Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.26303

206 (2020) 307–314
December

Diagnosis of leachate from a closed landfill, impact on the soil, and treatment by coagulation flocculation with alginate and ferric chloride

Malika Kastali[a], Latifa Mouhir[a], Mohamed Assou[a], Abdelkader Anouzla[a,*], Younes Abrouki[b]

[a]*Laboratory of Process engineering and Environment, Faculty of Science and Technology Mohammedia, Hassan II University of Casablanca, Mohammedia, Morocco, emails: aanouzla@gmail.com (A. Anouzla), partenariat20@gmail.com/kastali.m@gmail.com (M. Kastali), is29702020@gmail.com (L. Mouhir), ifni.2013@gmail.com (M. Assou)*
[b]*Faculty of Sciences, Mohammed V University in Rabat, Rabat, Morocco, email: younesabrouki@gmail.com (Y. Abrouki)*

Received 3 February 2020; Accepted 27 June 2020

ABSTRACT

This aim of study is to assess the diagnosis of leachate impacts on the soil of the closed landfill of the city of Mohammedia for several years and the treatment of these releases by coagulation–flocculation with a liquid effluent rich in $FeCl_3$ rejected by a company of steel (Maghreb STEEL) and also by alginate produced less expensive. Indeed, the leachate generated from closed dumping site at MESBAHIATE (Mohammedia, Morocco) was investigated. This leachate is characterized by a high chemical oxygen demand (COD) content which varies around 3,000 mg/L, a Kjeldahl total nitrogen concentration varying around 1,500 mg/L whereas the content in ammonium has a concentration of 960 mg/L. In addition, the BOD_5/COD ratio is much less than 0.2, which indicates that the organic matter is not easily biodegradable, and subsequently justifies the use of physico-chemical treatments such as coagulation–flocculation. In order to monitor the leachate treatment by coagulation flocculation, several parameters were analyzed including: the turbidity, the COD, and the volume of the sludge decanted. The results showed that coagulation–flocculation by ferric chloride and alginate were very effective for reducing turbidity. This reduction reaches 95% and 86% for $FeCl_3$ and Alginate, respectively. The removal of COD by $FeCl_3$ 30% and Alginate showed yields of 67% and 60%, respectively at optimal concentrations of 120 and 2,500 mg/L, respectively, for Alginate and $FeCl_3$ 30%.

Keywords: Landfill leachate; Closed dumps; Characterization; Environmental impact; Coagulation flocculation

1. Introduction

Leachate is the juice produced during the fermentation of waste. However, the genesis of leachate is the result of a very complicated process. As soon as they are deposited, the waste is subject to biodegradation processes, which are the result of a multitude of biological and physicochemical reactions. The water that infiltrates the waste layers is the main vector of this biodegradation. Thus, the leachate results from the solubilization of the compounds during the percolation of rainwater through the pile of waste, as well as from the humidity contained in the waste itself [1]. Climate and landfills are the main factors influencing the production and composition of leachate. Where the climate is subject to higher precipitation levels, there will be more water intrusion into the landfill, and hence more leachate generated. Another factor is the topography of the site, which influences the runoff regimes and the water balance in the site.

* Corresponding author.

Landfill leachate has been identified as a potential source of soil contamination, groundwater and surface water, as it can percolate through the soil, causing pollution of the watercourse and the water table. Whatever the mode of operation of a landfill, leachate is a source of nuisance, which is added to the numerous problems of environmental contamination, if it is not properly collected, treated, and eliminated in completely safe [2–7].

The treatment of landfill leachates is a complicated process due to the type of contaminants it contains, its variation in volume, and the age of the landfill [8–13]. The main processes currently used for the treatment of landfill leachate can be classified as follows (i) biological methods, (ii) physicochemical methods.

Biological processes are most effective when the BOD_5/COD ratio of the leachate is high. This ratio decreases with the age of the landfill. Young leachate from landfills are more easily biologically treated than older ones [10]. However, biological treatment is hampered by a high concentration of ammoniacal nitrogen or by the presence of specific toxic substances.

As a discharge stabilizes over time, the biodegradable organic content of the leachate tends to decrease and, therefore, the efficiency of the biological methods decreases and physicochemical methods become one of the most effective processes for the treatment of stabilized leachate [13–15].

Advanced physicochemical treatment processes as advanced oxidation processes (AOP) have been developed by several authors and applied for the decontamination of leachate releases [16]. AOP processes reduce the toxicity of wastewater through degradation of organic matter and therefore the discharge becomes biodegradable, making wastewater easily treatable by biological means. However, the cost of treatment remains high compared to conventional physicochemical processes such as coagulation–flocculation. The coagulation–flocculation processes are a relatively simple technique and often used in the treatment of water and wastewater [13]. This technique can be successfully used for the treatment of stabilized discharge leachates. The removal of pollutants primarily involves the neutralization charge of negatively charged colloids by cationic hydrolysis products, followed by the incorporation of impurities in an amorphous hydroxide precipitated by flocculation. However, it should be noted that the precipitation and adsorption of ions in leachate samples are strongly affected by the present amount of humic compounds, which affects the effectiveness of coagulation. Therefore, the determination of ferric salts or other coagulants or flocculants required for wastewater treatment is mainly defined by the concentration of flocculants known by their high load in leachate than in wastewater. In addition, many factors can influence the effectiveness of coagulation flocculation treatment such as the type and optimal concentration of coagulant/flocculant and optimal pH [17].

