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Anaerobic-aerobic treatments of leachate from municipal solid waste

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***Abstract*— This work aims in developing a technique to be used at large scale for treating leachates which are produced by compaction of Municipal Solid Waste (MSW) of Mohammedia city (Morocco). In order to avoid environment pollution, the MSW effluents are usually stored in basins before their treatment. However, sometimes these effluents are dumped directly in the landfill without any treatment, causing, hence, environmental problems. In the present work, anaerobic biological treatment, followed by aeration, were both used, to achieve removal of pollution load of fresh leachates from the MSW. Thus, high organic load effluents were treated by anaerobic process during 43 days, followed by intensive injection of 3.5 L of air per minute in 10 liters of leachate over a period of 30 days. The resulting characteristics of the treated leachate such as the COD, the BOD5 and the turbidity, were found to depend on the importance of the pollution load, and on the nature of the inorganic constituents initially present in the leachate. The anaerobic-aerobic treatments used in this work have lead to the purification of the leachate with reductions of 75% of COD; 66% of BOD5 and 60% of turbidity, from their respective initial concentrations of 58 880 mg/L, 24 000 mg/L and 2036 NTU. Finally, the anaerobic combined with aerobic treatment was found to be very efficient in the treatment of MSW leachate, enhancing hence its biodegradability.**

Keywords— ***Anaerobic treatment, Continuous aeration, Leachate; Municipal solid waste***

I. Introduction

In Morocco, the production of solid waste is increasing, due to population growth and increased economical activity [1]. Hence, according to this author, the production is estimated to be about 4.5 million tons per year of municipal solid waste (MSW) and about 800 000 tons per year of industrial waste. The waste generation rate is variable depending on the region and it can vary from 0.6 to 0.7 kg/capita/day [2]. The treatment of the municipal solid waste, in particular, has not been sufficiently developed.

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Further, the treatment method used can no longer be sustained since it causes serious damages to the environment (pollution of ground and surface water, soil pollution, impact on human health, emission of greenhouse gases) [3]. The evolution of wastes in landfills and their interactions with the external environment lead to the dispersion of pollutant flows, mainly through the emergence of the leachate, as resulting from water percolation and dissolution by physico-chemical pathways of contaminants. This contaminated waterby organic and inorganic substances, gives birth to the leachate [4].

In the present work, we have used an anaerobic process for treating the leachate, and we have subsequently, injected 3.5 L of air per minute to 10 liters to the sample. This treatment has allowed removing 66% of COD. Since the leachates treated by the biological process are not yet applied in the agriculture area, in the present work we aim to reduce the pollution load to its minimum value by the anaerobic treatment. Thus, the present study concerns both the reduction of pollution from leachate of MSW by implementing a biological treatment, and the optimization of the process operating conditions. Note that this biological treatment involves an anaerobic process which is followed by a continuous aeration.

II. Materials and methods

A. *Sample collection*

To obtain a collection of leachate, a garbage compactor truck was chosen at random, it contained about 5.5 tons of solid wastes. The MSW leachate samples were collected in 50 L plastic bottles, then transported to the laboratory, and finally stored at 4 °C. These samples were then removed from the refrigerator and left at ambient temperature, for about 2 hours, before their characterization and their biological treatment.

B. *Experimental procedure*

The leachate studied by the anaerobic-aerobic treatments, is stored in a polyethylene waterproof container of 30 liters having both a screw cap and a seal washer to prevent any kind of contact with air. It should be noted that during the anaerobic treatment which takes 43 days, the physico-chemical analysis were done three to four times per week. After the anaerobic treatment step, 10 liter of the same leachate was moved in another glass reactor for the aerobic treatment. In this subsequent step, a pump feeding the glass reactor with oxygen, at a rate of 3.5 liter per minute (3.15 kg $O_2/m^3/h$), was used. The aerobic reactor was held under a continuous stirring throughout the period of the test. The period of the aerobic treatment is 30 days during which the physicochemical analyzes are done three to four times per week, whereas the microbiological analyzes are made once a week.

