Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.28582

264 (2022) 252–258
July

Application of pollution prevention concept for reducing the impact of aircraft factory paint booth wastewater – case study Arab Organization for Industrialization

Mohamed A. El-Khateeb[a,*], Reham Ibrahem Mohamed[b]

[a]*Water Pollution Research Department, National Research Centre, Dokki 12622, Cairo, Egypt, Tel. +201003282503; email: elkhateebcairo@yahoo.com*
[b]*Pesticide Chemistry Department, National Research Centre, Dokki 12622, Cairo, Egypt, Tel. +201144568158; email: dr_reham2010@yahoo.com*

Received 28 January 2022; Accepted 23 May 2022

ABSTRACT

The aircraft factory maintains and paints the exterior surfaces of the aircraft structures. This work aims to treat the industrial wastewater of the aircraft factory. The concentration of phenol and chemical oxygen demand (COD) in industrial wastewater reached 125 and 11,763 mg/L, respectively. While the allowed limits for discharge on sewerage systems are 1,100 and 0.05 mg/L for COD and, phenol respectively. Fenton oxidation reaction (FOR) in addition to sawdust and date stone was tested for treating the wastewater. The effluent of the FOR was complying with the National Regulatory Standards. Another approach is to apply the pollution prevention concepts to remove the paint with the paint remover layer with the dry leaching. The suggestions were extended to the modification of the liquid waste collection tank to separate the floating matter in wastewater. The concentrations of phenol and COD were reduced from 125 and 11,763 mg/L to 0.04, and 985 mg/L, respectively. While the final concentrations of the phenol and COD were 0 and 572 mg/L in wastewater mixed with industrial wastewater from all the factory's sections. Thus, the industrial wastewater from the aircraft factory has become conforming to the National Regulatory Standards for discharge to the sewerage network.

Keywords: Pollution prevention; Cleaner production; Waste minimization; Fenton reaction; Sawdust

1. Introduction

Industrial wastewater contains organic pollutants which must be removed. Phenol is one of these organic contaminants. Phenol and its derivatives can be found in effluents of oil refineries, plastics, leather, paper, wood, and paint [1]. It is used in many industries as a raw material in cleaning agent manufacturing, pesticides industry, and automobiles construction. Phenolic compounds are the most common pollutants in an aqueous environment with harmful effects on living organisms even at their low concentrations. Phenols are considered hazardous pollutants due to their potential toxicity to human health [2,3]. The US Environmental Protection Agency (EPA) recommends that phenol levels in wastewater be reduced to less than 1 mg/L [4,5] and less than 0.002 mg/L as per the Indian standard in drinking water [6]. Low concentration (less than 0.1 mol/L) phenol can be treated with biological treatment. Solvent extraction can be most effective for the treatment of phenol at higher concentrations (more than 20 mg/L) [1,7].

The Fenton oxidation reaction (FOR) has attracted a lot of attention as an efficient technology for the degradation

* Corresponding author.

of various hazardous organic compounds such as phenolic compounds [8]. A mixture of ferrous sulfate ($FeSO_4$) and hydrogen peroxide is used in stoichiometric ratios in FOR. Theoretically, using FOR for wastewater treatment is appealing since Fe is a readily available and non-toxic ingredient. Due to its high processing efficiency, the FOR process is one of the most promising advanced oxidation processes (AOPs) [9–11].

The use of activated carbons as phenol adsorbents has shown high efficiency in the removal of phenolic compounds from wastewater [12]. Activated carbons are expensive materials and require many activation processes, so finding alternative adsorbents of the same removal efficiency but with low cost was very important. The use of agricultural wastes as biosorbents becomes promising [1,13].

Agricultural waste is a low-cost, abundant, and environmentally friendly resource that is used as a very effective adsorbent [14]. The most common sources to remove the dye and heavy metals are coconut shells, orange peel, pomegranate peel, banana peel, squash coal, tea waste, pistachio peel, rice hulls ash, coffee powder, pomelo peel, peat bagasse, and garlic peel [15]. The main components of agricultural waste include hemicelluloses, lignin, lipids, proteins, simple sugars, water, hydrocarbons, and starches which contain various types of functional groups. These functional groups lead to an increment of active sites and better adsorption of pollutants [16].