In our case, at the ecological level, the alarm is already sounding, because, in addition to air pollution, waters of Oued-El-Maleh River are highly polluted because of the leachates produced by the closed dump of Mohammedia city and discarded in the waters of this river without prior treatment. This is the reason why the objective of this study is to optimize the treatment of this stabilized landfill leachate by coagulation–flocculation processes using algae alginate and ferric chloride.

2. Materials and methods

2.1. Study area

This study was carried out in a municipal landfill closed since 2012 located at Mesbahiate, Mohammedia city, Morocco (Fig. 1 and Table 1). This landfill received all types of municipal waste, sludge, and industrial waste. In this landfill, the leachate flows through a drainage system to a retention lake, from which there is a river located 30 m from the reservoir storage. Moreover, the climate in Mohammedia City is Mediterranean (Köppen climate classification Csa). The moderating effect of the Atlantic Ocean influences strongly on the city climate and makes its winter soft and

Fig. 1. Geographical location of the study area.

warm, and its summer hot and cool. Mohammedia enjoys plenty of sunshine throughout the year with measurable precipitation annually.

2.2. Sampling and analysis

Leachate samples were collected in 50 L plastic bins, transported to the laboratory, and stored at 4°C. These samples were placed at room temperature for 2 h before analyzed according to the standard methods NFXPT 90–210 [18]. The pH was measured using electronic pH meter. Turbidity was measured using HI 93703 microprocessor turbidity meter. Conductivity was determined using deluxe conductivity meter. BOD_5 was measured with a respirometer by the manometric method and the COD was determined using the method developed by Knetchel [19]. Total nitrogen contents were determined with Kjeldahl methodology using an automated apparatus. The total suspending solid content was estimated by drying for 12 h at 105°C [20].

Heavy metals concentrations were measured after mineralization with aqua regia (nitric acid–hydrochloric acid) by atomic absorption spectroscopy [21].

2.3. Jar test: coagulants/flocculant dosage

$FeCl_3$ and algal alginate have been tested for the decontamination of leachate releases to destabilize the suspension of solids and colloids and eliminate pollution by coagulation–flocculation processes.

A laboratory scale evaluation of coagulation and flocculation was performed using the jar test technique. The experimental method is composed of three steps: a rapid mixture of leachates containing reactive flocculation coagulation reagents of 160 rpm for 10 min, followed by slow stirring at 30 rpm for 20 min, and then a decantation step final for 1 h. The coagulation–flocculation was performed with the operating parameters optimized and determined previously.

Six polyethylene beakers with a volume of 1 L were used to examine the different doses of coagulant. The samples to be tested were deeply agitated to suspend once again the settled solids, and the appropriate volume of the sample was transferred to the corresponding test beakers. So as to study the optimal dose of coagulant, the pH of the leachate solution is maintained at the optimum value and variable doses of the ferric ion or alginate. After 60 min of decantation, the supernatant was removed for analysis. To evaluate the effectiveness of $FeCl_3$ and Alginate for the treatment of leachates, the following parameters were followed: turbidity, chemical oxygen demand (COD), sludge decanted.

The COD removal was calculated by analyzing the COD before and after the treatment of leachates. The Eq. (1) was used to calculate the removal efficiency:

$$\text{COD removal } (\%) = \frac{\left(C_i - C_f\right)}{C_f} \times 100 \quad (1)$$

where C_i and C_f are the initial and final concentrations of COD of the leachate, respectively. The same equation was applied for the determination of the % removal of turbidity.

3. Results and discussion

3.1. Leachate characteristics

To evaluate the impacts of a leachate on the environment, it is necessary to characterize the effluents generated by solid waste. In fact, regardless of the type of the mode of exploitation of the discharge, the leaches constitute, if they are not treated before the rejection, a source of nuisance, which is added to various problems of contamination of surface water and ground water. The genesis of leachates is the result of a very complex process. As soon as they are deposited, the waste is subjected to biodegradation processes resulting from a multitude of biological and physicochemical reactions. The water that infiltrates the waste layers is the main vector of this biodegradation. Thus, leachate results from the solubilization of compounds during the percolation of rainwater through the pile of waste, as well as moisture contained in the waste itself [22]. The leachates are full of mineral and organic substances coming from the decomposition of waste. Physio-chemical parameters analyzed in the leachates of the discharge are illustrated in the Table 2.

