Moroccan Journal
of Chemistry
ISSN : 2351-812X

Mor. J. Chem., 2023, Volume 11, Issue 01, Page 119-128
https://revues.imist.ma/index.php/morjchem

The effect of treatment parameters on the coagulation-flocculation of leachate from the Great Agadir controlled discharge

Hajji C. [1], Bougdour N. [2*], A. Idlahcen A. [2], Elmouhri W. [2], Tajat N. [2], El Hayaoui W.[2], Radaa C.[2], Qourzal S.[2], Tamimi M.[2] , Bakas I. [2]

[1]*Faculté des sciences appliquées, CUAM, Université Ibn Zohr*

[2]*Team Catalysis and Environment, Faculty of Science, Ibn Zohr University, Agadir, Morocco*

**Corresponding author, Email address: nadia.bougdour@edu.uiz.ac.ma*

Received *12 Nov 2022,*
Revised *15 Dec 2022,*
Accepted *18 Jan 2023*

Citation*: Hajji C.1, Bougdour N. , A. Idlahcen A. , Elmouhri W. , Tajat N. , El Hayaoui W. 1, Radaa C. , Qourzal S., Tamimi M. , Baka I. (2023) The effect of treatment parameters on the coagulation-flocculation of leachate from the Great Agadir controlled discharge , Mor. J. Chem., 14(1), 119-128.*
https://doi.org/10.48317/IMIST.PRSM/morjchem-v11i1.35126

Abstract: One of the main obstacles to the management of public landfills is leachate from urban garbage. They do pose a harm to the environment and to human health given the amount of pollutants they contain. Depending on the type and age of the waste, the climate, and the terrain of the location, each landfill's composition is different. One of the locations with a leachate management issue is the controlled landfill in Greater Agadir. Leachates have been reduced using a recirculation and sprinkler system, although efficiency is still very poor. The leachate water was diagnosed as having significant organic contamination. This study aims to describe the leachates from several Greater Agadir areas and assess the efficacy of the coagulation-flocculation method of treatment. $FeCl_3$ considerably changed the hue of the leachate, which had a neutral pH, 90% turbidity, and 78.2% COD elimination. This leachate appears to be best suited for modest doses of 3g/L. The research conducted here has also demonstrated that the polyacrylamide flocculant, with a mass of 3 g in the presence of a mass of 3 g ferric chloride, has a turbidity level of 92% and 97% for COD. For 3 g/L of ferric chloride, however, the bioflocculant from "Opuntia cactus" juice also provides good flocculation, with a turbidity removal rate of 98.14% and a COD removal rate of 87%.

Keywords: landfill leachate, coagulation flocculation, coagulant, Flocculants, Opuntia cactus

1. Introduction

Household leachates and other wastes pose a real threat to the environment in Morocco. As soon as a controlled landfill is built, the leachate is no longer absorbed by the soil, as was the case with