The possibility to use such materials as adsorbents without any methods to make them an alternative using activated carbons. Low-cost adsorbents could be produced from raw materials such as agriculture and industrial waste [17–19]. The date palm tree is considered a provide food for millions of people, especially in North Africa and the Middle East Asia region. About 14% of the date palm fruit is waste material in the form of seeds (stones). Date stones represent about 10% of the total date weight. They are well documented in most of the reviews as a low-cost adsorbent for phenolic compounds [20].

Although, the treatment using a combination of chemical, biological, and physical (e.g., adsorption, filtration, etc.) may produce treated effluent complying with the National Standards. The running and fixed costs of such technologies are very high in terms of human, energy, and financial resources. Consequently, pollution prevention (also called cleaner production), which encourages a preventive approach, is a response to the increased financial burden imposed by pollution control and end-of-pipe treatment expenditures. Pollution prevention offers a significant mix of cost savings and environmental benefits, which is why it has been identified as a means of reconciling development and environmental conservation in Agenda 21 [21].

The present study aims to test the use of FOR as well as the adsorption process using natural waste materials for removing phenol. The adsorbent materials prepared from sawdust and crushed date stones (abundant and inexpensive materials) were also studied. The work has been extended to apply the pollution prevention concepts for the reduction of the impact of phenol-rich aircraft paint booth wastewater. The work has been carried out in the National Research Centre, Egypt, from 2021 to 2022.

2. Material and methods

Wastewater was collected from a paint booth in an aircraft factory – Arab Organization for Industrialization (AOI), Helwan, Egypt.

2.1. Work steps in the paint booth

The outer surface of aircraft components is checked for dents and other defects. Then the oily dirt is cleaned with gasoline.

2.1.1. Removal of the paint

The paint remover was applied to the surface with a brush and left for some time. Then the layer was removed using high-pressure water. For a layer of paint that was difficult to remove, a cloth dipped in paint remover was applied.

2.1.2. Cleaning

The surface of the vehicle component was rinsed with high-pressure water to remove paint residue and remover. A cloth was dipped in paint remover to clean the surface and then wiped with a dry cloth before volatilizing the solvent. The surface was cleaned with neutral soapy water. The surface was dried with a clean dry cloth. Then the surface was dried with compressed air.

2.2. Experimental studies

The treatment of wastewater was carried out in two scenarios. The first scenario was the combination of advanced oxidation using the FOR. The use of natural adsorbing material followed by the FOR reaction was the second scenario.

2.2.1. Adsorbents

Sawdust was obtained from the NRC Carpentry Workshop and dried in a laboratory oven at 80°C until a constant weight then preserved in desiccators for use.

Date stones were collected, washed with distilled water, and kept in wide dishes until dried. The stones were grounded in a Raymond Grinder, Model TGM.

2.3. Procedures

The sorption of solution on sawdust and date stones was studied at room temperature. The adsorption experiments were carried out in 500 mL flasks sealed with parafilm to prevent the loss of phenol by volatilization. The general method used for this study was 100 g from each sawdust or date kernel equilibrated with 3,000 mL of the aqueous solution at a temperature of 25°C and put on a shaker for a known period of 24, 48, and 72 h.

2.3.1. Fenton oxidation reaction

El-Gohary et al. [22] determined the best operating parameters for FORs (pH, H_2O_2/COD, Fe/H_2O_2, and reaction time).

2.4. Analysis of wastewater

The pH/conductivity meter (WTW) was used to determine the pH values of raw and treated effluents. LoviBond (Model RD 125), and LoviBond photometers were used to determine the chemical oxygen demand (COD). The biochemical oxygen demand (BOD) requirement was determined using the Köttermann Incubator. To determine total Kjeldahl nitrogen (TKN), a Gerhardt distillator (Model Vapodest) and digester (Model Kieldatherm) were utilized. The shaker water bath (LabTech), and the mesh analyzer (Model) were used during the study. All analyses were performed in compliance with APHA [23].

