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Biological versus Physicochemical Technologies for Industrial Sewage Treatment: Which Is the Most Efficient and Inexpensive?

Karima Elkarrach, Fatima Atia, Anass Omor, Omar Laidi, Saloua Biyada, Mohamed Benlmelih and Mohammed Merzouki

Abstract

Industries play a major role in the development of countries' economy. However, they are known as the biggest source of water pollution in the whole world. In fact, several industries use a huge amount of water in their manufacturing operations, and then, they reject a large volume of wastewaters such as tanneries, brassware, olive mills ... etc. The sewage of these industries may contain organic/inorganic matters or toxic components that harm human health and the environment. Therefore, the treatment of these effluents is necessary. For that, there are many treatment processes, including biological and physicochemical processes or both. The choice of adequate process is depending on many reasons, especially on the biodegradability degree of each effluent, as well as the presence of recalcitrant pollutants. Nevertheless, biological technologies, particularly bioremediation, are recently an emerging technology for the elimination of recalcitrant pollutants like heavy metals. Furthermore, these biotechnologies are simple, efficient, eco-friendly and inexpensive. Therefore, this environmental biotechnology may be a new approach for the treatment of industrial sewage, so, it can successfully replace physicochemical technologies that are very expensive.

Keywords: Industries, sewage, biological technologies, physicochemical processes

1. Introduction

Water is so essential in our daily life. However, water resources and their quality are progressively decreasing because of human activities, and then several countries are threatened by water scarcity, including Morocco. So, the rational management of these water resources is a big challenge in the whole world. Nowadays, the treatment and reuse of wastewater are known as the best solutions to deal with this lack of water. The constraint of this issue is pollution, especially industrial pollution, because industries generate high toxic substances, which may reduce the performance of the treatment [1]. For example in Morocco, the large hydraulic basin 'Sebou' receives more than 40% of pollution from industries of Fez city such as tanneries, textiles, brassware, olive mill ... etc.

Industries release organic and inorganic pollutants namely heavy metals, dyes, polyphenols ... etc. Heavy metals are toxic, in which their toxicity depends on several factors, particularly the metal dose and the time exposition. Arsenic, cadmium, chromium, lead, and mercury, have ranked as carcinogenic metals, because they may damage multiple organs even at lower exposure doses [2]. Likewise, textile dyes are highly toxic and potentially carcinogenic [3]. Thus, they can lead to various animal and human diseases, as well as the environmental degradation. Therefore, recalcitrant substances harm the environment and human health, and then their removal from wastewaters is mandatory.

The literature has shown several physicochemical and biological processes for the treatment of industrial sewage. Among physicochemical processes, there is coagulation [4], electrocoagulation [5], forward osmosis [6], chemical precipitation [7], adsorption [8], and oxidation [9]. As for biological systems, there are many technologies such as sequencing batch reactor [10], bioaugmentation [11], biosorption [12], membrane bioreactor [13], anaerobic digestion [14]... etc. In fact, each process has its advantages and disadvantages; hence the process performance is highly dependent on the nature of the effluent and the flow to be treated. For example, physical–chemical treatments are known for their high performance, but they are very expensive and can generate another serious pollution. Biological treatments are also efficient and ecological, but the presence of recalcitrant substances in huge amount can decrease their efficient. So, the issue is complex, because it is necessary to find a treatment process that will be eco-friendly, efficient, and economical at the same time.

Taking into account the above, this chapter focuses on various physicochemical and biological processes for the treatment of industrial sewage. Moreover, this chapter will show the effectiveness of biological technologies for the removal of toxic substances.

2. Treatment of industrial wastewaters

The treatment of industrial effluents is essential before their discharge into the natural environment. Several physicochemical and biological treatments of these effluents have been studied in the literature. These techniques have been considered simple, efficient, or even advanced, but each system has certain advantages over the other. Moreover, these treatment systems can be applied independently or combined.

2.1 Physicochemical treatments

2.1.1 Membrane filtration

2.1.1.1 Reverse osmosis

This technology is based on the use of a semi-permeable membrane, wherein pollutants will be captured. This treatment system is known for its high purification rate, and it may be used for the treatment of all industrial sewage [15]. A study has shown that reverse osmosis is an advanced and promising technique for industrial wastewaters. Despite the qualities of this treatment system, it presents certain disadvantages, particularly the high cost.