C. Physico-chemical and bacteriological variables

The pH was measured using a pH meter "Accumet Basic AB15 pH meter". The conductivity was measured using a conductivity meter mark "intelligent Conductivity pH meter YK-2001PH". The Chemical Oxygen Demand (COD) was performed according to the AFNOR standard in force (NF T90-101 February 2001 (T90-101)). The Biological Oxygen Demand after 5 days (BOD5) has been facilitated by the use of gauge method ((EN 1899 May 1998) (T90-103)) using BOD meter mark VELP. The absorbance measurements were carried out using a UV-visible spectrophotometer 9200 RAYLEIGH bandwidth 1 nm two-beam. The turbidity was measured using a turbidity meter according to NF EN ISO 7027 March 2000 (T 90-033). The determination of suspended matter was conducted by the centrifugation method of standard (NF T 90-105 January 1997 (T 90-105)). Further, phenolic compounds were determined by the colorimetric method using the Folin-Ciocalteu reagent [5]. The determination of nitrate in the sample was performed by the spectrometric method in the presence of sulfosalicylic acid according to norm EN ISO 78-90 January 1997 (T 90-045). The determination of the total phosphorus was performed by spectrometric method according to NF T 90-023 January 1997. The determination of the ammonia nitrogen was performed by the spectrophotometric method by using indophenol blue according to AFNOR NF T 90-015 January 1997. The heavy metals analysis was performed by using atomic absorption spectrophotometry equipped with a graphite furnace. Bacteria were isolated and counted either by the spread-plate procedure, after dilution in sterile water with 9% sodium chloride (NaCl), or by the membrane (HAWG 047 0.45 microns pore size; Millipore Corp.) filtration procedure. The bacteriological variable studied was: total viable count (TVC), corresponding to the cultivable aerobic heterotrophic bacteria, counted after incubation for 7 days at 20 to 25 °C on nutrient agar (bioMérieux). It should be noted that all the bacterial counts were first log-transformed (base 10), for two raisons: (i) bacteria often growth exponentially, consequently a logarithmic transformation makes the interpretation of the changes in the bacterial number or the activity more straight forward [6] and (ii) this transformation eliminates a good deal

analyzes are done three to four times per week, whereas the microbiological analyzes are made once a week.

The removal efficiency of pollutant concentrations were calculated accordingly by using Eq (1):

$$\textbf{Removal in \%} = (1 - C/C_0) * 100 \qquad (1)$$

Where C_0 and C, are the initial and the final pollutant concentrations, respectively.

III. Results and discussions

A. Characterization of the raw leachate

Table 1 presents the physicochemical characteristics of the MSW leachate originating from Mohammedia city.

Leachate turbidity, suspended matter content, pH, conductivity, COD and BOD5

As can be seen in Table 1, the observed value of the turbidity of the raw effluent is 2036 NTU, which indicates a fresh leachate, highly rich in colloidal, and suspended matter (SM) which has a value equal to 16 g/l. Table 1 shows also that the aqueous phase pH is 5.15, indicating hence a very young leachate that may be contaminated with industrial waste. The conductivity value, as measured at 25 ° C, is 10 300 $\mu s.cm^{-1}$. This parameter gives an overall assessment of the ion concentration present in the leachate, essentially of mineral type. Its value is low, as compared to the one observed for an old leachate having value of about 24 000 $\mu s.cm^{-1}$ due to the high organic load, associated by very young leachate in acetogenesis phase or by accidental pollution. The study of BOD5/COD ratio is a good indicator of the effluent biodegradability. It has been shown [7] that a BOD5/COD ratio value below than 0.1 indicates low biodegradability, whereas values above 0.3, indicate significant biodegradability. In the present work, the MSW leachate investigated has a BOD5/COD ratio equal to 0.41, indicating a high biodegradability.

Nitrogen, phosphorus and heavy metals contents of leachate

Table 1 shows also that the measured contents of nitrate-nitrogen (NO_3-N) and ammonia-nitrogen (NH_4-N) are respectively, 645 mg N/L and 169 mg N/L. Ammonia nitrogen (NH_4^+) is a gas which is soluble in water and it is one of the forms in the complex cycle of nitrogen in its primitive state.

As presented in Table 1, the total Kjeldahl nitrogen, TKN of the leachate, which encompasses organic and ammonia nitrogen; is TKN=1290 mg/L. This value is greater than that reported elsewhere [8]. Further, the total phosphorus value in the leachate is 1880 mg P/L. However, there is low content of heavy metals, as presented in Table 1 (concentrations ranging from, 0.53 mg/L for Pb to 2.5 mg/L for Cr.).