2.5. Characteristics of wastewater

Table 1 shows the main characteristics of wastewater. The wastewater was slightly alkaline. The organic continents expressed by COD, BOD, total suspended solids (TSS), and phenol were 11,763; 2,100; 295 and 125 mg/L. The ratio of BOD/COD which expresses the biodegradability of wastewater was very low (0.18). The low biodegradability was explained by the high concentration of phenol (125 mg/L). Fig. 1 shows that the effluent was not complying with the National Regulatory Standards [24]. Consequently, the choice of chemical and/or physical (adsorption) treatment was carried out.

3. Results

3.1. FOR treatability study

The first treatment scenario was the chemical treatment using the FOR. To facilitate the degradation of phenol the FOR was applied. This method is based on the creation of very reactive oxidizing free radicals, especially hydroxyl ($OH^•$) radicals. The catalytic breakdown of hydrogen peroxide (H_2O_2) produces FOR's, which produce OH radicals, carried out by a transition metal such as ferrous iron (Fe^{2+}) [22,25].

$$H_2O_2 + Fe^{2+} \rightarrow OH^• + Fe^{3+} \quad (1)$$

The doses of ferrous sulfate ($FeSO_4$), and hydrogen peroxide (H_2O_2) were optimized. Tables 2 and 3 show the performance of the FOR for the treatment of wastewater at various doses. The doses (1, 2, 3, 4, and 6 g/L) of ferrous sulfate were applied (Fig. 2). The trend line in Fig. 2 shows that as the concentration of ferrous sulfate increased the removal of COD increased. The optimum dose of 4 g/L of ferrous sulfate was selected since the COD was below the level stated by the National Regulatory Standards [24]. It can be noted that the Fe^{2+} increasing loads have a considerable effect on the degradation of phenols. This leads to a reduction in the concentration of COD. The sludge volume is increased from 1 to 2 g/L of ferrous sulfate addition. But at concentrations of 3 g/L and more, the compactness of the sludge is increased consequently the volume of sludge is decreased. Similar results were obtained by Martins et al. [26].

Different doses (20, 40, 60, 80, and 120 mL/L) of hydrogen peroxide were tested to select the minimum effective dose at a constant dose of 4 g/L ferrous sulfate. The COD level was reduced gradually as the volume of hydrogen peroxide increased from 20 to 40 then to 60 mL/L (Table 3 and Fig. 3). In contrast, when the concentration of H_2O_2 raises,

Table 1
Characteristics of wastewater used in the study

Pollutant	Unit	Result	Ministerial Decree 44/2000 (17)
pH		8	6.5–9
COD	mgO_2/L	11,763	1,100
BOD	mgO_2/L	2,100	600
BOD/COD	–	0.18	–
TSS	mg/L	295	800
Phenol	mg/L	125	0.05
TKN	mgN/L	2.04	100
TP	mgP/L	0	25

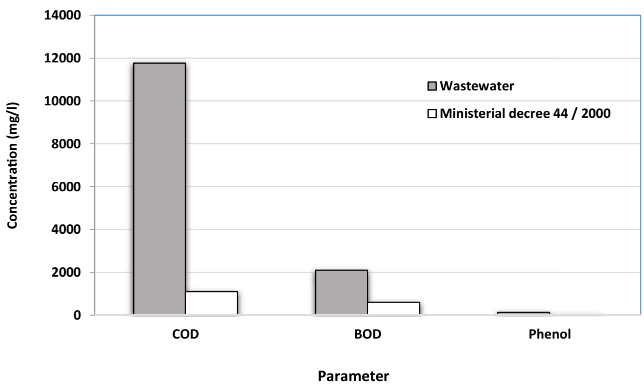

Fig. 1. The Ministerial Decree 44/2000 and the non-complying parameters.

