Degradation of sanitation facilities: prediction of effluent chemical impact of a cosmetics plant in Abidjan, Côte d'Ivoire

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Abstract: This work deals with Wastewater treatment plant deterioration in connection with effluents from a cosmetics production unit in Abidjan, Côte d'Ivoire. It highlights the chemical impact of these effluents on wastewater treatment infrastructures by underlining the importance of systematic assessment for predicting harmful effects on the environment and public health. The study uses predictive models to analyze the chemical composition of effluents to identify potentially toxic substances and propose recommendations for sustainable waste management. Colorimetry, gravimetry, AFNOR, and Rodier analysis methods were used during four sampling campaigns. The results of this study show that the effluent has average pH, temperature, and redox potential values equal to (5.22), (24.23 °C), and (103.45 mV), respectively. The effluent is oxidizing and acidic at room temperature. In addition, this effluent is highly charged in COD and BOD_5 with respective average values (39150 mg O_2 /L), (11930 mg O_2 /L). The effluent is, therefore, acidic, oxidizing, and abiotic. Such effluent is a source of hydrogen sulfide and sulfuric acid, highly corrosive pollutants for wastewater treatment plants. These results are, therefore, intended to sensitize involved actors about the need to improve sanitation and regulatory practices in the cosmetics sector.

Keywords: cosmetic effluent, chemical corrosion, gravimetry, colorimetry, hydrogen sulfide, sustainable development.

1. Introduction

The deterioration of sanitation facilities represents a significant challenge for public health, the environment, and the economy, particularly in fast-growing urban areas such as Abidjan in Côte d'Ivoire [1]. This phenomenon is exacerbated by increasing industrial activities, including the cosmetics industry, which generates effluent containing potentially harmful chemical substances [2,3]. These effluents, which are not often well treated, can significantly impact both wastewater infrastructure and the quality of the receiving water[4]. This can lead to the contamination of drinking potable water, increasing the risk of water-borne diseases such as cholera and typhoid [5,6], etc. Thus populations affected by these diseases face high medical fees, sometimes [7] expensive. Biodiversity and aquatic ecosystems are not spared from this disaster [8,9], as untreated effluent from dysfunctional wastewater treatment plants can contaminate rivers and soils [9,10]. For the local economy, pollution of both soil and water can deteriorate the quality of crops, reduce yields, and

affect food security [11]. Faced with this disaster, confidence in government action can only go down. Accordingly, restoring polluted environments imposes additional costs on communities and governments. This will inevitably lead to significant investment in their repair or replacement. For industry, effluent damage to wastewater treatment facilities has a significant economic impact on the manufacturer and its staff [12]. Consequently, the deterioration of wastewater treatment plants has various economic implications that can affect the financial viability of an industry [12]. In this context, it is crucial to develop predictive models to assess the chemical impact of effluents from cosmetics production units. This research aims to analyze the chemical composition of effluents and to study their interaction with the materials used in wastewater treatment plants. By identifying the primary degradation agents and quantifying their impact, this study aims to provide recommendations for improving effluent management, protecting wastewater infrastructure, and preserving the local environment. This research work is therefore

positioned at the intersection of ecology, engineering, and public health to contribute to a better understanding of the contemporary challenges associated with sanitation in developing urban areas.

2. Study methodologies
2.1 Study equipment and sampling
The study material consisted of effluent samples taken from a cosmetics unit in the commune of Abobo, with geographic coordinates 5.44°N, 4.04°W. This unit is the only one of the seventeen soap and cosmetics units listed by CIAPOL (Centre Ivoirien Antipollution), a body responsible for the environmental control, monitoring, and management of Ivorian industries, which was not studied in the context of our thesis on sixteen units [13]. In fact, unlike the other units, this one is specific because it manufactures only cosmetic products. These are the reasons, among others, that have guided this choice. After treatment is retained, the effluent leaving the plant (ESS) is discharged into the receiving environment. Four sampling campaigns were carried out per week during a month. After sampling into high-density polyethylene containers, the samples are labeled and stored in a dark place to preserve their chemical and microbiological integrity. They are then transported to the laboratory, stored in a freezer at 4°C, and analyzed within 24 hours [14]. Physical parameters such as pH, temperature (T°C), oxidation-reduction potential (E_H), and electrical conductivity (EC) are measured in situ.

