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Assessment of Biological Treatment of Odorous Gas using a Bacterial Consortium (*Bacillus* and *Pseudomonas)* to Deodorize Landfill Leachate

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Leachate accumulation is a major concern for municipal solid waste (MSW) landfills as it causes potential harm to public health and poses a significant threat to surface water and local groundwater systems. This article presents the results of analyses on malodorous treatment at the solid waste landfill located in Casablanca, Morocco, using bio-deodorization as a pre-treatment technology. The main goal of this study is to remove odorous gases from landfill leachate. Microbial strains of *Bacillus* and *Pseudomonas* were seeded in a leachate pond to treat the odorous emissions from landfill leachate and consequently improve environmental quality and human health. After 28 days of seeding, the results showed that the addition of *Bacillus* and *Pseudomonas* greatly reduced the concentration of chemical oxygen demand (COD), biological oxygen demand (BOD_5) and the ionic concentration of NH_4^+ to approximately 27.928 mg/L, 11550.3 mg/L and 1533 mg/L, respectively, with lower energy consumption, resulting in an average overall operational cost of 53.97 USD/m^3. In addition, a significant reduction in total nitrogen (32.80%), nitrites (NO_2^-) (99.82%), nitrates (NO_3^-) (46.81%) and total phosphorus (49.50%) concentrations was also achieved at a post-treatment environmental pH of 8.5. These findings extend the field of application of biological deodorization and provide new insights into malodorous treatment methods.

Keywords: Bio-deodorization, Health risk-reducing, Landfill leachate, Low-cost, Odorous flavour attenuation.

INTRODUCTION

Landfilling is one of the oldest and most widely used methods for municipal solid waste management due to its low cost and capacity to handle large waste volumes, alongside high-temperature composting and incineration [1-3]. However, it releases harmful volatile organic compounds (VOCs), posing risks to public health and community well-being [4,5]. Moreover, leachate can contain high levels of organic and inorganic compounds, as well as significant metal content. Before being discharged into natural waterways, leachates must undergo treatment to remove organic matter based on COD, BOD and ammonium levels [6].

The leachates are classified as waste degradation products, moisture in refuse and liquid effluents produced by rainwater percolating through landfill waste [7-9]. The leachate composition from the transfer station can vary depending on several factors, including the degree of compaction, waste composition, climate and moisture content in waste [10], landfill technology and the age of the landfill [11]. Leachate generally has high COD, pH, ammonia nitrogen and heavy metal values, as well as a powerful colour and disagreeable odor. In addition, the characteristics of the leachate vary from year to year depending on its volume, composition and amount of biodegradeable material [12,13]. All these factors make the treatment of malodorous leachate difficult and complex. As a general rule, leachate can be divided into three types depending on the age of the landfill: young (0-5 years), medium (5-10 years) and old (>10 years) [14]. Leachate composition studies have detected over 400 components, many of which have not yet been identified [15]. The most common components are ammonia nitrogen, chlorides, sulfates, heavy metals, humic acids, dioxins and furans [16-18].

A wide range of treatment methods are currently utilized by researchers to manage landfill leachate, including biological approaches and physico-chemical techniques such as flotation [19], coagulation/flocculation [20], adsorption [21,22], chemical oxidation [23,24], electrochemical processes [24], ion-exchange and advanced membrane filtration systems like microfiltration, ultrafiltration and reverse osmosis. Among these methods, microbial deodorizers are considered more suitable for waste treatment projects, such as transfer stations and landfill sites, due to their ease of use, excellent effect, low operating cost and the absence of secondary pollution [25-27].

In this research, a deodorant experiment and an application test in a refuse transfer station are conducted to assess the deodorization effect of a microbial compound, serving as a reference and basis for the practical application of this microbial deodorizer. This study aims to explore the biological treatment of odorous gases using a microbial consortium of *Bacillus* and *Pseudomonas* as a sustainable alternative to conventional physico-chemical methods. Furthermore, it investigates the bio-deodorization mechanisms involved in treating high concentration waste gases through this biological approach. The results of this study will be of great importance for the reduction of health risks associated with odors and for the development of a new biological deodorization technology.