2.1.1.2 Membrane filtration

Currently, this technique is well developed; it is based on the physical separation of pollutants under hydraulic pressure. This treatment system is very efficient

for industrial sewage treatment such as pharmaceutical [16], textile [17], pulp and paper effluents [18]...etc. The separation is based on three principles, which are adsorption, electrostatic phenomenon, and sieving [19].

According to the membrane's pore size, there are three filtration types:

- **Microfiltration:** it refers to remove substances with a size greater than 10 μm through a membrane with pores between 0.1–10 μm . It is characterized by the tangential passage, and it is done under low pressure gradient of 1–3 bars. This technique is effective for sewage purification and the elimination of microorganisms, especially bacteria.
- **Ultrafiltration:** the pores of the membrane are between 0.001 and 0.1 μm . Thanks to these small pores, only water and small molecules (Ions) can pass through this membrane, while macromolecules such as proteins, polymers, bacteria, and viruses, will be retained [20].
- **Nanofiltration:** the pore size of the membrane is less than 1 nm. This technique is effective for industrial sewage treatment. It may remove heavy metals and ions as chromium and nickel [21]. It can also retain organic substances with a molecular weight fewer than 300 daltons. Nevertheless, it could not produce demineralized water as the reverse osmosis technique.

Otherwise, the membrane can be mineral (metallic, ceramic, etc.) or organic (polyamides, cellulose acetate, etc.). Its structure can be uniform (Isotropic) or composite (Anisotropic). Indeed, organic membranes are the most used because of their low cost, but mineral membranes can resist extreme conditions (Temperature, pH, etc.).

Consequently, membrane filtration has several qualities, namely the removal of micro-organisms, heavy metals, turbidity, dyes, and also odors from industrial sewage. Despite these advantages, the technique has also some limits such as rapid membrane fouling, production of high amount of sludge, high investment costs, and high energy consumption.

2.1.2 Coagulation-flocculation

The coagulation-flocculation process involves the use of coagulant and flocculant agents that can regroup the pollutants together as heavy flocs. These flocs will be eliminated by precipitation or filtration. These agents may be iron or aluminum chemicals. According to Junio et al. [4], coagulation-flocculation is a simple, fast, and effective technique for removing pollutants from industrial wastewaters. In this study, ferric chloride was used as a coagulant agent for the treatment of tannery sewage, wherein the abatement rates of COD and suspended solids were above 80%. Nevertheless, this technique has several disadvantages, namely the production of high sludge and the increase of acidity and conductivity within the treated effluent. On the other hand, the use of bio-coagulants and bio-flocculants is a new approach of this technique in order to reduce the massive use of chemicals and their harmful effects. According to previous study, cactus juice can be used as a bio-flocculant to reduce chromium, in which chromium VI removal was around 98% [22].

2.1.3 Electrocoagulation

Electrocoagulation has considered as a new alternative of chemical coagulation, and it is a promising process for the treatment of industrial sewage [23]. This technique

is based on the principle of soluble anodes, and it induces the electrochemical separation of pollutants. These anodes are often made of aluminum or iron, from where metal cations (Fe^{3+} or Al^{3+}) are generated by imposing an electric current between these anodes. These metal cations react as a coagulant to destabilize the suspended particles, and then, the formation of flocs that will subsequently precipitate. Indeed, this technique has several advantages, but the production of sludge in high amount and the consumption of high energy are its main disadvantages.

2.1.4 Oxidation

Oxidation is based on electrochemical reactions between the oxidizing agent and the pollutant by changing the electrons. This technique aims to modify the characterization of refractory pollutants by making them insoluble to facilitate their elimination, or soluble but non-toxic. The most commonly used chemical oxidants are oxygen, hydrogen peroxide, chlorine, ozone, potassium permanganate, and ferric chloride. This system is known for its strong elimination of bad odors, either natural or produced during anaerobic conditions. In addition, the combination of ozone with ultraviolet rays (UV) or hydrogen peroxide produces free radicals that are powerful oxidants and can eliminate a large part of the COD [24]. The advantages and disadvantages of this process are depending on the oxidant agent and the type of pollutant (Table 1).