The characteristics of the leachate can generally be represented in the form of basic parameters such as COD, BOD_5,

Table 1
Geographical location of the sampling points

Notation	Samples	Locations	Latitude and Longitude		
			X (m)	*Y* (m)	*Z* (m)
*L*1	Stabilized leachate	Approximately 30 cm deep	314,497.51	342,174.02	9.66
*L*2	Stabilized leachate	Approximately 10 cm deep	314,496.93	342,195.57	9.34
*W*3	Water river	Just before the wastewater discharge outlet	314,376.08	342,586.11	11.37
*W*4	Water river	Below bridge of Oued-El-Maleh River	314,519.77	342,245.14	11.7
*S*1	Landfill sediment	0.5 m of stagnant leachate	314,493.83	342,176.81	9.49
*S*2	Landfill sediment	1 m of stagnant leachate	314,491.22	342,209.29	9.11
*S*3	Landfill sediment	5 m of stagnant leachate	314,477.95	342,269.92	10
*S*4	Soil in bank of river	Far from about 315 m of leachate	314,448.47	342,509.43	10.35
*S*5	Soil in bank of river	Far from about 412 m of leachate	314,378.27	342,570.57	11.69

Table 2
Characterization of Landfill Leachate

Parameters	Concentration	Moroccan standards
pH	8.2	6.5–8.5
Conductivity (ms/cm)	32.2	2.7
Turbidity (NTU)	154	–
HPO_4^{2-} (mg/L)	869	–
Sulfate (mg/L)	152	–
Phosphate (mg/L)	1,352	10
TNK (mg/L)	1,521	30
COD (mg/L)	2,958	500
BOD_5 (mg/L)	521	–
BOD_5/COD	0.17	–
O_2 (mg/L)	0.3	
NH_4^+ (mg/L)	957	
Matière organique (mg/L)	560	
UV (254 cm^{-1})	0.5 (dilué 20 fois)	
NO_3^- (mg/L)	251	
Cr (mg/L)	1.2	

color, pH, the content of metallic elements [23,24]. These results have shown that the leachate is characterized by strong concentrations of the organic substance, ammonium and nitrogen compounds (Table 2). The organic substance, in terms of the COD varies around 3,000 mg/L (stabilized leachate). So, high concentrations of ammonia nitrogen (950 mg/L) and TNK (1,500 mg/L) have been detected. The characterization of the leachate tool has shown that the rapport BOD_5/COD varies from 0.14 to 0.2, which shows that the organic matter in leachate is not biodegrable (humic and fulvic substances) [25]. Bakraouy et al. [37] have shown that the intermediate leachate presents a BOD_5/COD ratio varying between 0.1 and 0.3. This justifies that the leachate studied is an intermediate leachate. In addition, the leachate is rich in phenolic (0.5 cm^{-1}) compounds measured by the absorbance at 254 nm. A substantially lower value of UV_{254} (0.312 cm^{-1}), which is in coherence with study in leachate from a landfill in Poland reported by Leszczyński and Walery [26]. Furthermore, turbidity and conductivity mark high values exceeding the standards of the treated used water. This shows that decision makers in Morocco have to make an effort to save the current situation of the landfills in order to protect the health of the population.

The same writers have clarified that the values of the COD obtained range between 2,301 and 2,750 mg/L, which remain less than the content detected by Navarro and Veron [27].

We can deduce that the leachates studied are either intermediate or stabilized. The variety of the characteristics of the leachate have been attributed to different factors, such as variety in the composition of solid waste, age, and the hydrology of the landfill, precipitations, and specific weather conditions and the humidity of the waste [28–31].

After 10 y, a landfill contains less bio-degradable materials and the leachates present a value of COD less than 2,000 mg/L. At this age, it is designated as an "old dump" [32].

For a given leachate, fluctuations of pH, flow, and levels of COD and BOD_5 have been observed over time. This can influence the effectiveness of the removal by different treatment techniques and perturb the receiving environment in case the leachates are rejected without treatment which justifies the installation of a treatment plant. The age of landfilling is one of the principal factors which also influence the characteristics of the leachate. For an old landfilling, the decomposition of the leachate from a relatively short initial aerobic period to longer decomposition period, which consists of two phases: an acid phase and a methanogenic phase, the leachate from these distinct steps contain different constituents and therefore different characteristics.

3.2. Spatio-temporal variation of COD, NH_4^+, and chromium parameters

Seasonal variation of concentrations in leachate the concentrations of the parameters COD, NH_4^+, and chromium in leachate collected from the landfill sites between summer, autumn, spring, and winter.

The spatio-temporal variation of the parameters COD and NH_4^+ are illustrated in Fig. 2. Sampling campaigns were carried out the spatio-temporal variation of chromium is illustrated, respectively, in Fig. 3.

Higher component concentrations occurred for COD, NH_4^+, and chromium in summer. Winter months showed lower concentrations of COD and NH_4^+. The concentration of chromium was higher showed the lowest levels in spring.

The results of the study showed that the parameters COD, NH_4^+, and chromium vary from one season to another. There is a small variation in COD over time as ammonic decreases. Indeed, natural aeration could have an impact on the reduction of ammonium concentrations, which by natural nitrification is transformed into nitrate. This significantly reduces odors. In addition, the chromium content decreased from 3.5 to 0.6 mg/L after 1 y of storage. Indeed, a part of the chromium is precipitated and another part is adsorbed on the clays of the medium. This was confirmed by the analysis of metals fixed on the ground at the interface and a few centimeters deep. During the study carried out by Kulikowska et al. [33] showed that the stabilized leachate has a pH varying around 8.3 to 1,560 mg/L COD with a BOD_5/COD ratio of 0.11. This makes it possible to judge that the organic matter of the leachate is non-biodegradable rich in humic and fulvic substances. The results thus obtained (COD < 5,000 mg/L and BOD_5/COD < 0.2) confirmed that the leachate came from an old landfill case of the city of Mohammedia closed since 2012.