2.2 Assessment of the physicochemical quality of cosmetic effluent samples
Cosmetic effluents require our attention in this study because of the use of chemical raw materials of various formulations, leading us to suspect that these effluents are a source of hydrogen sulfide, a highly corrosive pollutant in wastewater treatment plants. The formation of this pollutant in treatment plants is governed by a certain number of physicochemical parameters such as temperature (T), redox potential (EH), hydrogen potential (pH), suspended matter (SSM), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5) and sulfate ions (SO_4^{2-}) [15,16]. These are parameters that are assessed in the different samples. The reagents used in this assessment are of good analytical quality. The pH, temperature (T°C), redox potential (E_H) and electrical conductivity (EC) were measured using a CONSORT multi-parameter analyzer C3020 multimeter. Suspended matters (SSM) in the water were analyzed using 45 µm pore-size glass filters and a SIGMA 2-6^E centrifuge. Biochemical Oxygen Demand was determined using Oxitop® WTW. Analysis of chemical oxygen demand (COD), sulfate ions, sulfide ions, and total iron was carried out using an Aqualytic AL800 UV-visible spectrophotometer. Analyses were carried out using the AFNOR and Rodier analytical methods [14,17].

2.3 Temporal monitoring of the effect of effluent on the study materials
Gravimetric and colorimetric methods highlight the effluent's effect on materials like iron and copper [18,19]. Gravimetry monitors the mass loss of the metal in contact with the effluent over time. Colorimetry highlights the temporal impact of the effluent on the metal by changing the color of the initial effluent.

The metal (M) is weighed to determine its initial mass ($M_M(0)$). It is then placed in the effluent contained in a ceramic jar. The system (effluent + metal) is monitored over 48 hours (2 days). The metal is removed, washed with distilled water, dried, and weighed by mass $M_M(t)$. A DENVER INSTRUMENT SI-234 analytical balance accurate to 10^{-4} g, two shavings of iron and copper are used for this purpose.

3. Results and discussion
3.1 Physico-chemical composition of analyzed effluents
The mean values of the physicochemical parameters in the effluent leaving the treatment plant (ESS) analyzed over the four sampling campaigns are shown in Table 1.

Table 1. Mean values for physico-chemical parameters were analyzed at the treatment plant outlet.

Parameters	Min	Max	Average ±SD
pH	5.08	5.22	5.24 ±0.05
T(°C)	22.20	25.95	24.23 ±1.34
EC (µs/cm)	284.50	705.50	493.67 ±148.85
E_H (mV)	84.25	120.90	103.45 ± 13.00
SSM (g/L)	0.55	1.81	1.04 ± 0.48
COD (g O_2/L)	5.60	103.50	39.15 ± 39.42
BOD_5 (g O_2/L)	3.73	26.50	11.93 ±8.94
SO_4^{2-} (g/L)	0.21	7.94	2.82 ± 3.16
S^{2-} (mg/L)	0.06	0.80	0.34 ± 0.29
Fe T (mg/L)	1.73	1.79	1.76 ± 0.02

Analysis of the parameter values in the table reveals the physicochemical composition and nature of the effluent from the studied unit. For all analyzed effluents, the mean pH value was 5.22 ±0.05 at a mean

temperature of 24.23 ±1.34°C. The effluent from the cosmetic's studied unit is acidic at ambient temperature. These pH and temperature values are different from those obtained during the study of the effluent from an industrial unit manufacturing soaps and cosmetics in the Yopougon industrial zone, which are respectively (6.67 ± 0.60) and (29.58 ± 0.82°C) [20]. However, these values are in the order recommended by the Classified Installations Inspectorate (SIIC) [21]. In addition, the mean conductivity of the studied effluent (493.67 ±148.85 µs/cm) was higher than the guide value (400 µs/cm) [20]. This effluent is, therefore, loaded with minerals [14]. The mean value of the redox potential of the study matrix is (103.45 ± 13.00 mV), positive and greater than 40 mV. This effluent is oxidant[14], unlike the cosmetics effluent from the Yopougon industrial zone, which was reducing, with a mean redox potential of (-13 ± 1.87 mV) [20].