Bacterial count in leachate

Table 1 shows that the Total Viable Count (TVC) concentration in the leachate achieves a value of 7.5 log10 CFU/ml which indicates that the fresh leachate of MSW of Mohammedia city is extremely rich in microorganisms and it is potentially treatable biologically.

B. *Biological treatment*

Variation of pH and conductivity during the treatment of the leachate

Figure 1: Variation of the pH and conductivity

Fig. 1 shows the variation of the pH and conductivity during the anaerobic and aerobic treatments of the MSW leachate. The initial leachate pH value was 5.15, it increased to 6.5, between the 22th and 35th day of the treatment, and then remained constant up to the end of the anaerobic period. In the next aerobic step, during which oxygen was introduced into the leachate, the pH was found to increase slightly from 6.5 to 6.87, except for the 48th day of the treatment where an abrupt decrease of the pH value from 6.5 to 5.53 was observed, as depicted in Fig. 1. Note that the vast majority of microorganisms develop in neutral pH conditions. However, some bacteria were found to growth even in acidic or alkaline pH media. The leachate conductivity was found to vary throughout the trial period between 9 and 12 mS/cm. A slight decrease of the conductivity from 10.3 to 9.3 mS/cm occurs during the first 15 days of the treatment, followed by an increase to 12 mS/cm at the end of the anaerobic process. Moreover, after aeration, the conductivity is slightly increased from 11.94 to 12.7 mS/cm (Fig. 1). It should be emphasized that the aeration has an effect on the leachate conductivity as it was described elsewhere [9]. Further, it has been shown that the decrease in conductivity is influenced by the presence of microorganisms, naturally present in the leachate of the biomass, indicating a strong correlation between electrical conductivity and biomass, [10, 11]. Several researchers have studied aerobic versus anaerobic solid waste degradation by using columns filled with solid waste under different experimental conditions. Hence, changes in pH, COD, BOD5, TOC, and biogas in leachate recirculated through aerobic and anaerobic solid waste columns, were observed, [12].

TABLE 1: PHYSICOCHEMICAL AND BACTERIOLOGICAL CHARACTERISTICS OF THE RAW LEACHATES (L1, L2 AND L3)

Parameter		$(L_1)^1$	$(L_2)^1$	$(L_3)^1$
pH		5.15	3.80	4.12
Conductivity ($ms.cm^{-1}$)		10.30	12.07	10.54
Turbidity (NTU)		2 036	1 620	1 305
COD (mg $O_2.L^{-1}$)		58 880	61 440	44 160
BOD_5 (mg $O_2.L^{-1}$)		24 000	28 750	25 000
BOD_5/COD		0.41	0.47	0.56
Surfactant ($mg.L^{-1}$)		63.00	512.54	414.15
Phenol ($mg.L^{-1}$)		620.00	71.12	60.30
Decanted sludge ($mL.L^{-1}$)		65	18	8
Absorbance^2	l_1=254 nm	1.110	0.600	0.400
	l_2=436 nm	0.032	0.038	0.023
	l_3=540 nm	0.019	0.028	0.018
	l_4=660 nm	1.110	1.500	0.019
Suspended matter ($g.L^{-1}$)		16.00	10.87	7.65
SO_4^{2-} ($\mu g.L^{-1}$)		158	181	156
Total Phosphorus (mg $P.L^{-1}$)		1 880	1 580	1 880
Orthophosphate (mg $P.L^{-1}$)		0.43	0.41	0.30
NO_3^- (mg $N.L^{-1}$)		645	780	650
NH_4^+ (mg $N.L^{-1}$)		169	-	200
TKN ($mg.L^{-1}$)		1 290	-	1 050
Cu ($mg.L^{-1}$)		1.03	-	-
Zn ($mg.L^{-1}$)		1.45	-	-
Cr ($mg.L^{-1}$)		2.5	-	-
Ni ($mg.L^{-1}$)		0.27	-	-
Pb ($mg.L^{-1}$)		0.53	-	-
Sb ($mg.L^{-1}$)		0.9	-	-
Sn ($mg.L^{-1}$)		0.6	-	-
T.V.C. (Log_{10} CFU/ml)		7.5	-	-

[1]L1, L2 and L3 = Three samples of leachates
[2]Absorbance was taken at a dilution factor (DF) of 200

In that reported work, it has been shown also that the pH value was lower, about 5.5, in the anaerobic column, as compared to pH value about 7 measured in the aerated column, indicating a strong acidic phase in the anaerobic column, in good agreement with our data presented in Fig. 1.