traditional landfills. Instead, they accumulate in the waterproof pond at the bottom of the landfill. One of the major problems facing the Greater Agadir landfill is the massive increase in solid waste. The daily flow of household waste is around 900 tons. In addition, the high moisture content, which can reach 70% of the waste weight, has generated large quantities of leachate requiring treatment (Azougarh *et al.,* 2019). In recent years, the amount of leachate produced in the Agadir landfill increased at a rate of 130 tons per day(t/day) in 2018, and is likely to reach 160 t/day by 2024 (*Bougdour et al.,* 2022). In addition to the odors it emits, leads to surface quality and groundwater deterioration due to its high pollutant load, if not properly treated. Leachate may contain a large amount of organic matter (biodegradable but also resistant to biodegradation) consisting largely of humic substances (*Kang et al.,* 2002), as well as ammonia nitrogen, heavy metals, organochlorines and inorganic salts (*Chemlal et al.,* 2014). Therefore,it is necessary to seek economical and ecological solutions for the treatment of leachate because of the insufficiency of the effectiveness of some treatments, due to the high cost which exceeds the financial capacities of the communes (*Bougdour et al.,* 2022). In recent years, coagulation and flocculation have shown a high efficiency in pollution removal in effluent treatment (Idlhsen et *al.,* 2021, Idlhsen et *al.,* 2022). This process can be applied directly to leachates to remove organic matter with suspended matter, without affecting the leachate composition's complexity (Amor et *al.,* 2015). A wide wide range of laboratory and pilot-scale experiments have been conducted to assess the effect of several coagulants. The most commonly used in wastewater treatment are the trivalent salts of iron $FeCl_3$, $FeSO_4$ and aluminium $Al_2(SO_4)_3$ and to a lesser extent ferrous sulphate $FeSO_4$. The objectives of this study are therefore to examine the effectiveness of flocculation coagulation processes for leachate treatment, particularly in terms of turbidity, COD abatement and color removal. The optimum conditions for effective leachate treatment by flocculation coagulation were achieved using four coagulants such as $Ca(OH)_2$ lime, $FeCl_3$ ferric chloride, $FeSO_4$ ferrous sulphate and $Al_2(SO_4)_3$ aluminium sulphate. Then the best coagulant is combined with Opuntia cactus and polyacrylamide flocculants.

1. Materials and methods

2.1 Site Presentation and Leachate Removal

The Greater Agadir region, located in the southwest of Morocco, is characterized by a semi-arid climate. Urban waste from Greater Agadir is deposited in the Tamellast Technical Landfill Centre (CET). The CET is located at the Lambert coordinates (X: 104182 to 105182 Y: 388640 to 389926) **figure 1**. It was commissioned on April 12, 2010, covering a total area of 41ha and consists of six leachate basins equipped with an active sealing system (geomembrane and bentonite) and back-up pumps to promote the natural evaporation of leachate by using floating sprayers installed on the

surface of the tanks. The construction, development and operation of the CET site are part of delegated management. The leachate was collected and stored in large polyethylene PE bottles. The samples were transported directly to the laboratory and stored at 4°C. This operation was repeated during the period from February to April 2019.

Figure 1. Satellite view of the Tamellast landfill location.

1.2. Jar Test Procedure

The flocculation coagulation test was carried out using a helix flocculator (jar test). The test equipment consists of a four-stirrer flocculator (Fisher 1198 flocculator) with an individual rotation speed of between 0 and 200 rpm. This device allows the liquid contained in a series of beakers filled with 500 mL of leachate to be stirred at the same. Different concentrations of the selected coagulant were added to the leachate. The pH adjustment was done by adding HCl (4N) or NaOH (2N). The mixture is stirred rapidly at 200 rpm for 10 min then the speed is reduced to 60 rpm for 30 min. After 60 min of settling, the supernatant is recovered to analyze the pollution parameters.

1.3. Measurements of physico-chemical parameters

Several analyses were conducted on the collected leachate such as measurements of temperature, electrical conductivity, pH, biological oxygen demand (BOD_5), chemical oxygen demand (COD), turbidity and ammonium, nitrate and sulphate (AFNOR,1997). The pH was measured using a standard pH meter (HANNA Instrument pH209, HI 1332), the conductivity was determined by an Adwa AD 3000 conductivity meter, the COD was analyzed using a COD-thermo-reactor type meter and BOD_5 using a cooled incubator type BOD FOC215I. Turbidity was determined by a WTW TURB 430 IR turbidity meter.

1.4. *Leachate Characterization*

Tamellast's Technical Landfill Centre (CET) leachates contain many organic and mineral contaminantsthat are often highly toxic. Their composition thus varies according to the nature of the waste, the landfill age, the operating technique and the climatic conditions. **Table 1** shows the main physico-chemical parameters of these leachates.