Whatever the mode of exploitation of a landfill, leachate constitutes, if they are not treated before their rejection, a source of nuisance is added to the numerous problems of environmental contamination.

3.3. Heavy metals

The analysis results of heavy metals obtained for stabilized leachate and the waters of Oued-El-Maleh River are shown in Table 3.

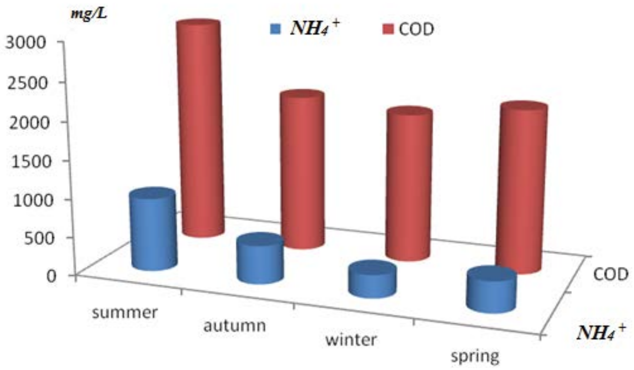

Fig. 2. Spatio-temporal variation of COD and NH_4^+ parameters in leachate.

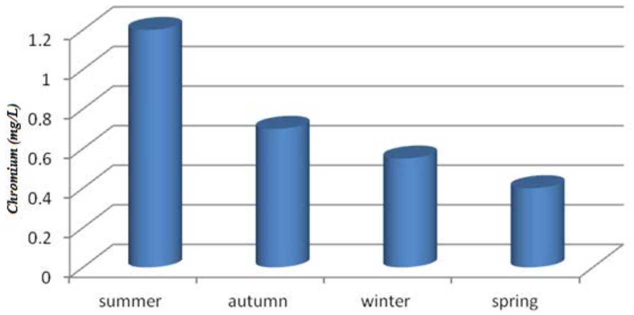

Fig. 3. Spatio-temporal variation of chromium content in leachate.

The analysis of these results showed that the stabilized leachate puddles from the leachate percolation of the old landfills were rich in inorganic pollutants composed of several heavy metals. Consequently, the risk of contamination of the surface water and groundwater by inorganic pollution is still possible although the landfill was closed since 2012. These results showed that the discharges of leachates were heavily loaded with materials that are difficult to biodegrade and heavy metals whose concentrations are higher than the limits of Moroccan standards [34].

On the other hand, another study carried out in our laboratory (Table 3) on the evaluation of the pollution generated by the leachates of the same flow drilled toward the edges of the Oued-El-Maleh River before the closing of this landfill, revealed very less concentrations of heavy metals *W*1 and *W*2 compared to those obtained in samples *L*1 and *L*2 analyzed in stabilized leachates.

3.4. Soil contamination by leachate

The results obtained for the analysis of heavy metals accumulated by sediments are shown in Table 4.

In fact, the results of the analysis of different soil samples taken near and far from the puddles of stabilized leachates showed moderate metal concentrations.

The various concentration of heavy metals measured in the investigated soils was expected to be originated from the landfill leachates. These metal substances can be released from the soil to the leachate and then seep into the aquifer. This probably explains the low concentrations in the wet samples compared to the dry samples. The results obtained by this work showed (Table 4) that leachate puddles from the old wastewater dump in the city of Mohammedia, closed since 2012, are heavily loaded with metal pollutants, which has a definite impact on groundwater and surface water. Indeed, the concentrations of the Cr, Mg, Ni, As, Cu, Co, Cd, and Zn, elements, obtained in the leachate samples, remained below the general release limit values applicable to Moroccan wastewater discharges and lead to the conclusion that metallic pollution due to these metals and generated by the discharges of these leachates decreased after closure of the uncontrolled landfill of the Mohammedia city. This may be due to the adsorption of the metal elements on the soil during the time of leachate storage. The soil aboard on the Oued-El-Maleh River seems less contaminated by these leachate residues since the concentrations of metallic pollutants are not remarkable whereas the concentrations of selenium, of silver and of cadmium, do not present any trace of these elements in all samples.

The concentrations of the same elements (As, Cd, Cu, Ni, Pb, and Zn) obtained in the sediments collected at the different points of the city of Fez (Morocco) discharge during the study carried out by Chtioui et al. [35] are clearly much higher than those obtained for the samples that are the subject of this study. This appears normal since the samples are taken aboard the Oued-El-Maleh River and far from the site of the old dump (closed since 2012) to more than 300 m on the one hand, and secondly, household waste from the city of Fez landfill is collected in mixtures with industrial waste according to the same authors.

