Environmental Technology, Vol. 28. pp 225-234

COUPLING OF ABIOTIC AND BIOTIC PARAMETERS TO EVALUATE PERFORMANCE OF COMBINING NATURAL LAGOONING AND USE OF TWO SAND FILTERS IN THE TREATMENT OF LANDFILL LEACHATES

L. ALEYA*[1], H. KHATTABI[1], E. BELLE[2], H. GRISEY[2], J. MUDRY[2] AND J. MANIA[3]

[1]Laboratoire de Biologie Environnementale, Université de Franche-Comté, 1, Place Leclerc, 25030 Besançon cedex, France
[2] Laboratoire de Géosciences, Université de Franche-Comté, 16, route de Gray, 25030 Besançon cedex, France
[3] Département de Géotechnique et Génie civil, Ecole Universitaire D'Ingénieurs de Lille (EUDIL), 59655 Villeneuve d 'Ascq France

(Received 4 January 2006; Accepted 2 October 2006)

ABSTRACT

A study in the Etueffont landfill, located in Belfort (France), was conducted to evaluate the performance of combining natural lagooning and use of two sand filters for treating leachates through the coupling estimation of several abiotic and biotic parameters. Two gravel filters were installed in the upstream of the first basin which communicates with the remaing 2, 3 and 4 basins. The distribution of physical-chemical (T, pH, Eh, EC, O_2, SM, SO_4^{2-}, Cl^-, Zn, Fe, Mg, Ni, Al, As, Ba, Cu, Sn, Zn, BOD, COD, KN, NH_4^+, NO_2^- ,TP, AOX: absorbable organic halides, VFA: volatile fatty acids, and atrazine) and biological (bacteria, protozoa, phytoplankton) parameters was assessed in the leachate entering in basin 1, and downstream of the filters. The results showed slight variations in the physical-chemical composition of the leachate between 1999 and 2000, most likely ascribed to the maturation of the landfill but a very significant removal of SM (suspended matter) by the sand filters. This, applied to the majority of the studied parameters. Thus, the sand filter treatment of the leachates combined with natural lagooning was efficient in the improvement of water clarification.

Keywords: Landfill leachate, sand filters, metals, bacteria, protozoa, phytoplankton.

INTRODUCTION

Landfill leachate generated by the biodegradation of solid wastes migrates away from a landfill and may pollute ground as well as surface waters [1,2]. While landfilling is the most attractive option for waste disposal, it may be a source of large quantities of organic and inorganic matters and heavy metals [3,4]. In particular, heavy metals that accumulate in the body with long biological half-lives [5], have been shown to cause several health hazards [6,7]. Thus, understanding the mechanisms fueling leachate generation may be a clue to reduce efficiently their unfavourable impacts on the surrounding environments [8]. Furthermore, leachate composition has been shown from laboratory experiments [9, 10] and *in situ* [11] to be closely linked to climate, hydrology and waste-hiding techniques. The stabilization ponds, that are generally designed to treat only an average quality of the leachate, are commonly put under extreme pressure-induced organic matter overload. Therefore, the process of leachate treatment, when it is conceived must take into account 'worse case scenario', i.e., intense increase in the concentration of polluting compounds.

In the Etueffont landfill (Belfort, France), leachate components are treated by 4 stabilization ponds. However, in periods of high concentrations of organic matter in the basins, this option of leachate treatment showed low performance as it seemed unable to fulfill european standards (ISO 14000) to discharge into the surface and ground waters [12]. This study aimed thus at improving the performance of leachate treatment by combining natural lagooning and use of two sand filters upstream from the first basin. The capability for removing metals and other pollutants, together with microbial populations, was assessed through the measurement of several abiotic (major elements, metals and organics AOX: absorbable organic halides, VFA: volatile fatty acids and atrazine) and biotic parameters (bacteria, protozoa and phytoplankton).

MATERIALS AND METHODS

Study Site

The Etueffont municipal solid waste landfill was opened in 1974. It is located in the North-East of France

(Belfort, Figure. 1) and extends on 2.2 hectares from impermeable schistous layers. The width, length and depth are respectively 110, 200 and 5m. The landfill contains 200 000 tons of crushed household refuse, and operates in the open air without cover after grinding the waste before landfilling. The site has been exploited until July 2002 and was covered by a layer of vegetal soil coming from the old crushed organic wastes (wood, residues of lawn shearings, straws, fabrics). The leachates were collected downstream by a draining system and treated by a four-basin lagooning system. Two sand filters, with perforated drains, were placed upstream from the first basin (Figure. 2). Geotextiles consisted of synthetic fibers (polymeric materials) which are made of flexible porous fabrics by standard weaving machinery (woven geotextile).