Table 2
Optimization of the doses of ferrous sulfate

$FeSO_4$ (g/L)	CaO (g/L)	COD (mg/L)	Sludge volume (mL/L)	H_2O_2 30% (mL/L)
1	12	4,750	280	100
2	13	4,460	500	100
3	13	1,785	440	100
4	13	695	430	100
6	13	305	280	100

the final degradation rate decreases. When the concentration of H_2O_2 is high enough, it has a radical-scavenging action [Eq. (2)], which reduces the number of hydroxyl radicals available to destroy organic loads. Other radicals (hydroperoxide radicals, $HO_2^•$) are generated, although their oxidant strength is significantly lower than that of $OH^•$ [26]. While at the doses of more than 60 mL/L of residual hydrogen peroxide may oxidize the COD reagents and interfere with the COD results [22,27]. According to Tables 2 and 3 the optimum doses of ferrous sulfate and H_2O_2 were 4 g/L, and 60 mL/L, respectively.

$$OH^• + H_2O_2 \rightarrow HO_2^• + H^+ \quad (2)$$

The concentrations of H_2O_2 and Fe^{2+} have a lot of interaction. Because of the hydrogen peroxide scavenger effect, when Fe^{2+} load is low, a rise in H_2O_2 concentration causes a decrease in COD elimination, as previously mentioned. Despite this, an increase in Fe^{2+} speeds up the conversion of H_2O_2 to hydroxyl radicals, reducing the amount of hydrogen peroxide available to scavenge those radicals. As a result, when Fe^{2+} levels are high, a rise in hydrogen peroxide concentration allows for greater effluent degradation. Ormad et al. [28], and Martins et al. [26] discovered a similar pattern. Consequently, optimization of the FOR process is of vital importance to get the highest efficiency of phenol degradation. Table 4 shows the performance of the FOR for the treatment of wastewater at optimum conditions. Hydrogen peroxide is environmentally friendly since it slowly decomposes into oxygen and water. Besides, the abundance, lack of toxicity, and ease of removal from the water make Fe^{2+} the most commonly used transition metal for FOR applications [29]. In addition, the generation of harmful by-products associated with FOR applications is noticeably lower compared to some other advanced oxidation processes [30].

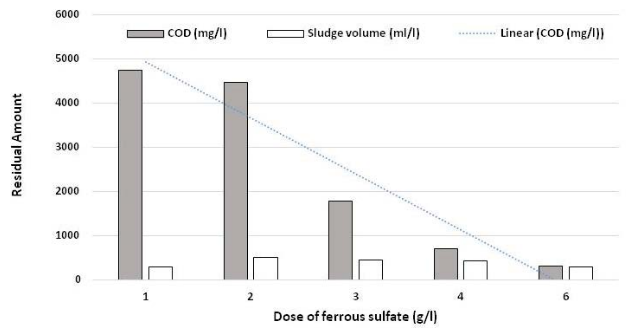

Fig. 2. Performance of the FOR at different doses of ferrous sulfate.

Table 3
Optimization of the doses of hydrogen peroxide[a]

H_2O_2 30% (mL/L)	CaO (g/L)	COD (mg/L)	Sludge volume (mL/L)
20	2.3	3,800	190
40	6.5	1,090	200
60	10	585	220
80	12	2,325	240
120	13.5	2,400	280

[a]This experiment was carried out at the optimum dose of ferrous sulfate (4 g/L).

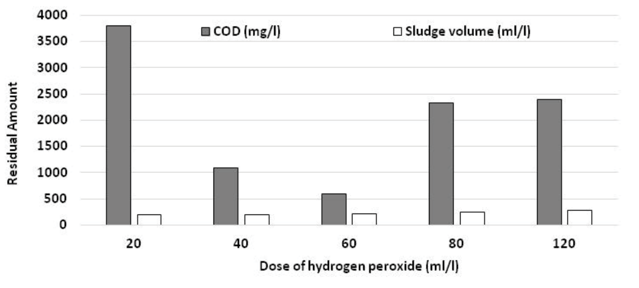

Fig. 3. Performance of the FOR at different doses of hydrogen peroxide.

3.2. Natural materials treatability study

Adsorption is considered a cost-effective method to treat wastewater and leads to flexibility in design and utilization, and in many cases, high-quality effluents. The desorption process is reversible, and the used adsorbents can be recycled [31].

