It was noticed that the consumption of energy increased with increasing the electrolysis time which implies that the electrolysis time is the most important parameter in measuring the consumption of energy, which is also indicated in Ref. [38].

4. Conclusions

This study showed the feasibility of using the electro-Fenton oxidation in treating RWW contains oil by direct connection of the electro-oxidation reactor to the photovoltaic generator. The provided current from the photovoltaic array depended on the photovoltaic modules’ temperature and solar irradiation. Operational conditions were optimized and presented to achieve the best results with the highest reduction in oil content. For all tested samples, the response shows high regression coefficients were obtained in the proposed mathematical correlations, and demonstrating that the second-order polynomial model has been modified adequately. At pH 3, and the reaction time of 15 min and at the temperature of 70 °C, the optimal percentage of oil removal was reached to 98%. The suggested photovoltaic electro-oxidation method may have advantages in wastewater treatment in remote areas where there is a scarcity of electric power. In addition, the process eliminates battery maintenance problems and improves the sustainability of the system. The electro-Fenton operation can be recommended as a simple and effective method for RWW treatment.

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References

[1] A. A. Hassan and Haider T. Naeem, “A Comparative Study of Chemical Material Additives On Polyacrylamide to Treatment of Waste Water in Refineries,” IOP Conf. Series: Materials Science and Engineering, 518, 2019.
[2] A. Fakhru’l-Razi, A. Pendashteh, L. C. Abdullah, D. R. A. Biak, S. S. Madaeni, and Z. Z. Abidin, “Review of technologies for oil and gas produced water treatment,” J. Hazard. Mater., vol. 170, no. 2, pp. 530–551, 2009.
[3] A. A. Aziz, W. M. A. W. Daud, and others, “Oxidative mineralisation of petroleum refinery effluent using Fenton-like process,” Chem. Eng. Res. Des., vol. 90, no. 2, pp. 298–307, 2012.
[4] B. H. Diya’uddeen, S. R. Pouran, A. A. Aziz, S. M. Nashwan, W. M. A. W. Daud, and M. G. Shaaban, “Hybrid of Fenton and sequencing batch reactor for petroleum refinery wastewater treatment,” J. Ind. Eng. Chem., vol. 25, pp. 186–191, 2015.
[5] G. T. Tellez, N. Nirmalakhandan, and J. L. Gardea-Torresdey, “Comparison of purge and trap GC/MS and spectrophotometry for monitoring petroleum hydrocarbon degradation in oilfield produced waters,” Microchem. J., vol. 81, no. 1, pp. 12–18, 2005.
[6] Y. O. Fouad, “Separation of cottonseed oil from oil–water emulsions using electrocoagulation technique,” Alex. Eng. J., vol. 53, no. 1, pp. 199–204, 2014.
[7] S. Shokrollahzadeh, F. Golmohammad, N. Naseri, H. Shokouhi, and M. Arman-mehr, “Chemical oxidation for removal of hydrocarbons from gas–field produced water,” Microchem. J., vol. 81, no. 1, pp. 12–24, 2005.
[8] E. Hernández-Francisco, J. Peral, and L. M. Blanco-Jerez, “Removal of phenolic compounds from oil refinery wastewater by electrocoagulation and Fenton/photo-Fenton processes,” J. Water Process Eng., vol. 19, pp. 96–100, 2017.
petrochemical industry using Ti/IrO2–Ta2O5 and BDD in flow reactor,” Chem. Eng. J., vol. 233, pp. 47–55, 2013.

[11] J. R. Alvarez-Corena, J. A. Bergendahl, and F. L. Hart, “Advanced oxidation of five contaminants in water by UV/TiO2: reaction kinetics and byproducts identification,” J. Environ. Manage., vol. 181, pp. 544–551, 2016.

[12] M. Fathy, M. El-Sayed, M. Ramzi, and O. H. Abdelraheem, “Adsorption separation of condensate oil from produced water using ACTF prepared of oil palm leaves by batch and fixed bed techniques,” Egypt. J. Pet., 2017.

[13] S. A. O. Galvão, A. L. Mota, D. N. Silva, J. E. F. Moraes, C. A. Nascimento, and O. Chiavone-Filho, “Application of the photo-Fenton process to the treatment of wastewaters contaminated with diesel,” Sci. Total Environ., vol. 367, no. 1, pp. 42–49, 2006.

[14] R. Hosny, M. Fathy, M. Ramzi, T. A. Moghny, S. E. M. Desouky, and S. A. Shama, “Treatment of the oily produced water (OPW) using coagulant mixtures,” Egypt. J. Pet., vol. 25, no. 3, pp. 391–396, 2016.

[15] Q. Li, C. Kang, and C. Zhang, “Waste water produced from an oilfield and continuous treatment with an oil-degrading bacterium,” Process Biochem., vol. 40, no. 2, pp. 873–877, 2005.

[16] G. A. El-Din, A. A. Amer, G. Malsh, and M. Hussein, “Study on the use of banana peels for oil spill removal,” Alex. Eng. J., 2017.