Samplings and Analysis Procedures

Leachate samples were collected at the input and output of the sand filter, in the four basins and at the output of the last basin in 1999 and 2000 (4 samplings/year) in pyrex glass containers prerinsed with bidistilled water. Temperature, pH, dissolved oxygen and electric conductivity were assessed in situ by a multiparameter probe (WTW, Multiline P3 PH/LF-SET). Concentrations of Cl^-, NO_2^-, NO_3^-, SO_4^{--}, Cl^-, were analysed by an ion chromatograph (Dionex DX-100) and those of BOD, COD, iron (Fe), zinc (Zn), nickel (Ni), barium (Ba), tin (Sn), copper (Cu) and magnesium (Mg) determined by UV/vis spectrophotometry (WTW Photolab). Total nitrogen (Nitrogen Kjeldhal: NK) was estimated by distillation, after mineralization in $N\text{-}NH_4$ [13] and (NH_4) by spectrophotometry, following a sodium nitroprussiate alkaline reaction. Total phosphorus (TP) was assessed by colorimetry [13]. Suspended matter (SM) was estimated by filtration and concentrations of fatty volatile acids (FVA), absorbable organic halides (AOX), and atrazine were estimated according to Eisenreich et al [14] and Rodier [15].

Abatement rates

Abatement rates were calculated by the following formula:

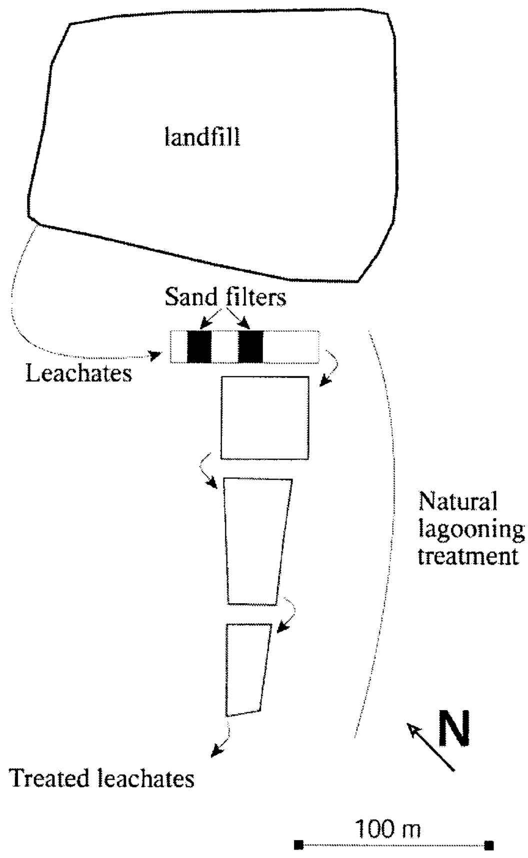

Figure 1. Map of the Etueffont station.

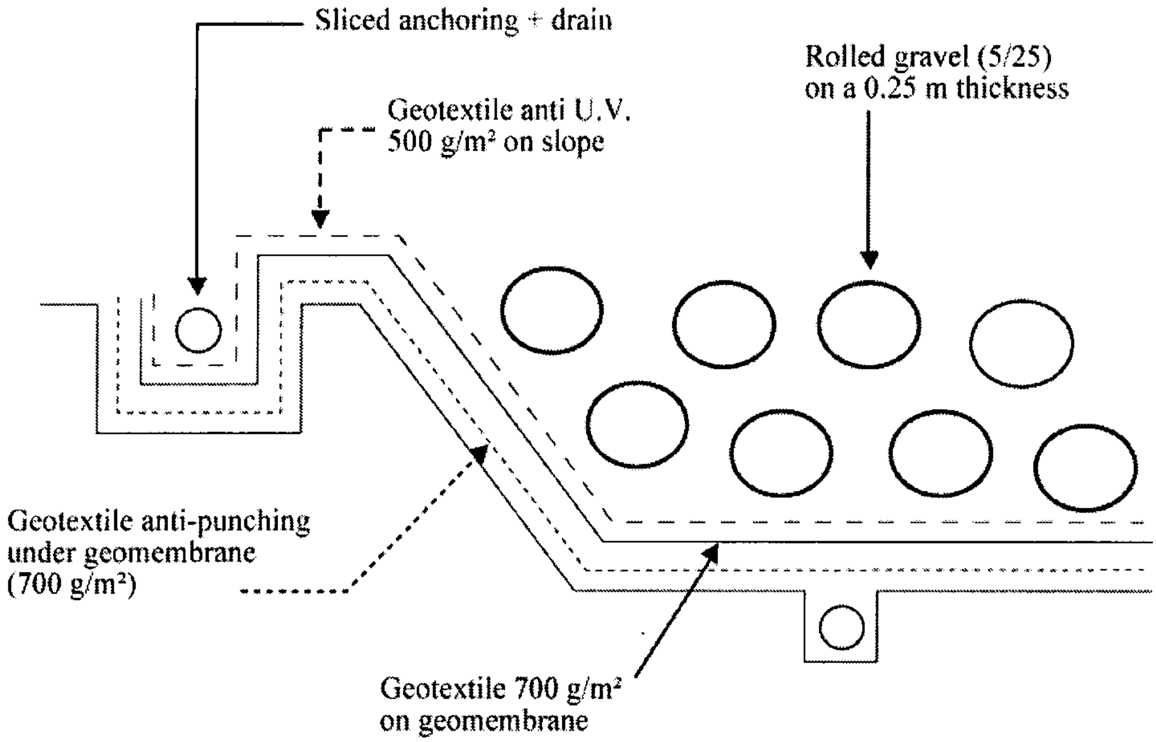

Figure 2. Simplified diagram of the used sand filters.