Table 1. Physico-chemical characterization of leachate

Parameters	pH	Turbidity NTU	THIS mS/cm	DCO mg O_2/L	DBO_5 mg O_2/L	COD/ BOD_5	SO_4^{2-} mg/L	NO_3^- mg/L
Leachate	5.4	1220	92.76	12135	6015	2	154	45
Moroccan standards	5,5-8,5	250,00	2,70	600	300	3	500	5

The leachate studied has a brownish color and a foul smell. The results showed great variability in the composition of the leachate. Also, the results summarized in Table 1 revealed that the studied leachate has a diversified and high pollutant load. The electrical conductivity is 92.76 mS/cm, indicating the high mineralization of the Tamelaset landfill leachate. The temperature is 20 – 26°C, which favors the maintenance of colonies of "mesophilic" micro-organisms that develop at a temperature between 20 and 40°C. As for the organic load, the mean COD and BOD_5 levels are 12135 and 6015 mg O_2/L, respectively, with a COD/BOD_5 ratio of 2. This shows that leachates are loaded with biodegradable organic matter.

3. Results and Discussion

3.1. *Characterization of cactus powders*

*3.1.1. Fou*rier Transform Infrared Spectroscopy (FTIR) analysis

Chemical analysis of cactus (*O. ficus indica*) powder (**figure 2**) shows broad bands in the 3600-3000 cm^{-1} region which are due to the elongation of -OH bonds. Bands around 2950 cm^{-1} and 2850 cm^{-1} can be attributed to symmetric and antisymmetric vibrations of the $-CH_3$ and $-CH_2$ groups of the methylene functions of the aliphatic chains (El Felset *al.*, 2014). The band at 1735 cm^{-1} is attributed to the vibrations of the C=O groups of carboxylic acids, ketones and aldehydes(Kaiser el *al.*, 2005). The band at 1596.9 cm^{-1} corresponds to the vibration of the C=C groups of carboxylic acids and ketones. The band at 1319.2 cm^{-1} is derived from the vibration of the -OH groups of phenolic compounds. The band at 1620 cm^{-1} corresponds to the C=O vibration of the COO- ionic form of carboxylic acids (Celi et al., 1997, Abouelwafa et al.,2008).The peaks observed at 1370.45 cm^{-1} reflect symmetric or asymmetric valence vibrations of the carboxylic groups of pectins. We also identified an absorption band characteristic of C-O-C or -OH groups in polysaccharides at 1026 cm^{-1}. Absorption bands with wave numbers below 800cm^{-1} can be attributed to nitrogenous bioligands (Barka et al., 2013).