All in all, the studied cosmetic effluent, which is acidic and oxidant, has high electrical conductivity and is at ambient temperature, is similar to effluents from chemical, petroleum, paper, and food industries [22]. Such effluents can significantly impact the environment and often require appropriate treatment to prevent corrosion and other environmental problems. An acidic, oxidizing effluent with high conductivity promotes corrosion by increasing the solubility of metals, thus facilitating electrochemical reactions that lead to the formation of corrosive products such as hydrogen sulfide and sulfuric acid [23]. This type of effluent increases the reactivity of materials with their environment through redox reactions, leading to faster and more severe corrosion [24,25]. Concerning suspended matters, the studied effluent had an average value of (1.04 ± 0.48 g/L, i.e., 1040 mg/L, well above the reference value (150 mg/L). This SSM value for the studied effluent is very high compared with those measured in soap factory effluents in the Abidjan district [20,26]. This effluent, which is very high in SSM, can intensify corrosive processes through mechanical, electrochemical, and chemical mechanisms by making metal protection more complex [27,28]. SSM can promote metal corrosion by several mechanisms. SSM contains chemical pollutants, particularly acids and sulfides, which interact with metals and increase the corrosion rate [27,28]. In addition, suspended matter can adsorb corrosion inhibitors, reducing their effectiveness and leaving metal surfaces vulnerable [29]. According to humidity retention, suspended particles can retain humidity by creating an environment favorable to corrosion, particularly in conditions where water is present [30].

The mean value of biochemical oxygen demand (BOD$_5$, 11930 mg O$_2$ /L) was well above 150 mg/L. The chemical oxygen demand is (COD, 39150 mg O$_2$ /L). These values are much higher than those recommended by the Classified Facilities Inspection Service, which are 150 mg O$_2$ /L and 500 mg O$_2$ /L

for BOD$_5$ and COD, respectively. The effluent from this unit is very high in COD and BOD$_5$, like those from the food, textile, and paper industries [31,32]. Such effluent can have several consequences for the corrosion of wastewater treatment plants [33,34]. These high concentrations of organic matter encourage microbial activity, leading to the proliferation of microorganisms that can contribute to corrosion, particularly sulfate-reducing bacteria that produce hydrogen sulphide[35]. Anaerobic decomposition processes generated by microorganisms govern the increase of the environment's acidity. An acid pH promotes the corrosion of materials, mainly concrete and metal. This decomposition of organic matter can lead to hydrogen sulfide production, which is particularly corrosive to concrete and metal infrastructures[36]. This production is exacerbated by the high sulfate ion content in the effluent, which is 2.82 g/L. Furthermore, the factor of biodegradation ($F_B = \frac{DCO}{DBO_5} = 3{,}28$), greater than 3, shows that the studied effluent is challenging to biodegrade with predominant chemical pollution [37,38]. Consequently, the studied effluent is abiotic [37,38]. The different ionic species present in the effluent (Fe^{2+}, Fe^{3+}, SO_4^{2-} et S^{2-}) indicate a medium susceptible to chemical reactions. These chemical reactions, which can be linked to the transfer of protons or electrons, can lead to the chemical degradation of a wastewater treatment facility containing metals such as iron or copper. In the case of metals, chemical degradation is possible by redox reaction. The physicochemical composition of the complex from the studied effluent allows us to predict significant impacts on the materials used in wastewater treatment plants, particularly iron and copper, which are highlighted in the following paragraph.

3.2 degradation Predicting of Wastewater Treatment Plants by effluent
3.2.1 Highlighting of the effect of effluent on iron and copper metals

The effect of the effluent on the possible degradation of the structures was highlighted using colorimetric and gravimetric methods over fourteen days. Time tracking of the color change of the initial sample in contact with the study materials (iron and copper) in the ceramic containers is illustrated in Figure 1. Photographs taken while the effluent is in contact with the iron or copper show changes in the color of the initial effluent. The effluent, therefore, interacts with the studied materials. This reaction of the cosmetics effluent with the iron and copper is confirmed by the mass losses of the materials over time. The mass loss of the metal over an immersion time (t) in the effluent ΔMM (t) is determined by the following relationship:

$$\Delta M_M(t) = M_M(0) - M_M(t)$$

Avec $M_{Fe}(0) = 0{,}6358$ g et $M_{Cu}(0) = 0{,}5169$ g

The mass loss values for iron ΔM_{Fe} (t) and copper ΔM_{Cu} (t) over eight days are shown in bold in Table 2.
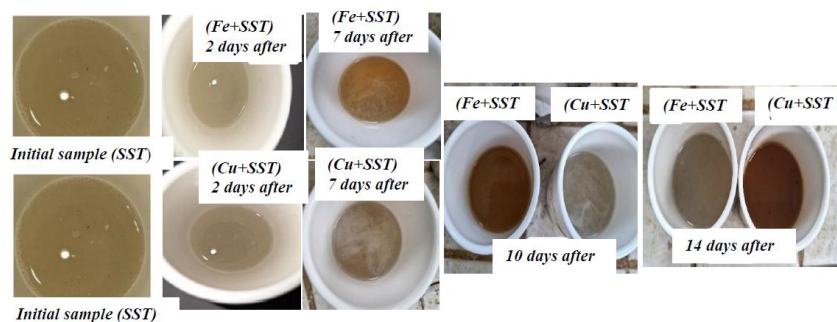

Figure 1. Temporal monitoring of the effect of effluent on iron (Fe) and copper (Cu) using colorimetry

Table 2. Temporal monitoring of the effect of the effluent on iron and copper metals using gravimetry.

t (j)	M_{Fe} (t)	ΔM_{Fe} (t)	M_{Cu} (t)	ΔM_{Cu} (t)
0	0,6358	**0,0000**	0,5169	**0,0000**
2	0,6299	**0,0059**	0,5170	**0,0026**
4	0,6288	**0,0070**	0,5162	**0,0034**
6	0,6240	**0,0118**	0,5143	**0,0053**
8	0,6232	**0,0126**	0,5138	**0,0058**

The loss of mass and color change observed over the analysis period result from chemical reactions between the cosmetic effluent and the iron or copper in contact. Analysis of the mass loss values for the study materials shows that iron loses 12.6 mg by mass, compared with 5.8 mg for copper. The effluent corrodes the iron metal more than the copper metal. Therefore, chemical degradation of iron and copper metals is possible in contact with the effluent. Analysis of the reactions susceptible to oxidizing iron and copper, according to the chemical composition of the effluent, will give an idea of the chemical degradation mechanism for iron and copper.

3.2.2 Elucidation of a mechanism for the chemical degradation of iron and copper by effluent

Based on the above, the average temperature of characterized effluents was around 25°C (24.23 ±1.34°C). Consequently, standard redox potentials can be used to elucidate the different mechanisms of chemical degradation. Thus, the ionic species found in the medium (Fe^{2+}, Fe^{3+}, SO_4^{2-} et S^{2-}) can be used to identify the oxidants in the redox couples susceptible to oxidizing iron (in red) and copper (in blue) (Table 3).

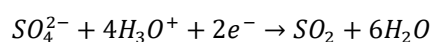**Table 3.** Couples and standard redox potentials of chemical species found in the analyzed effluents.

Redox couples	*Standard redox potentials (V) (25°C)*
Fe^{3+} / Fe^{2+}	+0.77
Cu^{2+} / Cu	+0.34
SO_4^{2-} / SO_2	+0.17
SO_4^{2-} /H_2SO_3	+0.16
S/H_2S	+0.14
S/S^{2-}	-0.45
Fe^{2+} / **Fe**	-0.44
Fe^{3+} / **Fe**	-0.04

According to the redox potentials SO_4^{2-} / SO_2, SO_4^{2-}/H_2SO_3, Fe^{2+} / Fe et Fe^{3+} / Fe, only the SO_4^{2-} ions found in the effluent can degrade iron in an aqueous medium, forming either sulfur dioxide (SO2) or sulfurous acid (H2SO3) by applying the gamma rule. In the presence of the SO_4^{2-} / SO_2 and Fe^{2+} / Fe redox couples in the medium, the metal iron is oxidized by the strong sulfate oxidant, inducing its chemical degradation by redox according to equations 1, 2, and 3.
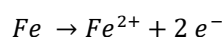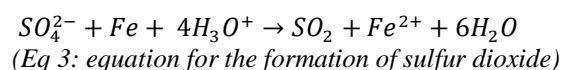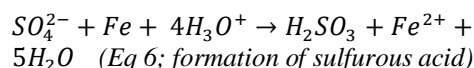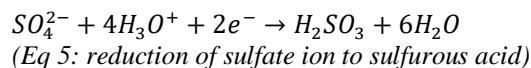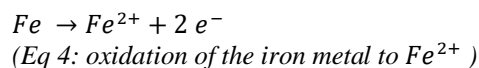
$$Fe \rightarrow Fe^{2+} + 2\,e^-$$
(Eq 1: oxidation of the metal iron to Fe^{2+})
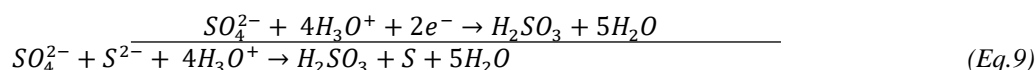
$$SO_4^{2-} + 4H_3O^+ + 2e^- \rightarrow SO_2 + 6H_2O$$
(Eq 2: reduction of sulfate ion to SO_2)