EXPERIMENTAL

Study site: The Mejjadra Ouled Taleb landfill is located in Casablanca, Morocco. This site covers a surface of about 35 ha, it has been in operation since 1986 and receives approximately 3700 T/day of solid waste. The landfill of Mejjatia Ouled Taleb receives household and similar waste as well as green waste coming from the towns and centres belonging to the Prefectures of Casablanca. It is accessible *via* the regional road RR315, which passes about 600 m from the main portal of the site, at the average Lambert coordinates of the site X: 301 000 and Y: 322 500 (Fig. 1). The waste delivered to the landfill is collected on the platform and sorted so that recyclable materials can be recovered. After that bentonite geomembranes separate the waste in the alveoli. Gravitation was used to collect the produced leachates and transport them to the treatment facility. The climate of the site is of the temperate oceanic type with an annual rainfall of 243.8 mm, the temperature is moderate, with an annual average of 18 ºC up to a maximum of 40 ºC in summer or down to a minimum of 2 ºC in winter, with a high atmospheric humidity of 76%.

Leachate sampling and characterization: The raw leachate samples were collected from the leachate storage pond. The samples were taken in sterile bottles with labels, indicating the basin and date of collection and saved at a temperature below 4 ºC. The leachate was characterized by several parameters, including the conductivity (EC) was identified by a CD-2005 conductivity meter, the pH was measured using a pH-2006 meter, the chemical oxygen demand (COD) was determined by the spectrophotometer (direct reading spectrophotometer DR/2000) according to the closed-back colorimetric method (5220-B), the biochemical oxygen demand in 5 days (BOD_5) was tested by the standard method (5210), the NH_4^+-N and titrimetry concentrations were measured by distillation using 4500-NH_3 B and 4500-NH_3 C, respectively and the NO_3-N concentration was determined using the Devarda's alloy reduction method, as described by APHA [28].

Source and preparation of bacterial inoculum: The bacterial strains used in this study included *B. subtilis* and *P. fluorescens*, obtained from the culture collection of Microbiology Laboratory at the Institute Pasteur of Morocco. The strains were cultured in nutrient broth (for *Bacillus*) and King's B medium (for *Pseudomonas*) and incubated at 28 ± 2 ºC for 24 to 48 h. The cultures were then centrifuged at 6000 rpm for 10 min and the bacterial pellets were resuspended in sterile distilled water.

Experimental methodology: A schematic representation of the operating protocol for the bio-deodorization process is

Fig. 1. Location of the Casablanca landfill

detailed in Fig. 2. In the first phase of the process, an aeration tank with a capacity of 100 m^3 was created with an aeration system composed of a microbull diffuser with a VERTEX effect of 5 discs with an average unit capacity of 32 L/min, the disk that works with a box containing 2 pistons of the THOMAS brand with a unit power of 300 W and a flow rate of 158 L/min. The diffuser, installed at the bottom of the basin, is connected to the box by pipes of dimensions 16 × 24 diam/mm, with a length of 50 m and a pressure of 20 bar, its objective is to ensure the supply of oxygen (concentration of dissolved O_2 in the tank will be 7 mg/L) necessary for the proper functioning of microorganisms. An injection of a water-soluble allows the homogenization of all the leachate of the basin to have the same quality at the bottom, on the surface of the basin, as well as in the corners. During the second phase of aeration (after 10 days), the microorganisms contained in the bacterial consortium at a dose of 15 mL/m^3 were diluted in 50% of additional water volume, then seeding (addition of the bacterial consortium was approved and subsequently the degradation of the organic matter in the leachate started. The physico-chemical analyses were performed on leachate samples that had been cleaned after the addition of the bacterial complex. The tests were conducted from the aeration tank before (E), at the start (E_0) and after the addition of the bacterial complex during 3 (E_0 + D3), 10 (E_0 + D10) and 28 (E_0 + D28) days of stocking, following the protocol below.