$X=((C_0 - Cf)/C_0)*100$

With: X: Abatement rate (%), C_0: Concentration of a given parameter at the outlet of the discharge (i.e., in the effluent sent to the sand filters prior to first basin), Cf: Concentration of a given parameter at the exit of the fourth basin.

Bacterial Enumeration (in Gross Leachate)

The enumeration of bacteria was performed by epifluorescence microscopy. Samples were stained with DAPI (4-6-diamino-2-phenylindol) [16], and filtered on a polycarbonate filter (Millipore, pore size: 0.2 mm, GTBP type) at low vacuum (<13 KPa). 1500 to 2000 cells were counted on 20 fields (measurement error not exceeding 7%, [17, 18]) with a Leica DM IRB inverted microscope.

Protozoa (in Gross Leachate)

Autotrophic and heterotrophic flagellated protozoa were fixed (25 μl) with glutaraldehyde, stained with primuline and counted by epifluorescence microscopy. Ciliated protozoa and amoebae were fixed with mercuric chloride ($HgCl_2$) and counted with a Leica DM IRB inverted microscope [19,20]. Ciliates abundance was estimated from three replicates [21].

Phytoplankton (in basins)

Phytoplankton enumeration were made with an inverted microscope by Uthermöl's method [22], modified by Legendre and Watt [23] after fixation with a Lugol's (4%) iodine solution [24].

RESULTS AND DISCUSSION

Leachate Characterization

Organic components

The organic matter contained in leachates have been demonstrated to consist of valuable amounts of humic substances [25,26]. These substances can be compared to those encountered in the normal organic matter (NOM) in aquatic environments. Humic substances in leachates contain aromatic and aliphatic compounds with mainly carboxylic and phenolic functional. The carboxylic functional groups account for between 60 and 90% of the functional groups [27]. The dissolved organic matter in leachates is crucial in the study of landfill leachates from domestic wastes covering a variety of degradation products, extending from low volatile acids to refractory fulvic and humic acids [25]. However, few studies targeted the characterization of the organic matter of leachates generated from household wastes [28], and the contents of organic matter are very dependent on physical factors such as temperature. Harmsen [29] highlighted a predominance of the VFA in the young leachate (more than 95% of the COD). Weiss [30], by comparing the various fulvic acids from leachates with those from lake and marsh waters, pointed out that fulvic acids extracted from the leachate contained high rates of C, H, and S, but low levels of phenolic groups that presented low Cu binding potentials and decreased weight. The organic component of the leachate in Etueffont that has been characterized previously by biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [31] was approched in this study through VFA. The results are summarized in Table 1 and showed low VFA levels (mean 450 mg l^{-1}) which have commonly been quoted from old landfills undergoing a full stabilization phase [12]. Moreover, the temporal distribution of the organic load in the leachate between 1999 and 2000 [31], pointed out a clear decrease in the two descriptors of organic pollution (BOD and COD) most likely attributable to degradation by microorganisms. This translated into a decrease (from 0.09 to 0.05) in BOD/COD ratio and a slight increase in pH. Our findings are in agreement with others [27, 32] who demonstrated that a BOD/COD ratio close to zero means the landfill is old with a fermentation-inducing alkaline leachate production.

Table 1. Physical-chemical and biological composition of the Etueffont landfill leachates (1999 and 2000).

Etueffont leachate	1999		2000	
	Average	s	Average	s
T °C	13.4	5.81	18.8	2.61
pH	7.76	0.42	7.8	0.11
EC μS cm^{-1}	5343	1344	4673	1371
SM mg l^{-1}	157	160	32	19
BOD mg l^{-1}	98	79	46	15
COD mg l^{-1}	1085	587	892	597
NO_2 mg l^{-1}	0.00	0	7.11	3.08
NO_3 mg l^{-1}	47	77	254	353
SO_4 mg l^{-1}	163	64	139	38
Cl mg l^{-1}	620	63	630	49
Mg mg l^{-1}	34	6	42	8
NH_4 mg l^{-1}	178	43	178	94
NK mg l^{-1}	188	74	174	68
TP mg l^{-1}	1.36	0.49	1.58	1.41
Cu mg l^{-1}	0.73	0.9	0.22	0.05
Fe mg l^{-1}	2.93	2.21	3.61	0.96
Al mg l^{-1}	0.16	3	0.39	2.5
Ni mg l^{-1}	3.23	4.69	0.13	0.07
Sn mg l^{-1}	0.51	0.48	0.11	0.08
Zn mg l^{-1}	0.61	0.28	0.4	0.32
VFA mg l^{-1}	-	-	73	0.04
Atrazine ng l^{-1}	-	-	268	31.13
AOX μg l^{-1}	-	-	950	0.6
Bacteria x 10^6 cell ml^{-1}	0.20	64	0.19	39
Protozoa cell l^{-1}	9320	51	8840	43

Biological Components

Bacteria: the bacterial numbers recorded in the gross leachate varied from 0.04 x 10^6, in 1999 to 0.35 x 10^6 cell ml^{-1}, in 2000. Overall, this abundance was lower than that reported from other aquatic systems [16, 17, 33-39]. This may be ascribed to lower levels in oxygen concentrations in the Etueffont leachate, and competition between autochthonous and allochthonous microorganisms with the need, for the latter, to adapt to both new environmental conditions and leachate toxicity [20, 40-46] .