Table 3
Heavy metals concentrations of stabilized leachate samples and the waters samples of Oued-El-Maleh River

Heavy metals	Unit	*E*3	*E*4	*L*1	*L*2
Vanadium	mg/L	0.017	0.021	0.385	0.351
Chromium	mg/L	0.003	0.006	0.914	0.857
Manganese	mg/L	0.07	0.115	0.245	0.206
Cobalt	mg/L	0.001	0.001	0.063	0.056
Nickel	mg/L	0.007	0.008	0.23	0.215
Copper	mg/L	0.003	0.003	0.093	0.081
Zinc	mg/L	0.056	0.049	0.315	0.32
Arsenic	mg/L	0.002	0.002	0.087	0.081
Silver	mg/L	0.0002	0.0001	0.0022	0.002
Cadmium	mg/L	0.0003	0.0002	0.0021	0.0025
Lead	mg/L	0.002	0.003	0.012	0.007
Iron	mg/L	0.868	2.183	4.4	3.681

3.5. Treatment of leachate by alginate and $FeCl_3$

3.5.1. Alginate only

The study of the elimination of leachate pollution by coagulation–flocculation with alginate alone is given in Fig. 4. The results obtained, showed that the optimal dose of alginate for the removal of COD and the turbidity is, respectively, 60% and 75% varies around 120 mg/L of alginate at

Table 4
Analysis of heavy metals accumulated by sediment samples

Heavy metals	Unit	S1	S2	S3	S4	S5
Vanadium	mg/L	0.022	0.01	0.022	0.016	0.012
Chromium	mg/L	0.02	0.009	0.04	0.041	0.015
Manganese	mg/L	0.222	0.128	0.262	0.224	0.22
Cobalt	mg/L	0.004	0.002	0.003	0.002	0.002
Nickel	mg/L	0.011	0.007	0.009	0.007	0.006
Copper	mg/L	0.012	0.006	0.006	0.004	0.006
Zinc	mg/L	0.041	0.026	0.02	0.015	0.017
Arsenic	mg/L	0.004	0.003	0.006	0.005	0.002
Silver	mg/L	0	0	0	0	0
Cadmium	mg/L	0	0	0	0	0
Lead	mg/L	0.013	0.01	0.007	0.024	0.006
Iron	mg/L	13.12	6.2	10.03	7.63	7.073

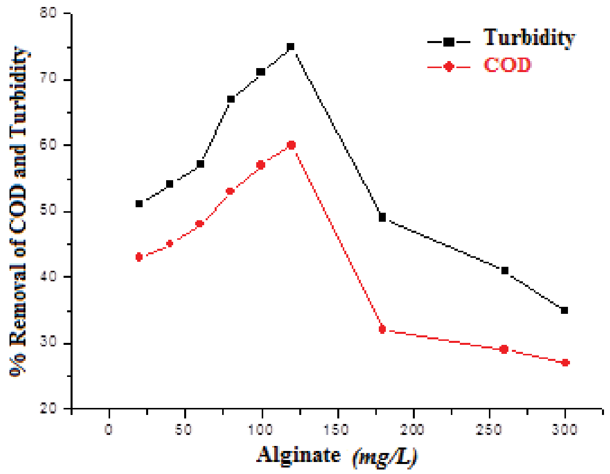

Fig. 4. Effect of alginate alone on removal of COD and turbidity.

pH 6.5, with low production of sludge (40 mL/L). We found it was observed that the use of bio-flocculant with concentrations higher than 120 mL/L did not improve the removal rate of COD and turbidity.

3.5.2. Alginate and $FeCl_3$

The study of the elimination of the pollution of leachate discharges by the mixture of $FeCl_3$ and alginate are given in Fig. 5.

These results show that the mixture of $FeCl_3$ and alginate have a concentration of the optimal order of 120 mg/L of Alginate and a variable concentration of $FeCl_3$ makes the COD from 2,900 to 1,100 mg/L and with a 60% yield of the COD and 65% of turbidity. Furthermore, under optimal conditions (7.2 g/L of $FeCl_3$ and 0.2 mL/L of flocculant), Taoufik et al. [36] showed that $FeCl_3$ reduces. The application of the same rejection rich in coagulant ($FeCl_3$ 30%) for the treatment of leachates from the public landfill of the city of Kenitra, Bakraouy et al. [37] showed a 77% reduction in color, 78% in COD and 97% in detergents. Similarly,

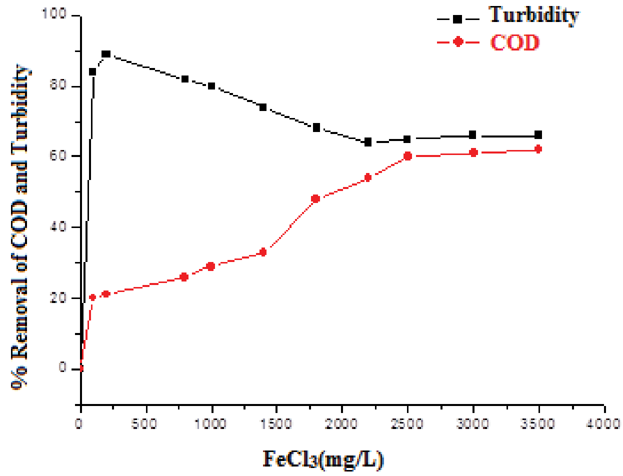

Fig. 5. Effect of mixture alginate (120 mg/L) and variable $FeCl_3$ on removal of COD and turbidity.

Anouzla et al. [38] showed that the rejection rich in $FeCl_3$ allows a good reduction in COD and color 56% and 60%, respectively.