According to the literature, several types of research have shown the efficiency of this process for the elimination of sulfides, of which hydrogen peroxide is the most used. This oxidant can eliminate 85–100% of sulfides by using 1.3 to 4.0 mg/L of H_2O_2 for 1 mg/L of sulfides [26].

In recent decades, this process has been developed using the combination of two powerful chemical oxidants ($\text{H}_2\text{O}_2/\text{Fe}^{2+}$ and $\text{H}_2\text{O}_2/\text{O}_3$), photo-catalysis (UV),

Oxidant	Advantages	Disadvantages
Oxygen	Low investment costs. Simple process	Incomplete oxidation. Production of colloidal sulfur and poly-sulfides. Difficult to control and build. Increase of the turbidity.
Chlorine	Low investment costs. Simple process	Incomplete oxidation. Use of high dose. Lack of security. Increase the turbidity
Ozone	Easy process Production of high water quality	Expensive process Increase the turbidity Ozone concentration is low than 2 mg/L
Potassium Permanganate	Easy and economical process	Requires the use of filters for the removal of residual MnO_2 . Increase the turbidity. Use of a large quantity of the product. Expensive product.
Hydrogen peroxide	Easy and economical process	Incomplete oxidation. Increase the turbidity Use of high amount of products. Requires a long contact time.
Ferric chloride	Economical and powerful oxidant	This process has not been demonstrated on a pilot scale for the treatment of drinking water.

Table 1.
Advantages and disadvantages of oxidation agents [25].

sonochemical oxidation, or electrochemical oxidation. As a result, this oxidation is called advanced oxidation (POA), which is considered an innovative process and an emerging technology for the treatment of industrial sewage. The principle of advanced oxidation is based on the production of hydroxyl radicals, which are very active and react rapidly on organic and inorganic compounds [9]. This advanced process has several qualities like high removal rates in a short time and minimal sludge production. However, it also has some disadvantages namely the high operating and investment costs, as well as the treatment efficiency depends on nature and pollutant concentration.

2.1.5 Adsorption

Adsorption is well known for the treatment of industrial sewage, so it is characterized by its high purifying capacity [27]. This process is based on the use of a material that will retain pollutants. This material can be applied as a fixed bed or can be used in suspension with the effluent (Fluidized Bed). The adsorption material can be inorganic (rocks, ashes ...), or organic (fruit, vegetables, wood, bacteria). Moreover, it can be used natural or activated.

The activation of a material can be carried out with a physical process (Pyrolysis, calcination, carbonization), a chemical process (Acids, bases), or the both. Physical activation involves high temperatures (800–1000°C), whereas chemical activation requires low temperatures. The most commonly used chemical agents are potassium hydroxide, sodium bicarbonate, sodium hydroxide, zinc chloride, sulfuric and phosphoric acids. However, phosphoric acid is frequently used comparing to other agents because of its low cost and activation temperature, as well as this acid can be recoverable ($< 600^{\circ}\text{C}$) [27]. On the other hand, the activation of materials with potassium hydroxide is considered as the most effective [28]. In fact, chemical activation has several advantages, especially the increase in the specific exchange surface and the material porosity [8]. Although the activated carbon is a powerful adsorbent, its use is so limited due to its high cost. For that, this technique will be very attractive and promising if the material will be efficient and inexpensive at the same time. Thus, several attempts have been made to find novel materials such as organic waste, fly ash [29], olive pomace [30], and sawdust [31].

2.1.5.1 Adsorption types

According to the literature, the principle of adsorption is based on the binding forces between ions of adsorbent and adsorbate. Consequently, the involved forces divide adsorption into two types:

- Physical adsorption or physisorption: this type of adsorption is characterized by the absence of electron exchange between the adsorbent and the adsorbate. However, the adsorbate is retained by the adsorbent through non-specific physical forces of Van der Waals type, where multiple layers can be formed. This adsorption type requires low heat and it is reversible and non-specific.
- Chemical adsorption or chemisorptions: it is based on the exchange of electrons between the adsorbent and the adsorbate. This process requires high energy compared to physical adsorption. This energy corresponds to the eternal covalent bonds between ions of the adsorbent and the adsorbate, and then the phenomena of ion exchange and protonation/deprotonation are the main mechanisms. Moreover, a single layer could be only formed through this adsorption type, while other layers can be retained by physisorption.