The enumeration of the protozoan community in the Etueffont leachate showed that flagellated protozoa were the main contributors to the total protozoan abundance (98% and 94%), followed by ciliated protozoa (1.7 and 3%) and naked amoebae (0.3 and 3%), in 1999 and 2000, respectively. These heterotrophs, through grazing on bacteria, may have contributed to the control of bacterial populations, whose number was reduced in 2000 [47,48,49]. Our suggestions are in line with several studies showing the significance of protozoa in biological wastewater treatment plants. In addition to removing a fraction of bacteria, protozoan communities can be involved in primary removal of organic matter in polluted waters and suspended matter [50,51,52].

AOX and Atrazine

In order to go further in characterizing Etueffont leachates, we estimated AOX and atrazine since little is known on their concentrations in landfill leachates (Table. 1). The AOX that are poorly prone to biodegradation, were high on average (950 μg l^{-1}) and most likely due to specific wastes in the landfill. Triazinic atrazine (2-chloro-4-ethylamino-6-isopylamino-1,3,5-triazine) which is commonly used in agriculture (chiefly in corn fields), showed low concentrations (268 ng l^{-1}), likely ascribed to atrazine-treated and landfilled plant detritus. Moreover, the levels of triazinic atrazine detected were lower than those previously reported [53,54,55].

Inorganic Components

Contrary to organic compounds, the distribution of leachate inorganic substances between 1999 and 2000 was relatively stable (Table 1), except a slight increase in Mg (from 34 to 42 mg l^{-1}), NO_2^- (from 0 to 7 mg l^{-1}), NO_3^- (from 47 to 254 mg l^{-1}), and Fe (from 2.93 to 3.61 mg l^{-1}) concentrations, attributable to the low-autumnal precipitations recorded in 2000. However, the decrease in Ni and Cu concentrations may most likely be attributed to complexation of both metals with anions which were frequently observed in the lixiviate. This was favoured by increased pH. Sulfate concentrations were also lower over this year than those measured in 1999, due to microbial reduction of SO_4^{--} and S^{--}. The NH_4^+ concentrations observed did not show any temporal decrease going along with the results reported by others [56]. These overall stable distribution patterns also applied to heavy metals, putting our findings in line with those of Maehlum et al [57] and Christensen [12]. Fluctuations of the SO_4^{--}/Cl^- ratio may be informative on both oxygenation status and solubility of metallic cations. Indeed, the rapid decrease in SO_4^{--}/Cl^- from 0.36 in 1999 to 0.23 in 2000 was likely linked to the prevailing anaerobic conditions, inducing a decrease in initial sulfate concentrations. Ions resulting from sulfides will further react with metallic cations to form insoluble metallic sulfide precipitates. These latter may also coprecipitate with iron and other metals. The collapse of SO_4^{--}/Cl^- ratios in the leachate is symptomatic of the strong anaerobic activity within the Etueffont landfill. Our results go along with those reported by others [26,58].

Sand Filter Performance (2000)

The BOD and COD estimated in the leachate entering in the sand filter, were clearly higher than those measured at the outlet of basin 1 (Table 2). They decreased from 141 to 81 mg l^{-1} and 1293 to 932 mg l^{-1}, respectively, concomitantly to a drop in suspended matter SM, in summer (Table 2). This suggests that a large fraction of organic matter was particulate-based. In addition, the downstream waning of BOD (Table 2) correlated with a drop in bacterial numbers (0.19 to 0.079 x 10^6 cell ml^{-1}, before and after filter installation, respectively), and protozoans as reported by others [59]. Also, the sand filtration has been shown to significantly contribute to bacterial removal capacity of hydroponics (60-87%) in wastewater treatment experiments and surface waters (84-100%).

The temporal distribution of the abatement rates of several chemical species reflected a quasi-similar filter removal ability except for BOD. Indeed, because the abatement rate of this descriptor was closley related to temperature, any increase of the latter will induce a bacterial proliferation - inducing a drop in BOD. The mean removal rates of the remaining studied parameters were good (between 20 and 80%) except the negative values recorded for AOX, NO_2^-, Ba and Cu. This dysfunctioning is most likely linked to resuspension of elements from clays, induced by water turbulence in the first basin.

Lagooning Performance

In summer 2000, the abatement rates of several parameters were high (Figure 3) except for BOD and SM (suspended matter) which showed negative values (-146 and -57). This dysfunctioning may be ascribed to the summer spectacular proliferation of the Euglenophyta, *Phacus* sp. and *Euglena* sp., the metabolic activity of which through primary production and excretion [60,61,62] strongly masked the removal efficiency of the sand filters. The removal performance of bacteria and protozoa in the Etueffont station was high and close to that reported in literature [63]. The abatement rate of the COD is about 58% which seems satisfactory since biological treatment of landfill leachate

Table 2. Temporal variations of abatement rates (%) of several parameters by the two sand filters .