[17] Haider T. Naeem and Ali A. Hassan, “EFFECTIVENESS & ECONOMY OF SAWDUST WOOD ADSORBENTS IN REMOVING ANIONIC DYES OF AQUEOUS SOLUTIONS,” 15, pp. 311–320, 2018.

[18] M. Zoubek, M. Ismail, A. Salama, and A. Henni, “New developments in membrane technologies used in the treatment of produced water: A review,” Arab. J. Sci. Eng., pp. 1–26, 2017.

[19] T. Zsirai, H. Qiblawey, P. Buzatu, M. Al-Marri, and S. J. Judd, “Cleaning of ceramic membranes for produced water filtration,” J. Pet. Sci. Eng., vol. 166, pp. 283–289, 2018.

[20] J. M. Poyatos, M. Muñío, M. Almecija, J. Torres, E. Hontoria, and F. Osorio, “Advanced oxidation processes for wastewater treatment: state of the art,” Water. Air. Soil Pollut., vol. 205, no. 1–4, p. 187, 2010.

[21] J. J. Rueda-Márquez, M. Sillanpää, P. Pocostales, A. Acevedo, and M. A. Manzano, “Post-treatment of biologically treated wastewater containing organic contaminants using a sequence of H2O2 based advanced oxidation processes: photolysis and catalytic wet oxidation,” Water Res., vol. 71, pp. 85–96, 2015.

[22] P. V. Nidheesh and R. Gandhimathi, “Combined heterogeneous Electro-Fenton and biological process for the treatment of stabilized landfill leachate,” Clean Technol. Environ. Policy, vol. 13, no. 2, pp. 241–268, 2011.

[23] S. B. Hammouda et al., “Efficient heterogeneous electro-Fenton incineration of a contaminant of emergent concern-cotinine-in aqueous medium using the magnetic double perovskite oxide Sr2FeCuO6 as a highly stable catalayst: Degradation kinetics and oxidation products,” Appl. Catal. B Environ., vol. 240, pp. 201–214, 2019.
[28] X. Dang, H. Chen, Z. Shan, W. Zhen, and M. Yang, “The oxidation of potato starch by Electro-Fenton system in the presence of Fe (II) ions,” Int. J. Biol. Macromol., vol. 121, pp. 113–119, 2019.

[29] G. Buftia, E. Rosales, M. Pazos, G. Lazar, and M. A. Sanromán, “Electro-Fenton process for implementation of acid black liquor waste treatment,” Sci. Total Environ., vol. 635, pp. 397–404, 2018.

[30] F. Y. AlJaber, “Investigation of electrocoagulation reactor design effect on the value of total dissolved solids via the treatment of simulated wastewater,” DESALINATION WATER Treat., vol. 120, pp. 141–149, 2018.

[31] S. Sundarapandian, V. Sivakumar, G. Rajeswari, and P. Saravanan, “Effect of Sonication on Electro-Oxidation of Organic Pollutants in Saline Wastewater,” Water Environ. Res., vol. 81, no. 3, pp. 319–324, 2009.

[32] L. Szpyrkowicz, “Application of electrochemical oxidation for treatment of industrial wastewater—the influence of reactor hydrodynamics on direct and mediated processes,” J. Chem. Technol. Biotechnol. Int. Res. Process Environ. Clean Technol., vol. 81, no. 8, pp. 1375–1383, 2006.

[33] M. Gaber, N. Abu Ghalwa, A. M. Khedr, and M. F. Salem, “Electrochemical Degradation of Reactive Yellow 160 Dye in Real Wastewater Using C/PbO 2-, Pb,” J. Chem., vol. 2013, 2012.

[34] Ö. APAYDIN, “REDUCTION OF COD IN WASTEWATER FROM A TEXTILE INDUSTRY BY ELECTRO-FENTON PROCESS,” Glob. NEST J., vol. 16, no. 3, pp. 536–542, 2014.

[35] X.-Y. Yong et al., “Bio-Electron-Fenton (BEF) process driven by microbial fuel cells for triphenyltin chloride (TPTC) degradation,” J. Hazard. Mater., vol. 324, pp. 178–183, 2017.

[36] A. P. M. Camargo, B. A. Previdello, H. Varela, and E. R. Gonzalez, “Effect of temperature on the electro-oxidation of ethanol on platinum,” Quim. Nova, vol. 33, no. 10, pp. 2143–2147, 2010.

[37] E. A. Carbonio, R. Nagao, E. R. Gonzalez, and H. Varela, “Temperature effects on the oscillatory electro-oxidation of methanol on platinum,” Phys. Chem. Chem. Phys., vol. 11, no. 4, pp. 665–670, 2009.

[38] S. O. Ganiyu, M. Zhou, and C. A. Martinez-Huitle, “Heterogeneous electro-Fenton and photoelectro-Fenton processes: a critical review of fundamental principles and application for water/wastewater treatment,” Appl. Catal. B Environ., 2018.