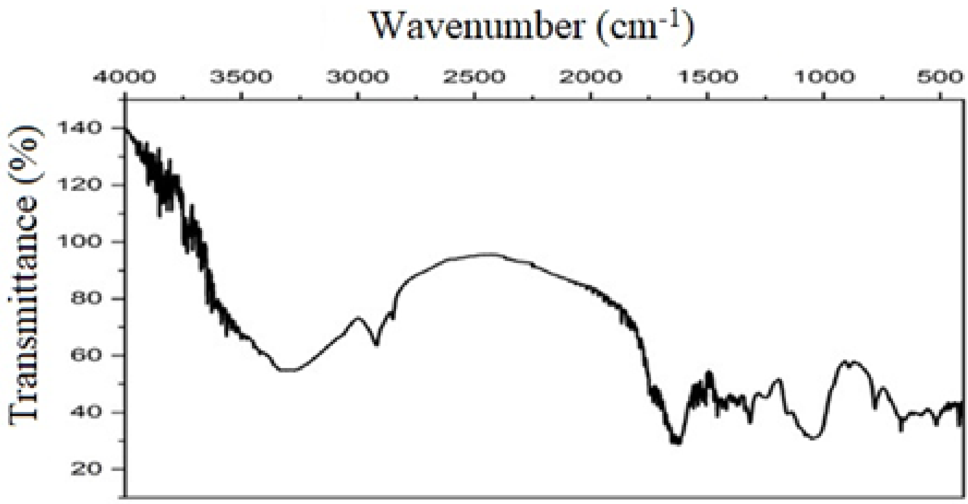

Figure 1. FTIR spectrum of Opuntia cactus

3.1.2. Scanning Electron Microscopy coupled with EDX

A better understanding of the nature of the powder, as well as the elemental composition, was obtained using SEM coupled with EDX analysis. The technique establishes the morphology, porosity, texture and elemental composition with the relative percentage in the (Barka et al., 2013; Prodromou et al.,2013; Hadjittofi et al.,2015). **Figure 3** shows that bioflocculants have an amorphous structure of a compact nature and a rough surface, porosity as well as the presence of mult-ilayer that have been implicated in the flocculation process (Peláez-Cid a et al., 2013; Prodromou et al.,2013; Hadjittofi et al.,2015).

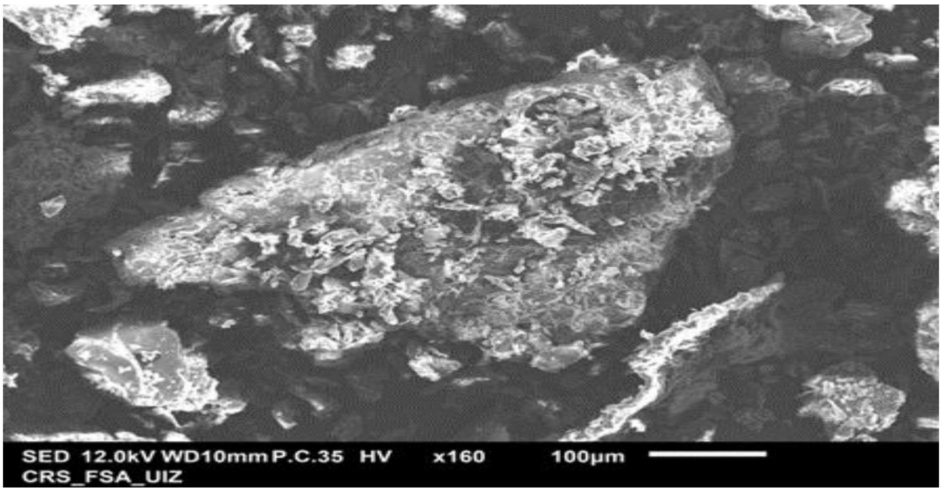

Figure 2. SEM images of the cactus

3.2. Leachate treatment by coagulation-flocculation

Several tests were carried out in order to optimize treatment parameters such as pH and the mass of the coagulants and thus have a better abatement of the COD.

3.2.1. Optimizing the dose of coagulants

To study the effect of the coagulant dose, a series of experiments were carried out by varying this dose from

1 to 6 g/L for FeCl3, $FeSO_4$, $Al_2(SO_4)_3$ and from 1 to 14 g/L for $Ca(OH)_2$. The results obtained from the reduction of the COD according to different applied doses are shown in **figure 4.**