Table 5 shows increasing in phenol and COD removal after contact with sawdust and date stones for 24, 48, and 72 h. The performance of sawdust was higher than that of date stones, after 72 h. The treatment of industrial wastewater with natural materials (sawdust and date stones) was not able to produce effluent complying with the National Regulatory Standards [24].

The adsorption process is explained as transferring of the pollutant substance from the liquid phase to the solid one. The contact time between the two phases affects the rate of transfer. Phenol removal reaches to maximum after 72 h of shaking. The removal rates of phenol from solution passes by three stages as follows: the first stage is rapid at the beginning of the adsorption process. After a rapid stage, phenol removal increases with time until reaches maximum and equilibrium values in 72 h [14,32]. The sawdust, as well as date stone, consists mainly of cellulose, hemicellulose, and lignin. Each cellulose and hemicellulose contains most of the oxygen functional groups which are present in the lignocellulosic material such as hydroxyl, ether, and carbonyl. While lignin is a complex, polymerized, highly aromatic substance and acts as a cementing matrix that

Table 4
Performance of the FOR for the treatment of wastewater

Parameter	Result	Ministerial Decree 44/2000
COD	585	1,100
BOD	250	600
BOD/COD	0.43	–
TSS	15	500
Phenol	ND	0.05

Table 5
Performance of sawdust and date stones for the treatment of wastewater[a]

Conditions	Sawdust				Date stones			
	Phenol (mg/L)	% *R*	COD (mg/L)	% *R*	Phenol (mg/L)	% *R*	COD (mg/L)	% *R*
24 h shaking	6.15	95.08	10,725	8.82	11.03	91.18	11,175	5.00
48 h shaking	1.34	98.93	7,225	38.58	2.17	98.26	9,650	17.96
72 h shaking	0.173	99.86	5,400	54.09	2.01	98.39	7,250	38.37

[a] Initial concentrations of phenol and COD were 125 and 11,763 mg/L, respectively.

holds between cellulose and hemicellulose particles. The surface area, surface functional groups, and pore size play important roles in determining the adsorption mechanisms [33,34]. This mechanism leads to the adsorption of phenol. The low adsorption of phenol at high concentrations may be attributed to the accumulation of phenol particles on the surface of the adsorbent [34].

3.3. Application of pollution prevention concepts

The use of the FOR had several drawbacks such as the need for skilled labor, high running cost, production of a large amount of sludge, required reaction vessels, and other equipment. These drawbacks choosing the FOR is not, the optimal solution. Unfortunately, the adsorption using both sawdust as well as date stone was not able to remove phenol and COD from the wastewater to comply with the National Regulatory Standards.

Consequently, the application of the pollution prevention concepts (PPC) is of utmost importance. The following steps were applied:

(1) When covering the outer fuselage with paint remover, scrape it off with a plastic scraper (remove dry).
(2) Solid residues are collected without mixing with water and are safely disposed of as solid waste.
(3) After that, the outer surface of the aircraft is rinsed and repainting work begins.
(4) The interior design of the industrial wastewater collection tank has been modified to contribute to increasing the separation of suspended and floating matter (Fig. 4).
(5) Construction of 2 sludge drying beds with dimensions of 2 × 3 m, lining them so that wastewater does not seep into the groundwater.
(6) Solid waste resulting from paint residues with remover, as well as dry sludge are disposed of in sludge drying beds by collecting them in drums, and sealing them, then coordinating with a contractor such as Nasiriyah landfill or similar entity for safe environmental disposal.
(7) Continuously disinfect the internal and external wells so as not to affect the results of wastewater analysis.
(8) Industrial wastewater can be drained from septic tanks so that it is mixed with the sewage leaving the factory after making sure that it complies with resolution no. 44 of 2000 amending the executive regulations of law no. 93 of the year, after analyzing industrial wastewater and matching it with the aforementioned resolution.