Indeed, the optimal concentration for the elimination of the COD and turbidity by alginate varies around 20 mg/L with a concentration of $FeCl_3$ from 2,500 mg/L to pH 6.5 (Fig. 6). Moreover, the results showed that the mixture of Alginate and $FeCl_3$ has an optimal concentration of the order of 2,500 mg/L and has resulted in significant removal of COD with an elimination efficiency of approximately 50%. The value of COD increases with that of alginate. The turbidity removal was 80% and remains constant starting from 50 mg/L of alginate, while the volume of the sludge produced increases with the increase of alginate stabilizes around 125 mg/L with an optimal concentration of alginate of 120 mg/L. the values removal of COD and turbidity for the optimal concentrations in $FeCl_3$ and alginate were in the order of 54% and 80%, respectively. On the other hand, these results showed that the $FeCl_3$ gives a significant removal of COD and turbidity with a high yield. The optimal concentration of alginate remains around 40 mg/L. COD moves from 2,040 to 1,020 mg/L with an approximate removal efficiency of 55% and turbidity increased from 210 to 25 NTU with an elimination efficiency of 88%. Sludge production varies around 75 mL/L for the optimal concentration of alginate which varies around 40 mg/L.

3.6. Removal of chromium

The concentration of the chromium detected in the young or stabilized leachate releases have shown that the liquid discharge is rich in heavy metals, particularly chromium. This is because the industrial unit of Mohammedia rejects tanning sludge in the old city dump, which can cause problems at the level of underground water and the river, which receives leachate without treatment. Monitoring the elimination of chromium by $FeC1_3$ in the leachate from Mohammedia has shown that the coagulation–flocculation by $FeC1_3$ 30% made it possible to decrease the concentration of chromium from 1.05 to 0.11 mg/L, with removal

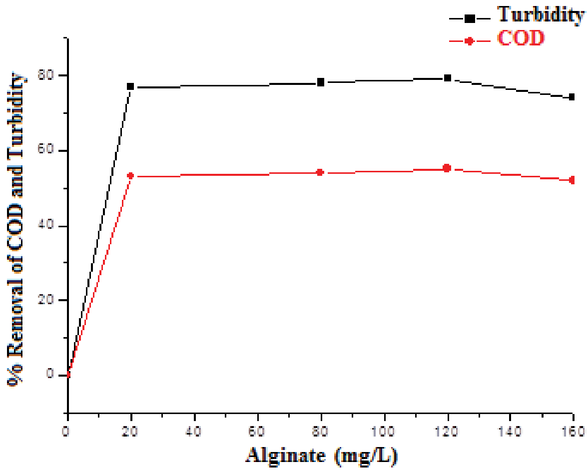

Fig. 6. Effect of mixture $FeCl_3$ (2,500 mg/L) and variable alginate on removal of COD and turbidity.

efficiency of 89.5%. These results of the elimination of chromium obtained during the present study were compared to that results obtained for the treatment of leachate collected from the dump of Fez city (Morocco) during the study carried out in our laboratory with removal efficiency of 71% during the treatment by $FeCl_3$ 40% alone, whereas the treatment of this latter with the mixture of ferric chloride and lime resulted in a 90% yield removal of chromium [39].

4. Conclusions

Characterization of the landfill leachate, generated by closed dump since 2012 located in Mohammedia city, has revealed that this leachate is old and stable with an important pollution load. Indeed, seasonal variation was observed for the measured chemical components due to different pollution source features and meteorological conditions. Higher component concentrations 3,000; 1,000; and 1.2 mg/L occurred for COD, NH_4^+, and chromium, respectively, in summer. Winter months showed lower concentrations 2,200, 290 mg/L of COD, and NH_4^+, respectively. The concentration 0.34 mg/L of chromium was higher showed the lowest levels in spring. Thus, the age and seasonal variations had a significant effect on leachate composition. Most heavy metals didn't pose a risk on soil, the concentrations of the elements Cr, Mg, Ni, As, Cu, Co, Cd, and Zn, obtained in samples of leachate puddles remain below the general limit values for Moroccan wastewater discharges. It can be concluded that metal pollution due to the analyzed metals and generated by the leachate flows decreased after the closure of the landfill.

Treatment of leachate from the city dump of Mohammedia using a coagulation–flocculation process was evaluated. Landfill leachate was characterized by a low pH value and a high concentration of pollutants. The organic matter ranges between 2,400 and 3,000 mg/L of COD, and between 730 and 950 mg/L of NH_4^+. As for turbidity, however, the elimination of turbidity remains dependent on the effectiveness of the coagulation, that is, the coagulant used for the study.

The optimal doses of $FeC1_3$ and alginate chosen for the study vary from one reagent to another. $FeC1_3$ remains the most suitable coagulant to further eliminate organic and metallic pollution. In fact, sludge produced by alginate alone (optimal concentration of 120 mg/L) or by alginate mixed with $FeCl_3$ at 2,500 mg/L are too compact and have a volume of 25 mL/L for alginate alone and 80 mL/L for the mixture $FeCl_3$ 30% (fixed 2,500 mg/L) + variable alginate. In addition, for the variable $FeCl_3$ mixture at an alginate concentration of 120 mg/L, the sludge volume varies around 700 mL/L for a setting time of the variable alginate mixture and 30% $FeCl_3$ at 120 min.