	Autumn			Summer		
	[i]	[f]	Abatment rates (%)	[i]	[f]	Abatment rates (%)
T °C	23.2	23.1	0	17.4	11.6	33
pH	7.75	8.14	-5	7.6	7.86	-3
EC μS cm^{-1}	10900	7500	31	4820	4200	13
SM mg l^{-1}	156	152	3	84	52	38
BOD mg l^{-1}	177	125	29	105	37	65
COD mg l^{-1}	1630	1177	28	956	688	28
TOC mg l-1	470	350	26	356	282	21
AOX μg l^{-1}	210	131	38	9	65	-622
NO_2 mg l^{-1}	1.93	0.46	76	8.2	12	-46
NO_3 mg l^{-1}	3	1.95	35	49	47	4
SO_4 mg l^{-1}	50	38	24	162	104	36
Cl mg l^{-1}	768	620	19	388	341	12
HCO_3 mg l^{-1}	5980	3843	36	2320	1891	18
K mg l^{-1}	862	594	31	369	307	17
Na mg l^{-1}	834	599	28	518	429	17
Ca mg l^{-1}	172	122	29	155	100	35
Mg mg l^{-1}	70	56	20	46	34	26
NH_4 mg l^{-1}	84	53	37	22	21	5
NK mg l^{-1}	730	450	38	204	186	9
TP mg l^{-1}	11.43	7.9	31	3.52	2.74	22
Atrazine ng l^{-1}	2149	427	80	405	266	34
Al mg l^{-1}	1.25	0.8	36	0.49	0.42	14
As mg l^{-1}	0.066	0.075	-14	0.023	0.028	-22
Ba mg l^{-1}	0.38	0.48	-26	0.37	0.48	-30
Cu mg l^{-1}	0.1	0.12	-20	0.16	0.14	13
Fe mg l^{-1}	10.9	6.7	39	3.38	3.58	-6
Ni mg l^{-1}	0.13	0.11	15	0.11	0.1	9
Sn mg l^{-1}	0.27	0.18	33	0.09	0.04	56
Zn mg l^{-1}	0.16	0.16	0	0.286	0.24	16
Bacteria x 10^6 cell ml^{-1}	0.09	0.11	-22	0.05	0.03	40
Protozoa cell l^{-1}	8840	7072	20	9040	5878	35

[i] : initial concentration
[f] : final concentration

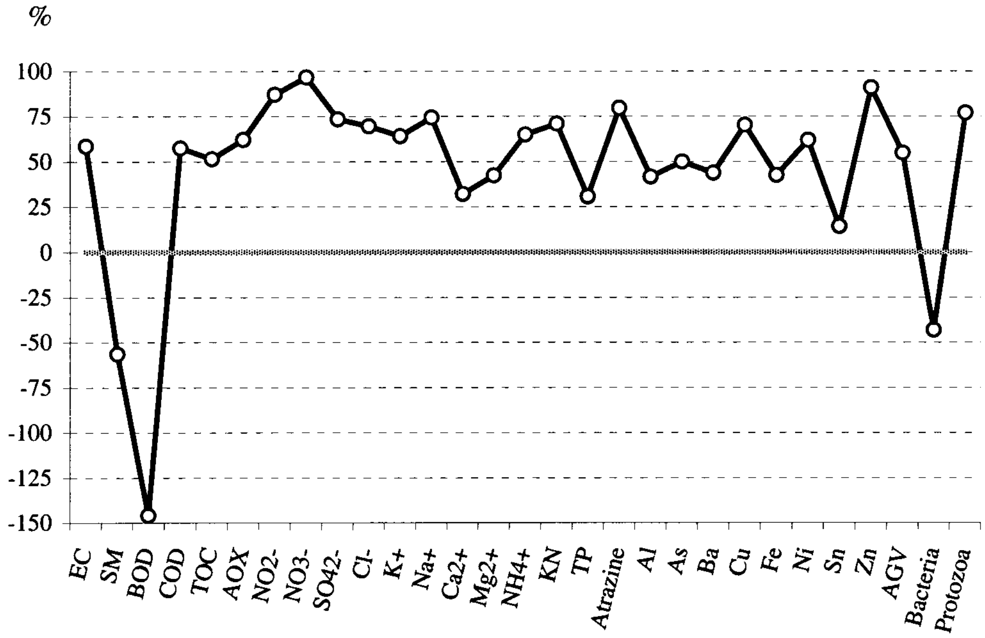

Figure 3. Abatement rates (%) of several parameters after both sand filters and natural lagooning treatments

usually yielded low treatment efficiencies because of high chemical oxygen demand (COD) [58]. Moreover, an encouraging result was the removal rate obtained for atrazine (80%), due to its degradation when the leachate transits from one basin to another, and/or its complexation with bottom muds. These two processes are supported by the rise in the oxidizing capacity of the leachate [64] which is induced by the mechanical mixing of the passing from basin to basin-water and by phytoplankton primary production - inducing increase in oxygen concentrations in water of the last basins. Also, bacteria may have contributed to overall oxidating potential of the leachate [65-68]. It would be thus useful further to estimate, from both leachate and mud samples, the concentration of the different molecules resulting from atrazine based-wastes. The removal rate of Zn (90%) is in line with that reported by Maehlum [69].