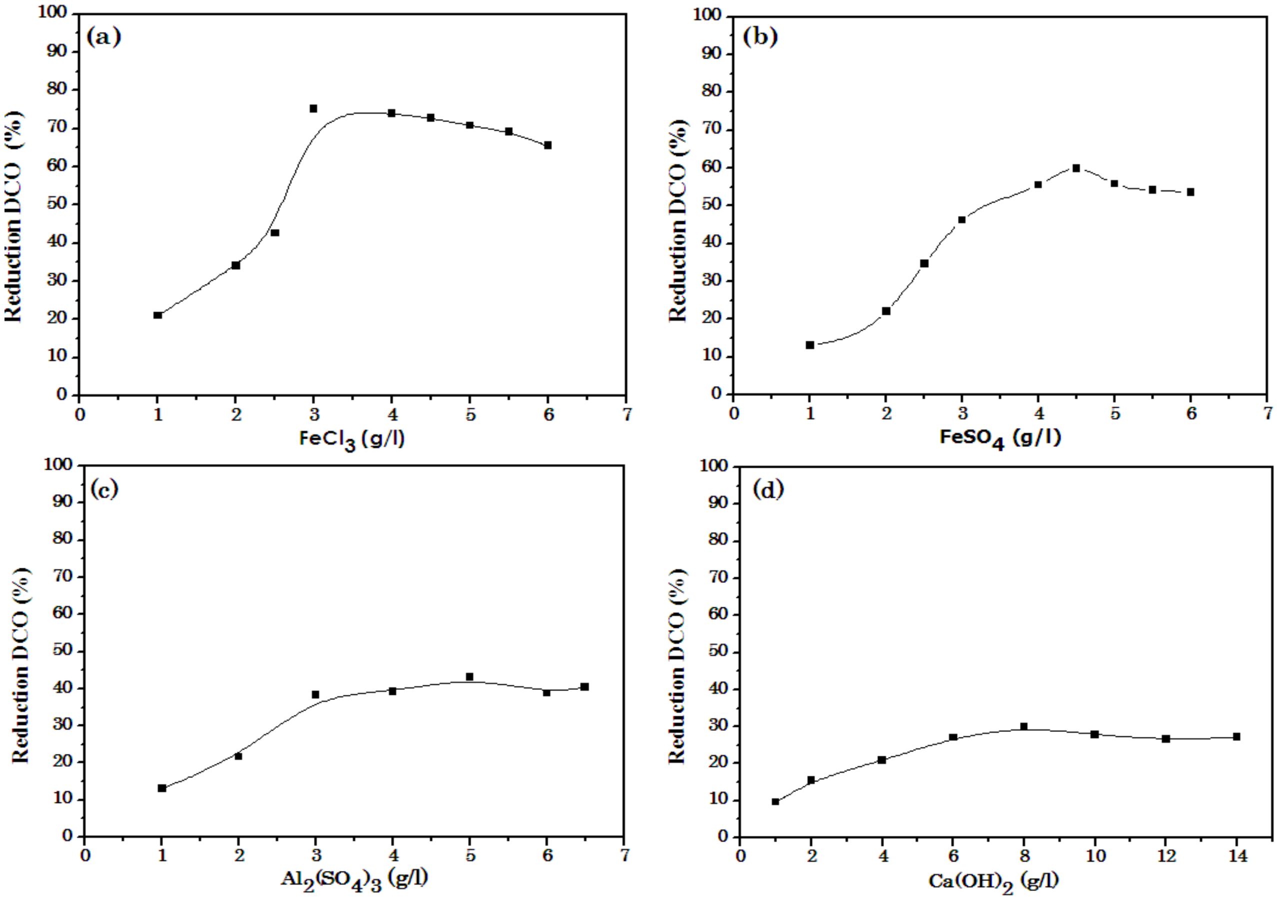

Figure 4. Effect of coagulant mass on COD removal (a) $FeCl_3$; (b) $FeSO_4$; (c) $Al_2(SO4)_3$, (d) $Ca(OH)_2$, pH Initial= 5.4

The coagulation/flocculation step is essential to reduce total suspended solids, organic matter content and color to improve the efficiency of further treatment. The dark color of the leachate is mainly due to the presence of high concentrations of humic substances that represent the majority of the organic compounds in the leachate (Vedrenne et al.,2012). From the data in **figure 4**, we note that highest COD removal (75%) was obtained at the optimal dose of 3 g/L for $FeCl_3$. For other coagulants a reduction of (50%, 43% and 30%) is obtained for doses of 4.5, 5.0 and 8.0 g/L respectively, for FeSO4, $Al_2(SO_4)_3$ and $Ca(OH)_2$. Beyond this dose, a decrease in COD abatement and an increase in turbidity was observed, with a shift from light yellow to dark. This behavior can be explained by the theory of load neutralization. When coagulants were added to the leachate, the cations and their hydrolyzed products interacted with the negative colloids and neutralized their loads, thereby promoting the destabilization of the colloids.