In conclusion, the physicochemical treatment of leachates by coagulation and flocculation by the industrial effluent rich in $FeCl_3$ 30% is effective which allows industrial recovery. This valuation has many advantages, in particular the reduction of pollution at the lowest cost.

Acknowledgments

Farewell our Friend Pr. Mohmed Assou. Our friend passed away on the 29th April 2020. May Almighty Allah have mercy upon his soul and dwell him in Jannatul Al-Firdaws, the most beautiful Paradise. We know that your kind soul is in Paradise watching over us.

References

[1] A. Anouzla, Valorisation des Rejets Liquides du Secteur Sidérurgique: Application au Traitement des Eaux Usées, Editions Universitaires Européennes, Riga, 2019.

[2] S. Souabi, K. Tawzar, H. Chtioui, F. Khalil, K. Digua, M. Tahiri, Problématiques du chrome et du plomb dans les lixiviats des décharges publiques des villes de Mohameddia et de Fès, Déchets Sci. Tech., 58 (2010) 37–44.

[3] A.F. Al-Yaqout, M.F. Hamoda, M. Zafar, Characteristics of Wastes, Leachate, and Gas at Landfills Operated in Arid Climate, Pract. Period. Hazard. Toxic Radioact. Waste Manage., 9 (2005) 97–102.

[4] M. Atta, W.Z.W. Yaacob, O.B. Jaafar, The potential impact of leachate-contaminated groundwater of an ex-landfill site at Taman Beringin Kuala Lumpur, Malaysia, Environ. Earth Sci., 73 (2015) 3913–3923.

[5] I.T. Enitan, A.M. Enitan, J.O. Odiyo, M.M. Alhassan, Human health risk assessment of trace metals in surface water due to leachate from the municipal dumpsite by pollution index: a case study from Ndawuse River, Abuja, Nigeria, Open Chim., 16 (2018) 214–227.

[6] A.A. Hamidi, A. Salina, N.A. Mohd, A.H. Nordin, Faridah, A.H. Asaar, S.Z. Mohd, Colour removal from landfill leachate by coagulation and flocculation processes, Bioresour. Technol., 98 (2007) 218–220.

[7] M.M. Abd El-Salam, G.I. Abu-Zuid, Impact of landfill leachate on the groundwater quality: a case study in Egypt, J. Adv. Res., 6 (2015) 579–586.

[8] M. Assou, L. El Fels, A. El Asli, H. Fakidi, S. Souabi, M. Hafidi, Landfill leachate treatment by a coagulation-flocculation process: effect of the introduction order of the reagents, Desal. Water Treat., 57 (2016) 21817–21826.

[9] U. Muhammad, A.A. Hamidi, S.Y. Mohd, Variability of parameters involved in leachate pollution index and determination of LPI from four landfills in Malaysia, Int. J. Chem. Eng., 13 (2010) 1–6.

[10] Q.A. Shuokr, A.A. Hamidi, S.Y. Mohd, J.K.B. Mohammed, U. Muhammad, Leachate characterization in semi-aerobic and anaerobic sanitary landfills: a comparative study, J. Environ. Manage., 91 (2010) 2608–2614.