Effectiveness analysis: The effectiveness of the bacterial consortium leachate odour treatment method at the Casablanca landfill was assessed using the removal of COD, BOD_5, suspended solids, total nitrogen, ammonium, nitrites, nitrates and total phosphorus.

Percent removal: The removal of the studied parameters from leachate was calculated based on eqn. 1 [29]:

$$\text{Removal (\%)} = \frac{C_i - C_f}{C_i} \times 100 \qquad (1)$$

where, C_i and C_f are the initial and final concentrations of the respective parameters.

Power consumption: The average cost of treating odorous gases from landfill leachate (\$/m^3) at the laboratory scale was estimated based on the cost of the energy amount consumption (E), the prices of electrical energy (P_e) (\$/KWh) and time (t). Labor costs, material costs and additional costs were not considered. The average cost per m^3 was calculated by using eqn. 2:

$$\text{Cost (\$/m}^3) = E \times P_e = P \times t \times Pe \qquad (2)$$

where E: energy consumed in kwh; P: piston power in KW; t: time in h; Pe: price of KWh/m^3.

For the Moroccan market, in 2023, the price of electrical energy for the industrial sector was 0.13 \$/kWh, for a monthly consumption between 301 and 500 kWh. In case of a box of two pistons with a power of 300 W each, the electricity consumption for 10 days is 144 kWh. Then, the monthly electricity price of 432 kWh was 56.16 \$/m^3. As a result, the energy consumption for pre-treatment of leachate for 10 days was 1.44 KWh/m^3 with a price around 0.19 \$/m^3. In comparison to the 50-day treatment study using a combination of the two methods [30], the performance of the submerged membrane electrobioreactor (SMEBR) and submerged membrane bioreactor (SMBR), the energy consumption was of the order of 0.414 kWh/m^3 with a price of 0.31 \$/m^3. The odour pre-treatment process proved to be both innovative and energy-efficient, with lower energy consumption than comparable biological methods reported in the literature.

RESULTS AND DISCUSSION

Characterization of leachate from the Casablanca landfill: Leachate characterization is necessary for the design of leachate treatment methods. Table-1 summarizes the main characteristics of raw leachate and their limit values for the