3.2.2. Determination of the optimal pH

To determine the influence of pH on COD abatement and turbidity, a series of experiments were carried out by determining the optimal dose of $FeCl_3$, $FeSO_4$, Al_2SO_4 and $Ca(OH)_2$ coagulants, respectively, at 3.4.5, 5

and 8 g/L and by varying the pH of coagulants from 4 to 8, except for coagulant $Ca(OH)_2$, it was varied from 6 to 12.

Figure 5(a) represents the pH effect on turbidity removal and COD using $FeCl_3$ coagulant. Note that the optimal pH of $FeCl_3$ coagulant is 6 resulting in a significant COD reduction reaching 78.2% and a 90% removal of turbidity. This is related to the nature of colloids and the growth of iron hydroxide flocs. In addition, the study of leachate treatment by ferrous sulphate is illustrated in **Figure 5(b)**. These results show that turbidity decreases with increasing pH and conversely for COD, with high COD removal efficiency and turbidity, 64.2% and 87% respectively at pH 6. The study of the treatment of leachate by aluminum sulphate is shown in **Figure 5(c)**. The results showed that the optimal pH is 6. It achieves a 47% COD reduction and 65.5% turbidity. **Figure 5(d)** reveals that calcium hydroxide $Ca(OH)_2$ has a low ability to remove COD although it was improved at pH 11 and 12, reaching 40% and 92%, respectively, for the removal of COD and turbidity.