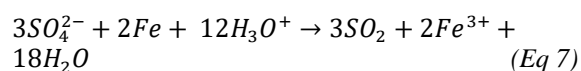$$SO_4^{2-} + Fe + 4H_3O^+ \rightarrow SO_2 + Fe^{2+} + 6H_2O$$
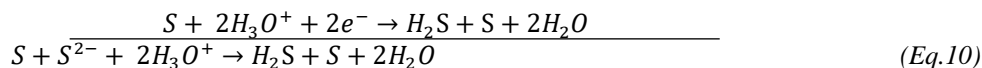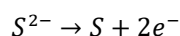*(Eq 3: equation for the formation of sulfur dioxide)*

Simultaneously, in the same medium, the iron metal undergoes another reduction in the presence of the SO_4^{2-}/H_2SO_3 couple to form sulfurous acid according to equations 4, 5, and 6:

$$Fe \rightarrow Fe^{2+} + 2\ e^-$$
(Eq 4: oxidation of the iron metal to Fe^{2+})

$$SO_4^{2-} + 4H_3O^+ + 2e^- \rightarrow H_2SO_3 + 6H_2O$$
(Eq 5: reduction of sulfate ion to sulfurous acid)

$$SO_4^{2-} + Fe + 4H_3O^+ \rightarrow H_2SO_3 + Fe^{2+} + 5H_2O$$ *(Eq 6; formation of sulfurous acid)*

The Fe^{3+}/Fe redox couple is also involved in the formation of sulfur compounds SO_2 and H_2SO_3 in the studied effluent, thus accentuating the continuous degradation of the iron metal according to respective formation equations 7 and 8 below:
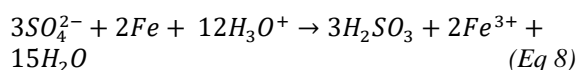
$$3SO_4^{2-} + 2Fe + 12H_3O^+ \rightarrow 3SO_2 + 2Fe^{3+} + 18H_2O$$
(Eq 7)

$$3SO_4^{2-} + 2Fe + 12H_3O^+ \rightarrow 3H_2SO_3 + 2Fe^{3+} + 15H_2O$$ *(Eq 8)*

It should be noted that iron in cosmetics effluent undergoes several reactions leading to its exceptionally rapid degradation. These observations are in high agreement with the iron mass loss curve, which is more accentuated than that for copper (Table 2). Moreover, these various reactions of the effluent with iron generate sulfur compounds, making the effluent richer in these compounds. Generally, sewage works are made of iron, cement, and gravel concrete. For these structures, degradation occurs via sulfur compounds, with elemental sulfur playing a significant role as an energy source for the bacteria. The various reactions catalyzed by this elemental sulfur lead to the formation of corrosive compounds, particularly hydrogen sulfide (H_2S) and sulphuric acid (H_2SO_4)[39]. In the case of the studied effluent, there are two possible pathways for the formation of elemental sulfur S. The first route is that of the redox reaction between the sulfate ions SO_4^{2-} and the sulfide ions S^{2-} according to equation 9.

$$S^{2-} \rightarrow S + 2e^-$$
$$\underline{SO_4^{2-} + 4H_3O^+ + 2e^- \rightarrow H_2SO_3 + 5H_2O}$$
$$SO_4^{2-} + S^{2-} + 4H_3O^+ \rightarrow H_2SO_3 + S + 5H_2O$$ *(Eq.9)*