CONCLUSION

Our work demonstrated that the sand filter treatment of Etueffont leachates was overall efficient in removing valuable amounts of organic loads and microbial populations. The protozoan community optimized this performance. The changes in bacterial abundance were linked to the amount of available inorganic and organic elements, to temperature and grazing by protozoa. Viral lysis might also have decreased bacterial numbers [70]. The treated effluent, whose quality is of good, may be discharged, with no risk, to the receiving river after lagooning.

REFERENCES

1. Silva A.C., Dezotti M. and Sant'Anna G.L., Treatment and detoxification of a sanitary landfill leachate. *Chemosphere*, **55**, 207–214 (2004).
2. Vrijheid M., Dolk H. and Armstrong B., Hazard potential ranking of hazardous waste landfill sites and risk of congenital anomalies. *Occup. Environ. Med.*, **59**, 768–776 (2002).
3. Kabata-Pendias A. and Pendias H., *Trace Elements in Soils and Plants*. CRC Press LLC, Boca Raton, Florida, USA (2001).
4. Schwarzbauer J., Heim S., Brinker S. and Littke R., Occurrence and alteration of organic contaminants in seepage and leakage water from a waste deposit landfill. *Water Res.*, **36**, 2275–2287 (2002).
5. Radha R., Tripathi R.M., Vinod K.A., Sathe A.P., Khandekar R.N. and Nambi K.S.V., Assessment of Pb, Cd, Cu, and Zn exposures of 6- to 10-year-old children in Mumbai. *Environ. Res.*, **80**, 215–221 (1997).

6. Omura M., Inamasu T. and Ishinishi N., Mutagenicity assays of leachate from domestic waste landfills in Japan: the establishment of a protocol for measuring levels of leachate. *Bull. Environ. Contam. Toxicol.*, **46**, 561–568 (1991).
7. Thacker S.B., Hoffman A., Steinberg K., Zack M. and Smith J., Effect of low-level body burdens of lead on the mental development of children: limitations of metal-analysis in a review of longitudinal data. *Arch. Environ. Health.*, **47**, 336–347 (1992).
8. Baccini G., Henseler R., Figi H. and Belevi A., Water and element balances of municipal solid waste landfills. *Waste Manage. Res.*, **5**, 483–499 (1987).
9. Blaky N.C., Model prediction of landfill leachate production. *Elsevier Applied Sciience London*, England, 17–34 (1992).
10. Bookter T.J.B. and Ham R., Decomposition of solid waste in test lysimeters. *J. Environ. Engin. Div.*, ASSCE. **108**, 1147–1170 (1982).
11. Kjeldsen P., Barlaz M.A., Rooker A.P., Baun A., Ledin A. and Christensen T.H., Present and long term composition of MSW landfill leachate. *Crit. Rev. Environ. Sci. Technol.*, **32**, 297–336 (2001).
12. Christensen T.H., Kjeldsen P., Bjerg P.L., Jensen D.L., Christensen J.B., Baun A., Albrechtsen H.J. and Heron G., Biogeochemistry of landfill leachate plumes. *Appl. Geochemistry*, **16**, 659–718 (2001).
13. Rodier J., *L'analyse de l'Eau*. 7ème édition Dunod, Paris (1984).
14. Eisenreich S., Schottler S. and Hines N., Standard Operating Procedure for Isolation, Extraction and Analysis of Atrazine. DEA and DIA, Dep. Environ. Sci., Rutgers Univ., New Jersey, USA 245–251 (1994).
15. Rodier J., *L'analyse de l'Eau: Eaux Naturelles, Eaux Résiduaires, Eaux de Mer*. 8ème édition Dunod, Paris (1996).
1. Porter K.G. and Feig Y.S., The use of DAPI for identifying and counting aquatic microflora. *Limnol. Oceanogr.*, **25**, 943–948 (1980).
17. Marvalin O., Aleya L., Hartmann H.J. and Lazarek S., Coupling of the seasonal patterns of bacterioplankton and phytoplankton in a eutrophic lake. *Can. J. Microbiol.*, **35**, 706–712 (1989).
18. Overbeck J.,Microbiology and biochemistry. *Mih. Int. Verein. Limnol.*, **20**, 198–228 (1974.).
19. Gifford D.J. and Caron D.A., Sampling, preservation, enumeration and biomass of marine protozooplankton. In: Harris R.P., Wiebe P.H., Lenz J., Skjoldal H.R. and Huntley M., Editors, *ICES Zooplankton Methodology Manual*, Academic Press, London 193–221 (2000).
20. Sime-Ngando T., Hartmann H.J. and Groliere C.A., Rapid quantification of Planktonic Ciliates: comparison of improved live counting with other methods. *Appl. Environ. Microbiol.* **56** 2234–2242 (1990).
21. Madoni P., I protozoi ciliati nel controllo di efficienza dei fanghi attivi. 82 pp. Centro Italiano Studi di Biologia Ambientale, Reggio Emilia (1988).
1. Utermöhl H., Zur Vervollkommung der quantitative Phytoplankton-Methodik. Mitt. *Int. Ver. Limnol.*, **9**, 1–38 (1958).
23. Legendre L. and Watt W.D., On rapid technic for plankton enumeration. *Ann. Inst. Oceanogr.*, Paris WLVIII, 173–177 (1971-1972).
24. Bourrelly P., *Les Aalgues d'Eau Douce, les Algues Bleues et Rouges*, , Boubée et Cie, Paris, France pp 606 (1985).
25. Chian E.S.K. and DeWalle F.B., Characterization of soluble organic matter in leachate. *Environ. Sci. Technol.*, **11**, 158–163 (1977).
26. Tatsi A.A. and Zouboulis A.I., A field investigation of the quantity and quality of leachate from a municipal solid waste landfill in a Mediterranean climate (Thessaloniki, Greece*). Adv. Environ. Res.*, **6**, 207–219 (2002).
27. Ehrig A., Beitrag zum quantitativen und qualitativen Wasserhaushalt von Mûlldeponien. *Verôffentlichungen des institut fûr Stadtbauwesen*, Technischen Universitât Braunschweig, Germany (1978).
28. Navarro A., Bernard D. and Millot N., Les problèmes de pollution par les lixiviats de décharges. *Tivoli Storage Manager J.*, **3**, 541–545 (1988).
29. Harmsen J., Identification of organic compounds in leachate from a waste tip. *Water Res.*, **17**, 699–705 (1983).
30. Weiss M., Abbt-Braun G. and Frimmel F.H., Humic-like substances from landfill leachates-characterization and comparison with terrestrial and aquatic humic substances. *Sci. Total Environ.*, **81/82**, 343–352 (1989).
31. Khattabi H., Lotfi A. and Mania J., Evolution temporelle de la composition du lixiviat d'une décharge à ciel ouvert: effet des précipitations. *Dechets-Sciences et Techniques*, **21**, 7–10 (2001).
32. Barkowski D., Gunther P. and Rochert R., *Atlasten*., Edition C.F. Muller, Karlsruhe, Germany pp 87–93 (1987).
33. Albright L.J. and MacCrae S.K., Annual cycle of bacterial specific biovolumes in Howe sound, a Canadian West Coast Fjord Sound. *Appl. Environ. Microbiol.*, **12**, 2739–2744 (1987).
34. Carrias J.F., La boucle microbienne en milieu lacustre: structure et fonctionnement des communautés picoplanctoniques et des protistes flagellés et ciliés. *Thèse de doctorat de 3ème Cycle*, Université de Blaise Pascal, France, Clement - Ferrand (1996).
1. Jordan M.J. and Likens G.E., Measurement of planktonic bacterial production in an oligotrophic lake. *Limnol. Oceanogr.*, **25**, 719–732 (1980).
36. Krstulovic N., Pucher-Petrovic T. and Solic M., The relation between bacterioplankton and phytoplankton production in the mid adriatic sea. *Aquat. Microb. Ecol.*, **9**, 41–45 (1995).