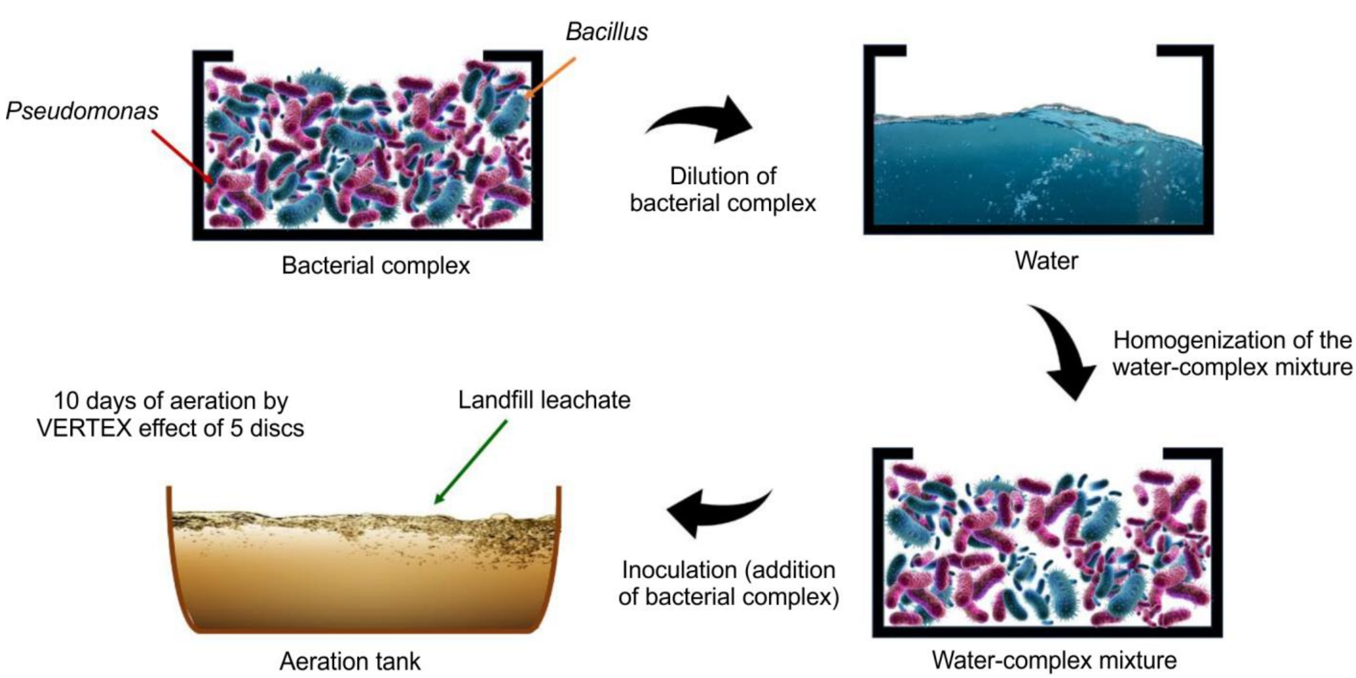

Fig. 2. Schematic representation of operating protocol of the bio-deodorization

TABLE-1
CHARACTERISTICS OF RAW LANDFILL LEACHATE

Parameters	Values	Limit values for the discharge of treated leachate surface waters
Temperature (°C)	23	23
pH	6.34	5.5-8.5
EC (µS/cm)	53600	2700
COD (mg/L)	69560	120
BOD_5 (mg/L)	10500	40
DCO/DBO_5	6,6	6.6
SS (mg/L)	5420	30
N (Total) (mg/L)	1250	1250
NH_4^+ (mg/L)	4981.14	40
NO_2^- (mg/L)	1.65	<1
NO_3^- (mg/L)	2.35	<1
P (Total) (mg/L)	60.47	2

discharge of treated leachate surface waters in Morocco. The Casablanca leachate has an acid pH (6.34), loaded with organic matter, while the values of COD and BOD_5 are respectively around 69560 mg/L and 10500 mg/L. These values are very high and exceed Moroccan standards, which are fixed at 120 mg/L for COD and 40 mg/L for BOD_5. The BOD_5/COD ratio is 0.15, which is greater than 0.1, characterizing the older or stabilized leachates, reflecting that these leachates are weakly biodegradable [31]. A significant electrical conductivity (EC) of leachates is detected around 53 600 µS/m, since the site receives standard industrial and agri-food waste. The concentration of suspended solids (SS) is achieved at 5420 mg/L, which is due to the presence of the high organic and mineral load, relating to the nature of the waste. The nitrate content (NO_3^-) is relatively high at 2.35 mg/L, which may be due to nitrification. This involves a series of reactions by nitro- and nitrate bacteria, as follows:

$$\text{Nitritation: } 4NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ \quad (3)$$

$$\text{Nitratation: } 2NO_2^- + O_2 \rightarrow 2NO_3^- \quad (4)$$

Effect of bio-deodorization process on pH: The fluctuation in the pH of leachate during the different stages of its treatment by bio-deodorization is shown in Fig. 3. The results demonstrated that the bacterial consortium influenced the pH of the environment. The leachate pH values vary between 6.34 and 8.5 in 28 days. It can be concluded that the increase in leachate pH after treatment is probably due to the consumption of acidic organic molecules, mainly volatile fatty acids (VFAs) by aerobic microorganisms [32]. The aeration of the leachate allows the CO_2 to be released through microbial activity, in which the CO_2 reacts with water to produce the bicarbonate ion HCO_3^-, buffering the pH towards neutrality [33,34]. The high pH value at 28 days (pH = 8.5) suggests the involvement of CO_3^{2-} carbonates or organic bases in the pH increase. Moreover, the denitrification reaction observed during aeration may contribute to the increase in pH through the consumption of proton [33].