Table 6 shows the main characteristics of industrial wastewater collected from the paint booth collecting tank. Without treatment, the effluent complied with National

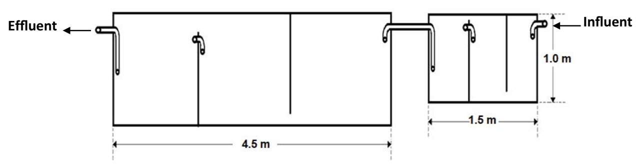

Fig. 4. A side view of the sedimentation tanks for industrial wastewater collection.

Table 6
Main characteristics after application of PPC

Parameter	Unit	Wastewater	PPC effluent	Ministerial Decree 44/2000
pH		8	7.5	6–9.5
COD	mg/L	11,763	985	1,100
BOD	mg/L	2,100	450	600
BOD/COD		0.18	0.46	–
TSS	mg/L	295	62	800
TKN	mg/L	2.04	1	100
TP	mg/L	ND	ND	25
Sulfides	mg/L	0.3	ND	10
Phenols	mg/L	125	ND	0.05
Oil & Grease	mg/L	0.5	0.524	100
Cyanides	mg/L	ND	ND	0.2

Regulatory Standards. PPC was the ideal, low-cost solution to the situation in the aircraft factory.

4. Conclusions

The use of FOR was found to effectively remove phenols and treated effluent was complying with the National Regulatory Standards. While the adsorption process using sawdust as well as date stones removed a considerable amount of phenols but the effluent was not complying with the National Regulatory Standards. The required sawdust or date stone was 34 kg for the treatment of 1 m^3 of wastewater. The sawdust or date stones contaminated with phenol are considered hazardous materials and must be disposed of safely. The advanced oxidation using FOR was efficiently removed phenol. At optimum dose of ferrous sulfate and H_2O_2 (4 g/L and 60 mL/L, respectively) the COD was reduced from 11,763 to 585 mg/L. The phenol was not detected in the FOR treated effluent. The FOR requires high skilled laborers, expensive processes, and produce sludge. Also, the adsorption process was not sufficient alone for the treatment of wastewater and produces a huge amount of sludge. Consequently, the application of the pollution prevention concept was found a cost-effective and less complicated solution to reduce the impact of the painting process. The final effluent of the paint booth in the aircraft factory – Arab Organization for Industrialization was complying with the Nation Regulatory Standards without the need for previous treatment.

Acknowledgment

The authors thank the management of the Arab Organization for Industrialization, represented by the Chairman of the Board of Directors, and all the employees of the aircraft factory, especially Eng. Medhat Al-Sheikh for the facilities that were provided to us to carry out this research.

Data availability statement

All data, models, and code generated or used during the study appear in the submitted article.

References

[1] A. Othmani, S. Magdouli, P. Senthil Kumar, A. Kapoor, P.V. Chellam, Ö. Gökkuş, Agricultural waste materials for adsorptive removal of phenols, chromium(VI) and cadmium(II) from wastewater: a review, Environ. Res., 204 (2022) 111916, doi: 10.1016/j.envres.2021.111916.

[2] O. Abdelwahab, N.K. Amin, E.-S.Z. El-Ashtoukhy, The investigation of phenol removal from aqueous solutions by water hyacinth, Sep. Sci. Technol., 49 (2014) 1604–1612.

[3] S.J. Tshemese, W. Mhike, S.M. Tichapondwa, Adsorption of phenol and chromium(VI) from aqueous solution using exfoliated graphite: equilibrium, kinetics and thermodynamic studies, Arabian J. Chem., 14 (2021) 103160, doi: 10.1016/j.arabjc.2021.103160.

[4] B.H. Hameed, A.A. Rahman, Removal of phenol from aqueous solutions by adsorption onto activated carbon prepared from biomass material, J. Hazard. Mater., 160 (2008) 576–581.

[5] G. Nirmala, T. Murugesan, K. Rambabu, K. Sathiyanarayanan, P.L. Show, Adsorptive removal of phenol using banyan root activated carbon, Chem. Eng. Commun., 208 (2021) 831–842.