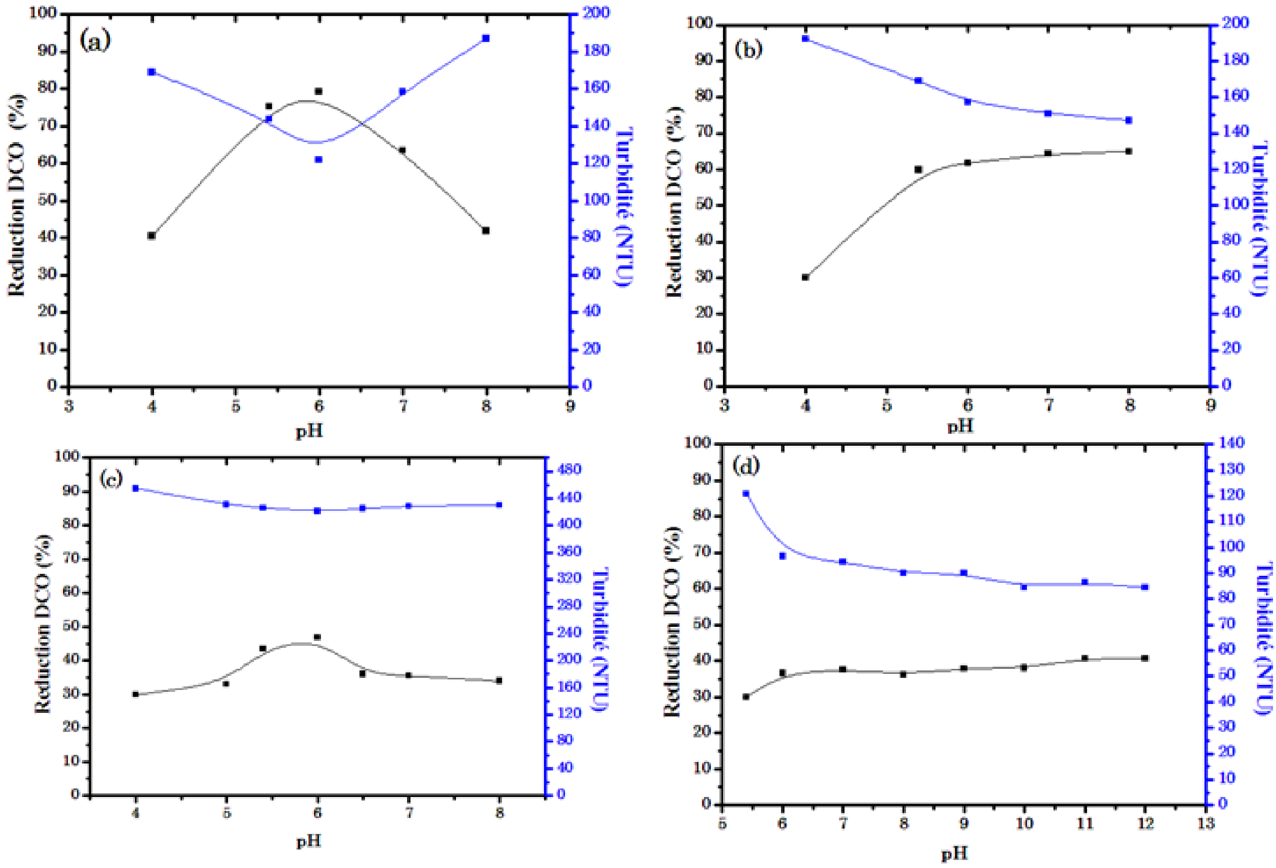

Figure 5. pH effect on turbidity removal and COD, (a) $FeCl_3$; (b) FeSO4; (c) $Al_2(SO_4)_3$; (d) $Ca(OH)_2$ ([$FeCl_3$]=3g/L ; [FeSO4] =4.5g/L; [$Al_2(SO_4)_3$] =5g/L ; [$Ca(OH)_2$]=8g/L**)**

According to the discussion presented above, ferric chloride was chosen as the most practical coagulating agent under the following experimental conditions: pH= 6 and a dose of 3 g/L, obtaining 78.2% COD and 90% turbidity elimination.

3.2.3. Optimal dose flocculant

Once the optimum dose for each coagulant was determined, experiments were carried out by varying the dose of the flocculant **(figure 7)** to determine the influence on the coagulation-flocculation process and to determine the optimum dose. $FeCl_3$ is still the most appreciated for a better elimination. Therefore, the effect of mixing $FeCl_3$ (3 g/L at pH=6) with different flocculants is studied, in order to improve the treatment by the combined effect of coagulant and flocculant.The optimal dose of a flocculant is defined as the value above which there is no significant increase in removal efficiency with the addition of a flocculant. Two types of flocculants were used, i.e., a synthetic flocculant (polyacrylamide) and a bioflocculant from the *Opuntia* cactus plant.

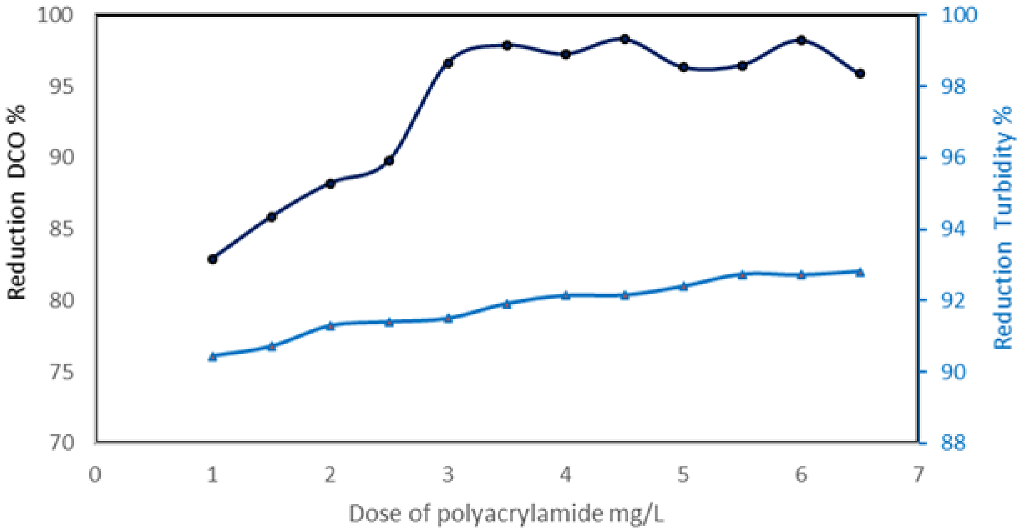

Figure 6. Evolution of leachate turbidity and COD as a function of polyacrylamide dose.