2.1.5.2 Adsorption isotherms and kinetics

The study of isotherms is essential because it expresses the static adsorption capacity for an adsorbent/adsorbate couple. There are four main types of isotherms, which are as follows (**Figure 1**):

- Type a, which reveals cooperative adsorption of the adsorbate molecules.
- Type b or “Langmuir type”, which is observed in the case of progressive microporous adsorption.
- Type c, which is observed in the case of a strong interaction between the adsorbate and the surface of the solid.
- Type d or linear isotherm, which occurs when the solutes penetrate more easily into the solid than into the solvent [32].

On the other hand, several mathematical models describe the adsorption mechanisms, where Langmuir, Freundlich, and Temkin are widely used.

- Langmuir’s model: indicates that the adsorption is monolayer and into homogeneous surface. It is the oldest and the most common model. A limited adsorption capacity (q_{\max}) is retained by the solid.
- Freundlich model: this empirical model reveals that the material surface is heterogeneous.
- Temkin’s model: It takes into account adsorbant-adsorbate interactions.

Adsorption kinetics allows also a better understanding of the adsorption mechanism. As well, it describes the adsorption rate that leads to the control of the equilibrium time. The mathematical models of the adsorption kinetics are numerous and they can be used for the optimization of treatment models. Among these models, we quote pseudo-first-order, pseudo-second-order, and Elovich.

2.2 Biological treatments

Although the COD/BOD₅ ratio reveals that physicochemical treatments are the most suitable for inorganic industrial sewage, the literature has shown that

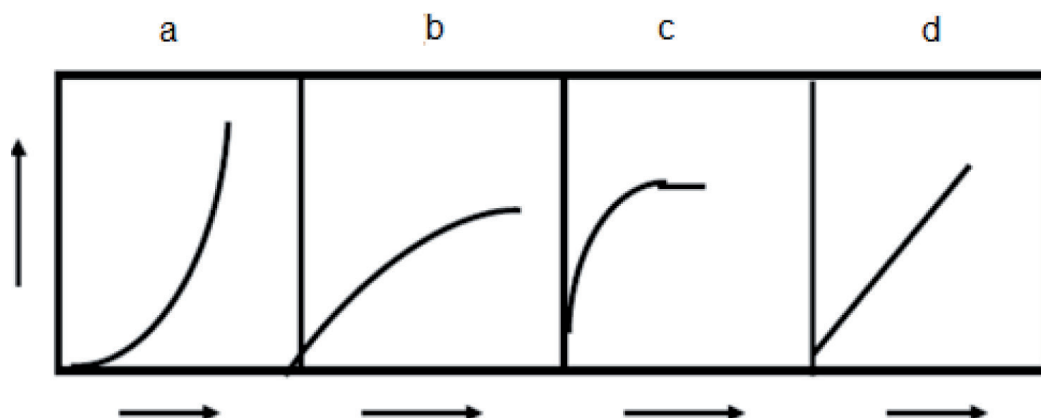


Figure 1.
Main types of adsorption isotherms according to [32].

biological treatments are also efficient and promising for the treatment of these effluents. Biological treatment involves the use of non-specific microorganisms (Activated sludge), well-selected microorganisms (Bio-augmentation), algae, or plants (Phytoremediation). These microorganisms can be bacteria, yeasts, fungi, etc.

Biological treatment consists of the use of pollutants of industrial sewage as a source of nutrition and energy by these microorganisms for their growth. This type of treatment has several advantages comparing to physicochemical treatments. Among these qualities, there are:

- Easy installation and control on a large scale.
- Attractive and economical processes.
- Ecological processes.
- Very effective for the removal of biodegradable organic matter, nitrogen, and phosphorus in particular.