Variation of the leachate turbidity

Fig. 2 shows the variation of the turbidity expressed in NTU, and also in percentage removal during anaerobic and aerobic treatments of the MSW leachate.

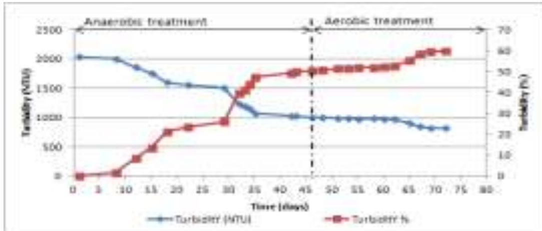

Figure 2: Variation of the turbidity in NTU and in percentage removal

As can be observed in Fig. 2, the turbidity begins to decrease from the 8th day; it passes from 2000 to 1507 NTU after 20 days of anaerobic degradation, and then rapidly decreases in a week to reach a stable value equal to 1035 NTU. The percentage of turbidity removal is 50% by anaerobic biodegradation. Further, from the first day of the aeration, the turbidity was found to decrease with time. A significant decrease was observed throughout the aerobic treatment period. The turbidity values are 1035 and 820 NTU at the beginning and the end of the aerobic treatment respectively. The percentage of turbidity removal in the aerobic phase is 21% (Fig. 2).

COD and BOD5 removal

Fig. 3 shows the variation of COD, expressed in mg/L, and in percentage removal during anaerobic and aerobic treatments of the MSW leachate.

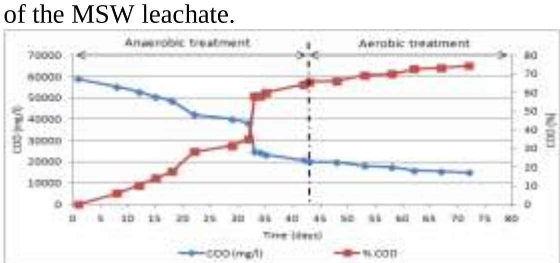

Figure 3: Variation of COD in mg/l and in percentage removal

The data indicate that the COD value decreases with time, it passes from 58 880 to 38 000 mg/L in 32 days with anaerobic treatment, and in the 33th day it decreases rapidly to reach the value of 25 000 mg/L. At the end of the anaerobic treatment, the final value reached is 20 056 mg/L. The percentage of COD removal by this treatment was 66%. After the introduction of oxygen into the leachate, an additional reduction in COD is observed, it passes from 20 056 to 15 000 mg/L. The resulting percentage removal of COD by the aerobic treatment is 25% and the total percentage removal of COD by the anaerobic-aerobic treatments is 75% (Fig. 3). Biological methods used for the leachate treatment can be classified as aerobic, anaerobic and anoxic processes which are widely used for the removal of biodegradable compound. Anaerobic biological treatment of landfill leachate has been studied by many investigators. Thus, up to 92% COD removals have been obtained by using up flow anaerobic sludge blanket reactors, [13]. In last decades, the performance improvement of the existing anaerobic process was believed to be a promising option and so, high rate reactors have been designed in order to reduce long digestion time, [14].

Fig. 4 shows the variation of BOD5 as expressed in mg/L, and in percentage removal during anaerobic and aerobic treatments of the MSW leachate.