Figure 6 shows that the tests carried out using this mixture ($FeCl_3$ and polyacrylamide) made it possible to reduce the pollution of the leachate, on the basis of the results obtained, it is noted that plyacrylamide, with a mass of 3 g/L, leads to good flocculation.

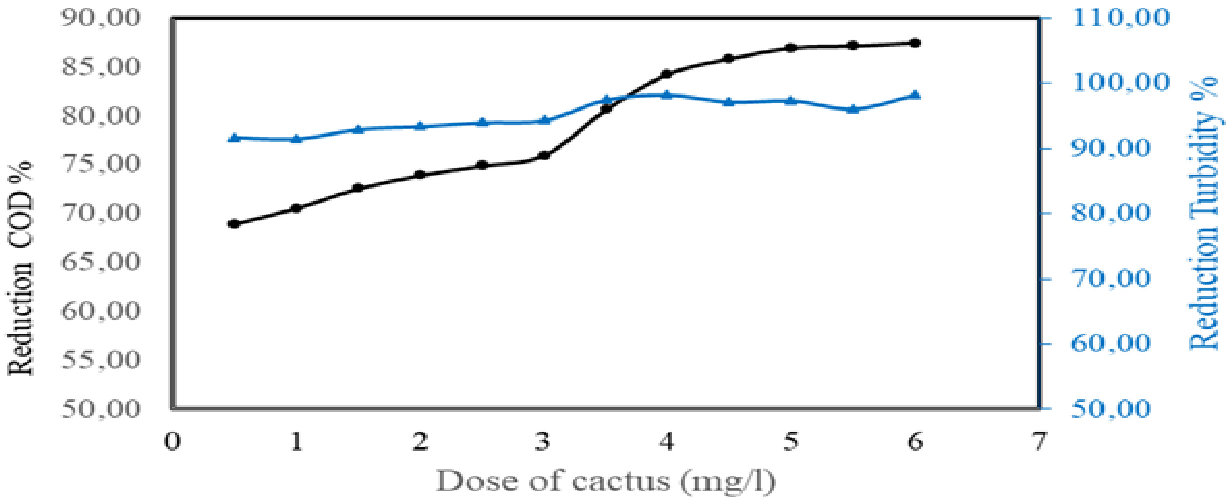

Figure 7. Evolution of turbidity and COD in wastewater as a function of the dose of bioflocculant (cactus).

Regarding the flocculation tests in the presence of *Opuntia* cactus bioflocculant juice, the results showed that flocculation is good, turbidity removal was 98.14% and 87% for COD removal. This behavior could be explained by the repulsion energy between the polymer and the pollutant after the increase of the flocculant dose, which hinders the formation of flakes (Mishra et al., 2006).

Conclusion

In this study, the treatment of leachate from the Great Agadir landfill by a flocculation coagulation process was evaluated. Several experiments were carried out to determine the optimum conditions for eliminating pollution by four coagulants (lime, ferric chloride, ferrous sulphate and aluminium sulphate). The efficiency of the process is assessed in terms of COD abatement and turbidity. Leachate was significantly discolored with $FeCl_3$, resulting in a 90% turbidity and 78.2% COD removal, which appears to be best suited for a low dose 3g/L and has a neutral pH.

In addition, the work undertaken here has shown that the polyacrylamide flocculant, with a mass of 3 g in the presence of a mass of 3 g ferric chloride, with a turbidity level equal to 92% and 97% for COD. However, the bioflocculant from "*Opuntia* cactus" juice, for 3 g/L of ferric chloride, also gives good flocculation, 98.14% for turbidity and 87% for COD removal.

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