Furthermore, the presence or absence of oxygen divides these biological treatments into two categories, which are aerobic and anaerobic treatments.

2.2.1 Aerobic treatments

2.2.1.1 Classical process of activated sludge

The activated sludge process is the most classic and most famous process since the 20th century. It is based on the treatment with aerobic micro-organisms. These micro-organisms are generally autotrophic or heterotrophic, and they are composed of several groups like bacteria (Gram-positive and/or Gram-negative), fungi, yeasts, protozoa, and metazoa. Consequently, activated sludge is composed of micro-organisms plus inert, organic or mineral matters. These elements are grouped through mucilaginous substances. In fact, those micro-organisms degrade the organic matter of wastewaters into carbon dioxide, water, new cells, and other non-toxic by-products. The separation between the treated effluent and the activated sludge takes place in a clarifier or decanter.

Even this process is very effective in the degradation of organic sewage like agri-food sewage; it also has some disadvantages, particularly the bulking phenomenon, the presence of high amount of recalcitrant pollutants, as well as nitrogen and phosphorus are not reduced at the same time and in the same reactor. This requires the addition of another tank to remove them, and subsequently the increase of installation and operation costs.

2.2.1.2 Sequencing batch reactor

The Sequencing Batch Reactor (SBR) is an emerging approach that has been well developed recently. This technique has the same treatment principle as the previous process, so it is based on the treatment by activated sludge under aerobic conditions. However, this process differs from the other one, because all treatment steps are performed in a single reactor, including nitrogen and phosphorus removal. In addition, the separation liquid/solid is done in the same reactor, where the good separation is linked to the presence of an adequate quantity of filamentous bacteria.

The treatment through this system is by cycle that involves four successive phases, which are:

- Phase one is the supply of the reactor with the effluent to be treated.
- Phase two is the aeration or treatment phase. In this phase, the effluent is brought into contact with the activated sludge in the presence of oxygen. During this stage, the effluent will be degraded by micro-organisms.
- Phase three is the settling phase during which the treated effluent will be separated from the activated sludge.
- Phase four is the withdrawal phase, from which the treated effluent will be withdrawn and the new cycle will be started.

The performance of this system depends on many parameters such as the volumetric organic load, daily cycle number of the treatment, level of dissolved oxygen, sludge index, sludge age, and time of the settling phase. The optimization of these parameters leads to very high abatement rates.

The reference [33] showed that SBR is a promising technique for the treatment of several types of sewage such as agri-food, pharmaceutical, pulp/paper, textile, tannery, chemical, and petrochemical effluents, ... etc.

Another study shows the efficiency of the SBR system compared to the conventional activated sludge process (**Table 2**). So, the SBR is the most efficient due to very high removal rates, and also the system is capable to remove nitrogen and phosphorus at the same time. Thus, this system is inexpensive and useful than the classic process. Furthermore, aerobic denitrification was highlighted within this reactor [10, 35]. In recent decades, this phenomenon has been very attractive and advanced according to various studies. The literature showed more than 37 aerobic denitrifying bacteria, where *Bacillus pulminus*, *Arthrobacter sp.*, and *Streptomyces lusitanus* were the latest shown [36].

Heavy metals could also be removed by this biological system. The reference [11] has shown that this system is capable to remove chromium from a tannery effluent with a removal rate of 96.1% using a low volumetric organic load. As well, [37] has indicated that several heavy metals (Nickel, chromium, cadmium, cobalt, zinc, and silver) were eliminated from brassware effluent through this system with high removal rates that reached more than 60%.

This system has many advantages such as low cost, short treatment time compared to the classic process, high removal of organic and mineral matter, simplicity of the process, the possibility of spreading excess sludge, limitation of bad odors,

Parameters	Abatement rate (%)	
	Sequencing batch reactor	Classic process of activated sludge
BOD ₅	89–99	85–95
Suspended solids	85–97	85–90
Total nitrogen	>75	Untreated
Phosphorus	57–69	Untreated
Total coliforms	99	90–96

Table 2.
Average abatement rates obtained by the sequential batch reactor and the conventional activated sludge process [34].

etc. ... Despite all these advantages, it also has some shortcomings like the bulking phenomenon.