[6] S.L. Gayatri, M. Ahmaruzzaman, Adsorption technique for the removal of phenolic compounds from wastewater using low-cost natural adsorbents, Assam Univ. J. Sci. Technol., 5 (2010) 156–166.

[7] D.N. Jadhav, A.K. Vanjara, Removal of phenol from wastewater using sawdust, polymerized sawdust and sawdust carbon, Indian J. Chem. Technol., 11 (2004) 35–41.

[8] M. Radwan, M.G. Alalm, H. Eletriby, Optimization and modeling of electro-Fenton process for treatment of phenolic wastewater using nickel and sacrificial stainless steel anodes, J. Water Process Eng., 22 (2018) 155–162.

[9] M. Tyagi, N. Kumari, S. Jagadevan, A holistic Fenton oxidation-biodegradation system for treatment of phenol from coke oven wastewater: optimization, toxicity analysis and phylogenetic analysis, J. Water Process Eng., 37 (2020) 101475, doi: 10.1016/j.jwpe.2020.101475.

[10] F.Z. Yehia, Gh. Eshaq, A.M. Rabie, A.H. Mady, A.E. ElMetwally, Phenol degradation by advanced Fenton process in combination with ultrasonic irradiation, Egypt. J. Pet., 24 (2015) 13–18.

[11] L.Y. Jun, L.S. Yon, N.M. Mubarak, C.H. Bing, S. Pan, M.K. Danquah, E.C. Abdullah, M. Khalid, An overview of immobilized enzyme technologies for dye and phenolic removal from wastewater, J. Environ. Chem. Eng., 7 (2019) 102961, doi: 10.1016/j.jece.2019.102961.

[12] M. Del Bubba, B. Anichini, Z. Bakari, M.C. Bruzzoniti, R. Camisa, C. Caprini, L. Checchini, D. Fibbi, A. El Ghadraoui, F. Liguori, S. Orlandini, Physicochemical properties and sorption capacities of sawdust-based biochars and commercial activated carbons towards ethoxylated alkylphenols and their phenolic metabolites in effluent wastewater from a textile district, Sci. Total Environ., 708 (2020) 135217, doi: 10.1016/j.scitotenv.2019.135217.

[13] N. Singh, A. Kumari, C. Balomajumder, Modeling studies on mono and binary component biosorption of phenol and cyanide from aqueous solution onto activated carbon derived from sawdust, Saudi J. Biol. Sci., 25 (2018) 1454–1467.

[14] S. Larous, A.-H. Meniai, The use of sawdust as by product adsorbent of organic pollutant from wastewater: adsorption of phenol, Energy Procedia, 18 (2012) 905–914.

[15] A. Farhadi, A. Ameri, S. Tamjidi, Application of agricultural wastes as a low-cost adsorbent for removal of heavy metals and dyes from wastewater: a review study, Phys. Chem. Res., 9 (2021) 211–226.

[16] D. Yelatontsev, A. Mukhachev, Characterization of a new low-cost sorbent based on walnut shell media, 3rd International Scientific Conference "Science progress in European Countries: New Concepts and Modern Solutions", Hosted by the ORT Publishing and The Center for Scientific Research "Solution", November 23, 2018 Stuttgart, German, 2018, p. 147.

[17] M. Sulyman, J. Namiesnik, A. Gierak, Low-cost adsorbents derived from agricultural by-products/wastes for enhancing contaminant uptakes from wastewater: a review, Pol. J. Environ. Stud., 26 (2017) 479–510.

[18] S. Singh, K.L. Wasewar, S.K. Kansal, Chapter 10 – Low-Cost Adsorbents for Removal of Inorganic Impurities from Wastewater, P. Devi, P. Singh, S.K. Kansal, Eds., Inorganic Pollutants in Water, Elsevier, Amsterdam, Netherlands, 2020, pp. 173–203.

[19] A. ElAziz A. Nayl, R.A. Elkhashab, T. El Malah, S.M. Yakout, M.A. El-Khateeb, M.M.S. Ali, M.A. Hazim, Adsorption studies on the removal of COD and BOD from treated sewage using activated carbon prepared from date palm waste, Environ. Sci. Pollut. Res., 24 (2017) 22284–22293.