The second route is the reaction between the formed elemental sulfur and the sulfide ions, according to equation 10.

$$S^{2-} \rightarrow S + 2e^-$$
$$\underline{S + 2H_3O^+ + 2e^- \rightarrow H_2S + S + 2H_2O}$$
$$S + S^{2-} + 2H_3O^+ \rightarrow H_2S + S + 2H_2O$$ *(Eq.10)*

In this reaction mechanism, it is important to note that elemental sulfur is regenerated in the medium as a catalyst, leading to the continuous production of hydrogen sulfide. This catalytic reaction is permanent in the studied effluent due to the SO_4^{2-} and S^{2-} ions in the effluent that generate elemental sulfur. The effluent is, therefore, a formation source of hydrogen sulfide, the primary pollutant in the corrosion of wastewater treatment plants. Another corrosive pollutant, sulphuric acid (H_2SO_4) is also formed in this effluent. The equations of reactions 6, 8, and 9 lead to the formation of sulfurous acid (H_2SO_3) in the effluent. In the presence of oxygen, this pollutant oxidizes to sulphuric acid according to the following reaction (Eq. 11):

$$H_2SO_3 + \frac{1}{2}O_2 \rightarrow H_2SO_4$$ *(Eq.11)*

This continuous formation of sulphuric acid in the effluent requires increased oxygen consumption, making the environment abiotic. This sulphuric acid formation reaction can partly explain the high COD observed value. From the above, the effluent under study is the site of continuous formation of corrosive pollutants and their derivatives; in particular, the hydrogen sulfide and sulphuric acid formed can corrode iron and copper depending on the

environmental conditions [40]. Hydrogen sulfide, which is highly corrosive in abiotic and acidic media, can corrode iron and copper in aqueous media [41], according to the following reaction equations 12 and 13, respectively:

$$Fe + H_2S \rightarrow FeS + H_2$$ *(Eq.12)*

$$Cu + H_2S \rightarrow Cu_2S + H_2$$ *(Eq.13)*

The metallic sulfides (FeS) and (Cu_2S) formed create corrosion and passivation problems, leading to the rapid deterioration of iron and copper [42]. Sulfuric acid is highly corrosive to iron in very high concentrations. In an abiotic environment, diluted and at ambient temperature like the studied effluent, it corrodes the iron into iron II sulphate[43] according to equation 14.

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$ *(Eq.14)*
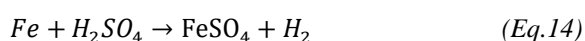
Moreover, concentrated sulphuric acid can corrode copper in an acid medium, causing an exothermic reaction as illustrated by equation 15.

$$Cu + H_2SO_4 \rightarrow CuSO_4 + H_2$$ *(Eq.15)*
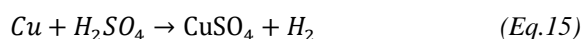
All these reactions show that the studied effluent can cause abiotic degradation of wastewater treatment plants in chemical ways. Hydrogen sulfide and sulphuric acid formed continuously in the effluent can

chemically degrade iron and copper structures, constituting actual health, economic, and environmental impacts [12,43]. These consequences underline the importance of proper effluent management to protect wastewater infrastructure and extend its lifespan to ensure sustainable development [44]. Governments and industry must make a firm commitment to this preventive approach.

3. Conclusion

This study highlighted the significant chemical impact of effluent from cosmetics production units on wastewater infrastructure. Obtained results reveal a correlation between the chemical composition of effluents and the deterioration of wastewater systems, underlining the need for strict regulation and rigorous environmental monitoring. Local authorities and enterprises must adopt appropriate wastewater treatment practices to minimize the negative impact on wastewater treatment plants. The introduction of innovative treatment technologies, combined with the sensitization of those involved in the sector, could contribute to the sustainability of infrastructures and the protection of water resources. Finally, this research paves the way for future research to assess the effectiveness of sanitation strategies and develop predictive models to anticipate the impacts of industrial effluents in Côte d'Ivoire and other developing countries facing similar challenges. To improve the situation, Côte d'Ivoire must build and strengthen the regulations in force, focusing on their practical application. This will help protect the environment, ensure public health, and promote sustainable development. Faced with this challenge, the recovery of effluents according to the promising axis of the economy, as well as treating this type of effluent using metal-organic networks (MOF).

4. Acknowledgments

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