37. Nagata T., The microflagellate-picoplankton food linkage in the water column of lake Biwa. *Limnol. Oceanogr.*, **33**, 504–517 (1988).
38. Ochs C.A., Cole J.J. and Likens G.E., Population dynamics of bacterioplankton in an oligotrophic lake. *J. Plankton Res.*, **17**, 365–391 (1995).
39. Scavia D. and Laird G.A., Bacterioplankton in lake Michigan: dynamics, controls, and significance to carbon flux. *Limnol. Oceanogr.*, **32**, 1017–1033 (1987).
40. Clement B., Persoone G., Janssen C. and Le Dù-Delpierre A., Estimation of the hazard of landfills through toxicity testing of leachates. *Chemosphere*, **11**, 2203–2320 (1996).
41. Deneuvy J.P., Les lixiviats de décharges, approche méthodologique de leur toxicité aiguë en fonction des différents modes de traitement. *Thèse de 3ème cycle*, INSA Lyon, France (1987).
42. Devare M. and Bahadir M., Biological monitoring of landfill leachate using plants and luminescent bacteria. *Chemosphere*, **28**, 261–271 (1994).
43. Ernst W.R.P., Hennigar K., Doe S., Wade H. and Julien G., Characterization of the chemical constituents and toxicity to aquatic organisms of a municipal landfill leachate. *Water Poll. Res. J. Can.*, **29**, 89–101 (1994).
44. Ferrari B., Radetski C.M., Veber A.M. and Ferard J.F., Ecotoxicological assessment of solid wastes: a combined liquid- and solid-phase testing approach using a battery of bioassays and biomarkers. *Environ. Toxicol. Chem.*, **18**, 1195–1202 (1999).
45. Marnie L., Ward G., Bitton T., Townsend T. and Booth M., Determining toxicity of leachates from Florida municipal solid waste landfills using a battery-of-tests approach. *Environ. Toxicol.*, **17**, 258-266 (2002).
46. Plotkin S. and Ram N.M., Multiple bioassays to assess the toxicity of a sanitary landfill leachate. *Arch. Environ. Contam. Toxicol.*, **13**, 197–206 (1984).
47. Brown S.L., Landry M.R., Christensen S., Garrison D., Gowing M.M., Bidigare R.R. and Campbell L., Microbial community dynamics and taxon-specific phytoplankton production in the Arabian Sea during the 1995 monsoon seasons. *Deep Sea Res.* **49,** 2345–2376 (2002).
48. Stoecker D.K., Mixotrophy in marine planktonic ciliates: physiological and ecological aspects of plastid-retention by oligotrichs. In: Reid P.C., Turley C.M. and Burkill P.H., Editors, *Protozoa and their Role in Marine Processes NATO Adv. Sci. Inst.* vol. G25, Springer, Berlin, pp. 161–179 (1991).
49. Thouvenot A., Richardot M., Debroas D. and Devaux J., Bacterivory of metazooplankton, ciliates and flagellates in a newly-flooded reservoir. *J. Plankton Res***., 21,** 1659–1679 (1999).
1. Aleya L., Hartmann H.J. and Devaux J., Evidence for the contribution of ciliates to denitrification in a eutrophic lake. *Europ. J. Protistol.*, **28**, 316–321 (1992).
51. Curds C.R. and Hawkes H.A., Biological activities and treatment processes. In: *Ecological Aspects of Used-Water Treatment*, Academic Press, London, Chapter 2 (1983).
52. Salvado H., Gracia M.P. and Amigo J.M., Capability of ciliated protozoa as indicators of effluent quality in activated sludge plants. *Water Res.*, **29**, 1041–1050 (1995).
53. Gintautas P.A., Daniel S.R. and Macalady D.L., Phenoxyalkanoic acid herbicides in municipal landfill leachates. *Environ. Sci. Technol.*, **26**, 517–521 (1992).
54. Lyngkilde J. and Christensen T.H., Redox zones of landfill leachate pollution plume (Vejen, Danemark). *J. Contam. Hydrol.*, **10**, 273–289 (1992).
55. Schultz B. and Kjeldsen P., Screening of organic matter in leachates from sanitary landfills using gas chromatography combined with mass spectrometry. *Water Res.*, **20**, 965–970 (1986).
56. Muhammad N., Parr J., Smith M.D. and Wheatley A.D., Adsorption of heavy metals in slow sand filters. Sanitation and water for all. In: *24th WEDC Conference*, Islamabad, Pakistan, Kaylani Editor, Pakistan pp 346–349 (1998).
57. Mæhlum T., Warner W.S., Stalnacke P. and Jenssen P.D., Leachate treatment in extended aeration lagoons and constructed wetlands in Norway. In: Mulamoottil G., McBean E.A. and Rovers F., Editors, *Constructed Wetlands for the Treatment of Landfill Leachates*, Lewis Publishers, Boca Raton, FL, USA 151–163 (1999).
1. Pohland F.G., Harper S.R., Chang K.C., Dertien J.T. and Chian E.S.K., Leachate generation and control of landfill disposal sites. *Water Pollut. Res. J. Can.*, **3**, 10–25 (1985).
59. Kargi F. and Yunus Pamukoglu M., Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation. *Biores. Tech.*, **94 (3)**, 285–291 (2004).
60. Aleya L., Devaux J. and Marvalin O., Primary production and bacterial heterotrophic activity potential in a eutrophic lake (Lake Aydat, Puy-de-Dôme, France). *Rev. Sci. Eau.*, **1**, 23–35 (1988).
61. Feuillade M., Dufour P. and Feuillade J., Organic carbon release by phytoplankton and bacterial reassimilation. *Schweiz. Z. Hydrol.*, **50**, 115–135 (1988).
62. Riemann B. and Sondergaard M., Carbon Dynamics in Eutrophic Temperate Lakes. Elsevier, Amsterdam pp 284 (1986).
63. Shuval H.I., Adin A., Fattal B., Rawitz E. and Yekutiel P., Wastewater irrigation in developing countries: Health effects and technical solutions. *World Bank Technical Paper*, No. **51**, World Bank, Washington D.C. (1986).