2.2.1.3 Membrane bioreactor

The membrane bioreactor is a new alternative to the classic activated sludge process, so it is based on the same principle of activated sludge treatment. However, the solid/liquid separation is done through membrane column instead of clarifier. Consequently, this technique is the combination of an activated sludge biological reactor and a membrane process such as microfiltration. It is widely used for the treatment of industrial sewage [13]. Furthermore, the use of membrane filtration increases the rate of effluent purification due to its removing capacity of high concentrations of suspended solids, nitrogen and phosphorus, as well as bacteria and viruses. However, membrane cleaning or regeneration after plugging is essential, so it increases considerably the process cost.

2.2.1.4 Bioremediation

The presence of a high concentration of heavy metals, salts, or other toxic substances, reduces or prevents the treatment by the activated sludge because of these extreme conditions. This issue allows us to highlight biotechnological technique that is bioremediation. This biotechnology regroups some processes like bio-augmentation, biosorption and phytoremediation. These techniques use a powerful microorganism, consortium, or plant, which can resist these extreme conditions.

Bioaugmentation is based only on the use of living microorganisms, whereas biosorption involves living or non-living microorganisms. Moreover, biosorption is one of the various mechanisms of bioaugmentation. For biosorption, the microorganisms can replace the activated carbon, and then reduce process cost. This method depends on cell wall compositions such as polysaccharides, which include amino, carboxyl, phosphate, and sulfate groups. According to a previous study, the biosorption method was applied to remove heavy metals using natural microorganisms [38], or as a bio-nanocomposite material, which were synthesized from microorganisms [39]. Biosorption depends on some mechanisms, namely adsorption, ion exchange, chelation, and complexation. While bioaugmentation, it is based on the metabolic capabilities of microorganisms for the detoxification of several compounds, including recalcitrant pollutants. Therefore, microorganisms can resist these toxic substances of industrial sewage through some mechanisms, among which figure biosorption, bioaccumulation, enzymatic reduction, SOS response, and enzymatic DNA repair system... etc. [40]. So, these mechanisms can be an effective way to remove the toxicity of the industrial sewage.

Furthermore, there are three approaches of bioaugmentation depending on the origin of these added microorganisms:

- Autochthonous bioaugmentation: It indicates that the microorganism is isolated from the same contaminated medium to be treated (native or indigenous microorganism).
- Allochthonous bioaugmentation: where the medium of isolation is different from the contaminated medium to be treated (endogenous microorganism).
- Gene bioaugmentation: this is when the inoculated microorganism is genetically modified to have certain functions.

Tannery effluents are known for their high salinity, due to the high use of salts during the tanning process. Therefore, [41] added a consortium of halophytic bacteria in the sequencing batch reactor to treat this tannery sewage. Despite the use of a high salt concentration of 34 g/L, the treatment achieved great abatement rates of 95%, 93%, 96%, and 92% respectively for COD, orthophosphate ions, NTK, and suspended solids.

Enterobacter sp. DU17 was isolated from the tannery effluent [42]. This bacterium was used to reduce hexavalent chromium. Indeed, the reduction rate of Cr(VI) could reach 100% when the initial chromium VI concentration is around 100 mg/L, and when glucose or fructose are carbon source. This high Cr(VI) reduction capacity by *Enterobacter sp.* DU17 has been justified by the presence of chromium reductase enzyme.

Several bacterial have shown their capacity to biosorb heavy metals such as chromium. Likewise, [11] showed that *Bacillus sp.*, *Enterobacteria erogenes*, and *Bacillus pumilus* are also chromate bacteria.

In conclusion, this biotechnology may be the most efficient and inexpensive technique for the treatment of industrial sewage because it involves the use of the most efficient microorganisms for each pollutant type.

2.2.2 Anaerobic treatments

Anaerobic treatments are generally the same as aerobic treatments but in the absence of oxygen. So, they consist of the degradation of effluents by anaerobic microorganisms. Although these anaerobic treatments have a low removal of COD and BOD₅, anaerobic co-digestion produces biogas from the organic matters. Indeed, biogas production passes through four stages under the intervention of fermentative bacteria, then acidogenic bacteria, followed by acetogenic and methanogenic bacteria [43]. The produced biogas contains a mixture of methane (50–75%), carbon dioxide (30–40%), and some traces of other components [43].