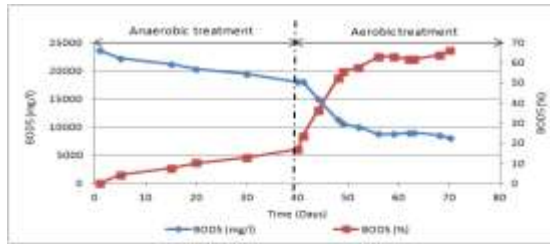

Figure 4: Variation of the BOD5 in mg/l and in percentage removal

The BOD5 is measured once per week for 70 days. As it was observed for the COD variation, the BOD5 value decreases as a function of time; it passes from 23 550 to 8 000 mg/L. The percentage of elimination of BOD5 by anaerobic combined with aerobic treatments is 70% (Fig. 4). The aeration, allowing the introduction of oxygen into the leachate, has facilitated the intensification of the bacterial activity. This enables the degradation of the biodegradable organic material present in the leachate, which results in decreased values of BOD5 [9]. Biological phenomena involved in the metabolisation of organic material are shown in Fig. 5 which reflects the variations, versus time, respectively, of the purifying biomass and remaining pollution (measured by BOD5) in the presence of oxygen. As can be observed in this figure, after the first day of ventilation, the biomass, in the ascending part of the curve, is ending with an inflection point at the 7th day. During this period of time, there is also a linear reduction in BOD5, related to the rate of synthesis where biomass growths at constant rates. Beyond the inflection point in the biomass curve, a decrease in the substrate concentration leads to a decrease in the biomass growth rate which will gradually vanish. Biological processes have been shown to be very effective in removing organic and nitrogenous matter from immature leachates when the BOD5/COD ratio has a high value (> 0.5). With time, the presence of refractory compounds (mainly humic and fulvic acids) tends to limit process's effectiveness [15].

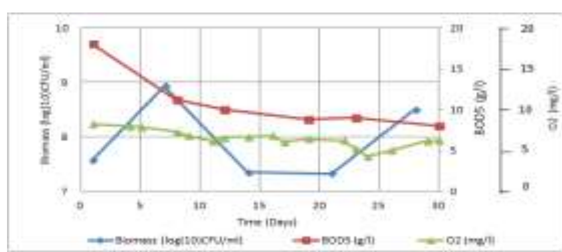

Figure 5: Variations with time of biomass, BOD5 and O_2

The variation of the COD/BOD5 ratios were found to decrease during the two treatment steps (anaerobic and aerobic). This is related to the presence in the leachate of organic material that degrades over time.

Nitrogen Removal

The proportion of NH_3 and NH_4^+ depends on pH and temperature.

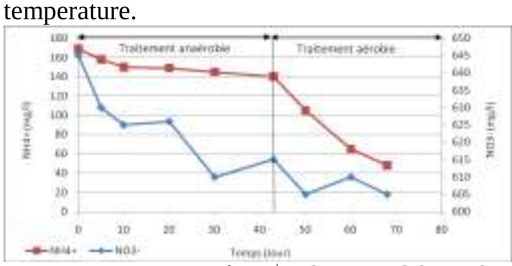

Figure 6: Concentration of NH_4^+ and NO_3^- mg/l during the anaerobic treatment combined with aerobic treatment

At pH 8.0 and a temperature of 20 °C, NH_3 is less than 10% and increases rapidly above pH 8.5 [16]. The variation with the anaerobic-aerobic treatments time of NH_4^+ and NO_3^- concentrations, are illustrated in Fig. 6. As observed in this figure, the nitrate content of the raw leachate (Fig. 6) shows an extreme value of 645 mg/L, and after the biological treatment, this amount decreases to 615 and 605 mg/L with the anaerobic and aerobic, treatments, respectively. However, the data of Fig. 6 do not show high nitrate removal after the treatment. This behaviour is mainly due to a strong bacterial nitrification related with mineralization ammonia nitrogen to nitrate and leading to decrease in the concentration of ammonia nitrogen going from 169 mg/L to 45 mg/L. In others reported studies [17], the nitrate concentration of the leachate was much less than that achieved in the present work. Hence, the reported work has shown that the nitrate concentration in the leachate was between 0 and 9.8 mg/L, whereas others studies, [1], on raw leachate from the Oujda city (Morocco) old landfill, have obtained nitrate concentration values ranging between 74.79 and 117.42 mg/L. According to others authors, [18], the nitrate concentration, from leachate originating from waste storage center, can reach a maximum value of 845 mg/L. A value of nitrate concentration of 751 mg/L was found in the landfill of the Meknes city (Morocco), [19]. It was argued that high concentrations of nitrates in rivers lead to eutrophication, reflected in a significant growth of microorganisms and algae, disrupting the natural ecological balances, [2].

IV. Conclusions

The MSW leachate of Mohammedia city investigated in the present work, was found to contain organic matters which are readily biodegradable. In addition, its initial COD, BOD5 and turbidity values were higher. Therefore, the biological treatment by anaerobic process, followed by aeration of the leachate, yielded remarkable results in terms of pollution reduction.

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