[20] A.H.F. Tahir, A.H.M.J. Al-Obaidy, F.H. Mohammed, Biochar from date palm waste, production, characteristics and use in the treatment of pollutants: a review, IOP Conf. Ser.: Mater. Sci. Eng., 737 (2020) 012171.

[21] W. Cong, L. Shi, Heterogeneity of industrial development and evolution of cleaner production: bibliometric analysis based on JCLP, J. Cleaner Prod., 212 (2019) 822–836.

[22] F.A. El-Gohary, M.I. Badawy, M.A. El-Khateeb, A.S. El-Kalliny, Integrated treatment of olive mill wastewater (OMW) by the

combination of Fenton's reaction and anaerobic treatment, J. Hazard. Mater., 162 (2009) 1536–1541.
[23] APHA, Standard Methods for Examination of Water and Wastewater, 23rd ed., American Public Health Association, Washington D.C., USA, 2021.
[24] EEAA, Ministerial Decree 44/2000, For the Discharge of Wastewater into the Sewerage System, The Egyptian Gazette, Egypt, 2000.
[25] E.G. Garrido-Ramírez, J.F. Marco, N. Escalona, M.S. Ureta-Zañartu, Preparation and characterization of bimetallic Fe–Cu allophane nanoclays and their activity in the phenol oxidation by heterogeneous electro-Fenton reaction, Microporous Mesoporous Mater., 225 (2016) 303–311.
[26] R.C. Martins, A.F. Rossi, R.M. Quinta-Ferreira, Fenton's oxidation process for phenolic wastewater remediation and biodegradability enhancement, J. Hazard. Mater., 180 (2010) 716–721.
[27] W. Maamir, Y. Ouahabi, S. Poncin, H.-Z. Li, K. Bensadok, Effect of Fenton pretreatment on anaerobic digestion of olive mill wastewater and olive mill solid waste in mesophilic conditions, Int. J. Green Energy, 14 (2017) 555–560.
[28] M.P. Ormad, R. Mosteo, C. Ibarz, J.L. Ovelleiro, Multivariate approach to the photo-Fenton process applied to the degradation of winery wastewaters, Appl. Catal., B, 66 (2006) 58–63.
[29] J. Kuntail, S. Pal, I. Sinha, Interfacial phenomena during Fenton reaction on starch stabilized magnetite nanoparticles: molecular dynamics and experimental investigations, J. Mol. Liq., 318 (2020) 114037, doi: 10.1016/j.molliq.2020.114037.
[30] A. Tufail, W.E. Price, M. Mohseni, B.K. Pramanik, F.I. Hai, A critical review of advanced oxidation processes for emerging trace organic contaminant degradation: mechanisms, factors, degradation products, and effluent toxicity, J. Water Process Eng., 40 (2021) 101778, doi: 10.1016/j.jwpe.2020.101778.
[31] G. Crini, E. Lichtfouse, L.D. Wilson, N. Morin-Crini, Adsorption-Oriented Processes Using Conventional and Non-Conventional Adsorbents for Wastewater Treatment, G. Crini, E. Lichtfouse, Eds., Green Adsorbents for Pollutant Removal: Fundamentals and Design, Springer, Gewerbestrasse 11, 6330 Cham, Switzerland, 2018, pp. 23–71.
[32] O. Sahu, D.G. Rao, N. Gabbiye, A. Engidayehu, F. Teshale, Sorption of phenol from synthetic aqueous solution by activated sawdust: optimizing parameters with response surface methodology, Biochem. Biophys. Rep., 12 (2017) 46–53.
[33] L. Semerjian, Removal of heavy metals (Cu, Pb) from aqueous solutions using pine (*Pinus halepensis*) sawdust: equilibrium, kinetic, and thermodynamic studies, Environ. Technol. Innovation, 12 (2018) 91–103.
[34] I.H. Dakhil, Removal of phenol from industrial wastewater using sawdust, Int. J. Eng. Sci., 3 (2013) 25–31.