This anaerobic process can treat industrial sewage such as mill olive, agrifood, domestic, and tannery effluents [44]. According to several studies, sulfides inhibit the proliferation of methanogenic bacteria [45]. Nevertheless, a study has shown that tannery effluents can be anaerobically degraded [44]. In this study, tannery effluents were mixed with the plant of *Phragmites karka*, and then they were incubated in the SBR under anaerobic conditions using different concentrations of the plant. This co-digestion of this mixture produced 0.26 L of methane per 1 g of COD eliminated (71%), where the plant percentage was about 25%. This rate of produced biogas decreased when the concentration of the plant increases.

In conclusion, anaerobic treatment becomes very attractive due to its production of renewable energy.

2.3 Coupled treatments

Although physicochemical and biological treatments are efficient, certain limits reduce their performance. Industrial sewage is very complex and toxic, so a physicochemical or even biological process is unable to eliminate the entire pollutant load, especially inorganic pollutants. For this reason, several researchers have combined two processes or more in order to increase the purification of these effluents and to obtain an effluent that fully meets discharge standards.

In the reference [46], they coupled the chemical process of ozone oxidation with the membrane bioreactor for the treatment of tannery effluents. The coupled treatment of these two processes produced a small amount of sludge (0.03 Kg sludge/kg COD removed), which was considered to be the lowest.

On the other hand, [47] has combined chemical coagulation using ferric chloride with advanced oxidation techniques (photo-oxidation, homogeneous oxidation, and photo-fenton) for the treatment of industrial sewage, where the coagulation coupled to photo-fenton is considered the best.

In another study, aluminum sulfate and ferric chloride were used to remove organic carbon and chromium before biological treatment of tannery effluents by the SBR. This study showed that aluminum sulfate is more effective than ferric chloride in terms of COD removal [48]. However, [36] has used ferric chloride as a coagulant following by the treatment through the SBR. This combined treatment gave 99.89%, 99.98%, and 99.99% respectively for the COD, the sulfide ions, and the total chromium, and then the treated effluent was well conformed to standards.

In [49], they have coupled coagulation with activated carbon adsorption to treat industrial effluents, where lime was used as a coagulating agent. This combined treatment removed 97% of suspended solids, 99% of color and turbidity, 98% of total phosphorus, and 99.7% of chromium.

On the other hand, [50] has studied the treatment of tannery effluents by coupling 3 processes: 2 anaerobic bioreactors, followed by ozone oxidation, followed by biofiltration. The filtration is carried out under aeration into ceramic-lined column, which is inoculated with activated sludge. The optimization of this system has led to the production of a satisfactory rate of biogas and a good elimination of COD, total chromium, chromium VI, total nitrogen, and suspended solids.

3. Conclusion

The pollution generated by industries has harmful impacts on the environment and human health. In addition, their effluents were classified as very dangerous due to the presence of recalcitrant pollutants. This imposes a prior treatment of these effluents before their discharge into the environment. In this regards, different physicochemical and biological techniques for the treatment of these effluents have been shown in this chapter such as reverse osmosis, membrane filtration, oxidation, adsorption coagulation, classic activated sludge, sequencing batch reactor, membrane bioreactor, bioremediation, and anaerobic processes. Indeed, each technique has advantages but also has certain limits. For that, the choice of a treatment system is linked to numerous criteria namely the nature of the effluent, the presence of toxic substances, the operating and investigation costs and the possibility of its application at a large scale. Generally, although physicochemical techniques are very efficient and well adapt with industrial sewage, they are expensive and could generate other pollutants. Otherwise, the presence of huge amount of recalcitrant pollutants is the main limit of biological but they are also more efficient, simple, eco-friendly and especially inexpensive.

Based on this study, we considered further investigating the treatment of industrial sewage through biological processes, bioremediation techniques in particular, because they are promising, attractive and emerging technologies.

Conflict of interest

The authors declare no conflict of interest.

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