64. Tuxen N., Peter L., Tüchsen P.L., Rügge K., Albrechtsen H.J. and Bjerg P.L., Fate of seven pesticides in an aerobic aquifer studied in column experiments. *Chemosphere*, **41**, 1485–1494 (2000).
65. Boon M., Snijder M., Hansford G.S. and Heijnen J.J., The oxidation kinetics of zinc sulphide with *Thiobacillus ferrooxidans*. *Hydrometallurgy*, **33**, 137–152 (1998).
66. Fowler T.A. and Crundwell F.K., Leaching of zinc sulfide by *Thiobacillus ferrooxidans*: Experiments with a controlled redox potential indicate no direct bacterial mechanism. *Appl. Environ. Microbiol.*, **64**, 3570–3575 (1998).
67. Lovley D.R., Dissimilatory Fe(II) and Mn(IV) reduction. *Microbiol. Rev.*, **55**, 59–28 (1991).
68. Shen H., Pritchard P.H. and Sewell G.W., Microbial reduction of Cr(VI) during anaerobic degradation of benzoate. *Environ. Sci. Technol.*, **30**, 1667–1674 (1996).
69. Mæhlum T., Treatment of landfill leachate in on–site lagoons and constructed wetlands. *Water Sci. TechNOL.*, **32**, 129–135 (1995).
70. Fuhrman J. and Noble R.T., Viruses and protests cause similar bacterial mortality in coastal seawater. *Limnol. Oceanogr.*, **40**, 1236–1242 (1995).