[11] M. Abouri, A. Taleb, S. Souabi, A. Pala, Removal of phenol and colour of leachate of municipal solid waste by physico-chemical treatment using a liquid waste as a coagulant, J. Mater. Environ. Sci., 7 (2016) 4290–4298.
[12] M.A. Rasool, B. Tavakoli, N. Chaibakhsh, A.R. Pendashteh, A.S. Mirroshandel, Use of a plant-based coagulant in coagulation-ozonation combined treatment of leachate from a waste dumping site, Ecol. Eng., 90 (2016) 431–437.
[13] F.J. Rivas, F. Beltrán, F. Carvalho, B. Acedo, O. Gimeno, Stabilized leachates: sequential coagulation flocculation + chemical oxidation process, J. Hazard. Mater., 116 (2004) 95–102.
[14] M.I. Aguilar, J. Saez, M. Llorens, A. Soler, J.F. Ortuño, V. Meseguer, A. Fuentes, Improvement of coagulation-flocculation process using anionic polyacrylamide as coagulant aid, Chemosphere, 58 (2005) 47–56.
[15] T. Yilmaz, S. Apaydin, A. Berktay, Coagulation-flocculation and air stripping as a pretreatment of young landfill leachate, Open Environ. Eng. J., 3 (2010) 42–48.
[16] T.A. Kurniawan, W.H. Lo, G. Chan, Degradation of recalcitrant compounds from stabilized landfill leachate using a combination of ozone-GAC adsorption treatment, J. Hazard. Mater., 137 (2006) 443–455.
[17] A.Z. Noor, A.A. Hamidi, S.Y. Mohd, U. Muhammad, The use of polyaluminum chloride for the treatment of landfill leachate via coagulation and flocculation processes, Res. J. Chem. Sci., 1 (2011) 34–39.
[18] AFNOR, Protocole d'evaluation d'une methode alternative d'analyse physico-chimique par rapport a une methode de reference [Protocol of evaluation of an alternative method of physico-chemical analysis relative to a method of reference], Vol. 58, Norme NF XPT [Standard NF XPT], 1999, pp. 90–210.
[19] R.J. Knetchel, A more economical method for the determination of chemical oxygen demand, Water Pollut. Control, 71 (1978) 25–29.
[20] A.F. Navarro, J. Cegarra, A. Roig, D. Garcia, Relationships between organic matter and carbon contents of organic wastes, Bioresour. Technol., 44 (1993) 203–207.
[21] P. Dehouck, F. Cordeiro, J. Snell, B. De-la-Calle, State of the art in the determination of trace elements in seawater: a worldwide proficiency test, Anal. Bioanal. Chem., 408 (2016) 3223–3232.
[22] S. De, S. Maiti, T. Hazra, A. Debsarkar, A. Dutta, Leachate characterization and identification of dominant pollutants using leachate pollution index for an uncontrolled landfill site, Global J. Environ. Sci. Manage., 2 (2016) 177–186.
[23] K. Kim, J. Kim, S. Hyun, Soil attenuation of the leaching potential of mine-related metallic elements (Zn, As, and Cd) under different leachate solute compositions J. Environ. Manage., 222 (2018) 402–408.
[24] M. Hussein, K. Yoneda, Z.M. Zaki, N.A. Othman, A. Amir, Leachate characterizations and pollution indices of active and closed unlined landfills in Malaysia, Environ. Nanotechnol. Monit. Manage., 12 (2019) 1–9.
[25] J. Długosz, Characteristics of the composition and quantity of leachate from municipal landfills - a review, Arch. Waste Manage. Environ. Prot., 14 (2012) 19–30.
[26] J. Leszczyński, M.J. Walery, The removal of organic compounds from landfill leachate using ozone-based advanced oxidation processes, E3S Web Conf., 45 (2018) 1–7.
[27] A. Navarro, J. Veron, Impact polluant des lixiviats de décharge: Les stratégies de traitement, Journée internationale de l'environnement, Poitiers, France, 1992.
[28] P. Kjeldsen, M.A. Barlaz, A.P. Rooker, A. Baun, A. Ledin, T.H. Christensen, Present and long-term composition of MSW landfill leachate: a review, Crit. Rev. Environ. Sci. Technol., 32 (2002) 297–336.
[29] A. Rassam, B. Boukhriss, A. Chaouch, L. El Watik, H. Chaouki, M. Ghannami, Caractérisation de lixiviats des décharges contrôlées au Maroc et solutions de traitement: cas de lixiviats de la ville d'Al Hoceima, Sci. Lib. Environ., 4 (2012) 1–9.
[30] S. Renou, J.G. Givaudan, S. Paulain, F. Dirassouyan, P. Moulin, Landfill leachate treatment: review and opportunity, J. Hazard. Mater., 150 (2008) 468–493.
[31] R. Stegmann, K.U. Heyar, R. Cossu, Leachate Treatment, Proceedings Sardinia, Tenth International Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy, 2005.
[32] P.A. Augusto, T. Castelo-Grande, L. Merchan, A.M. Estevez, X. Quintero, D. Barbosa, Landfill leachate treatment by sorption in magnetic particles: preliminary study, Sci. Total Environ., 648 (2019) 636–668.
[33] D. Kulikowska, B.K. Klik, Z.M. Gusiatin, K. Hajdukiewicz, Characteristic of humic substances from municipal sewage sludge: a case study, Desal. Water Treat., 144 (2019) 57–64.
[34] A. El Maguiri, B. Kissi, L. Idrissi, S. Souabi, Landfill site selection using GIS, remote sensing and multicriteria decision analysis: case of the city of Mohammedia, Morocco, Bull. Eng. Geol. Environ., 75 (2019) 1301–1309.
[35] H. Chtioui, F. Khali, S. Souabi, M.A. Aboulhassan, Evaluation de la pollution générée par les lixiviats de la décharge publique de la ville de Fès, Déchets Sci. Tech., 49 (2008) 25–28.
[36] M. Taoufik, R. Elmoubarki, A. Moufti, A. Elhalil, M. Farnane, A. Machrouhi, M. Abdennouri, S. Qourzal, N. Barka, Treatment of landfill leachate by coagulation-flocculation with $FeCl_3$: process optimization using Box–Behnken design, J. Mater. Environ. Sci., 9 (2018) 2458–2467.
[37] H. Bakraouy, S. Souabi, K. Digua, Valorization of a rejection rich in $FeCl_3$ from steel industry for the treatment of landfill leachate by coagulation, J. Mater. Environ. Sci., 7 (2016) 3154–3161.
[38] A. Anouzla, S. Souabi, M. Safi, Y. Abrouki, H. Loukili, H. Rhbal, Waste to treat waste of landfill leachates, Int. J. Environ. Prot. Policy, 2 (2014) 50–53.
[39] F. Khalil, O. Bouaouine, S. Souabi, H. Chatioui, M.A. Aboulhassan, A. Ouammou, Traitement des lixiviats de décharge par coagulation-floculation, J. Mater. Environ. Sci., 6 (2015) 1337–1342.