BOD_5 and COD removal by bio-deodorization process: The COD and BOD_5 are used to assess the pollutant load in the leachate and to check their evolution after treatment. Fig. 4 shows the effect of the bacterial consortium on the leachate deodorization from the waste received in the Casablanca landfill. A significant and regular decrease in leachate COD was

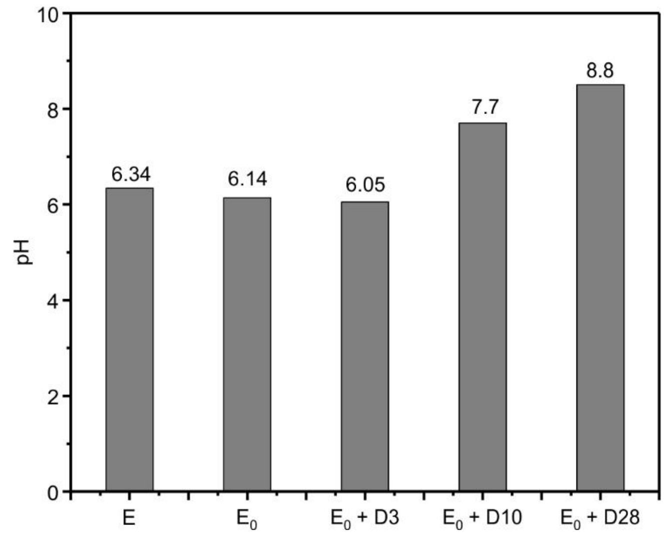

Fig. 3. Effect of the bio-deodorization process on pH

recorded for the first three days from 42172 mg/L to 39453.2 ± 18920 mg/L and then reducing to 35245.6 ± 15600 and 27928 ± 10232 mg/L on days 10 and 28, respectively (Fig. 4a and c). The BOD_5 of leachates was very high at the start of treatment at 14251 mg/L, over the first three days, it decreased sharply to 9340 mg/L and then stabilized around 10349.7 mg/L for 10 days until the 28 days when it returned to 11550.75 mg/L (Figs. 4b and 4d). The reduction in BOD_5 of 34% for E_0 + D3, 27% for E_0 + D10 and 19% for E_0 + D28 shows that the bacterial complex, accompanied by aeration, resulted in the degradation of organic matter. A decrease in the COD/BOD_5 ratio was reported after treatment with the bacterial complex, indicating an improvement in the biodegradability of the treated effluent. The reduction in COD and BOD_5 in pre-treated leachates demonstrates the positive and significant effect of the Exoliviat process on controlling organic matter pollution. The removal of COD (33%) and BOD_5 (19%) at 28 days is impressive in comparison with the results measured during an intensive 2-months aeration treatment of leachates from the Greater Agadir controlled landfill (99.3% for COD and 99.1% for BOD_5) [35]. This considerable decrease shows that the amount of oxygen injected is probably sufficient for the activation of complex aerobic microorganisms consuming organic matter [32-35].

Total nitrogen, ammonium, nitrites, nitrates and total phosphorus removal by bio-deodorization process: The monitoring of nitrogen, ammonium, nitrite, nitrate and total phosphorus in case of VERTEX microbull aeration systems for dissolved oxygen supply and a complex of microorganisms is shown in Fig. 5. The total nitrogen in the leachate reached 1355 mg/L at the start of the addition of bacterial complex, 1023 ± 576 mg/L after three days, 934.7 ± 320 mg/L for 10 days and 840 ± 301 mg/L for 28 days (Fig. 5a). This reduction in total nitrogen content was significant, with a 17.9% reduction in the concentration of total nitrogen.

The leachate prior to the addition of the bacterial consortium was heavily loaded with ammonium (NH_4^+) of around 4861.23 mg/L (Fig. 5b). From the third day, the ammonium content decreased from 2205 ± 756 mg/L to 1533 ± 892 mg/L, reflecting the transformation of ammonium in the presence of

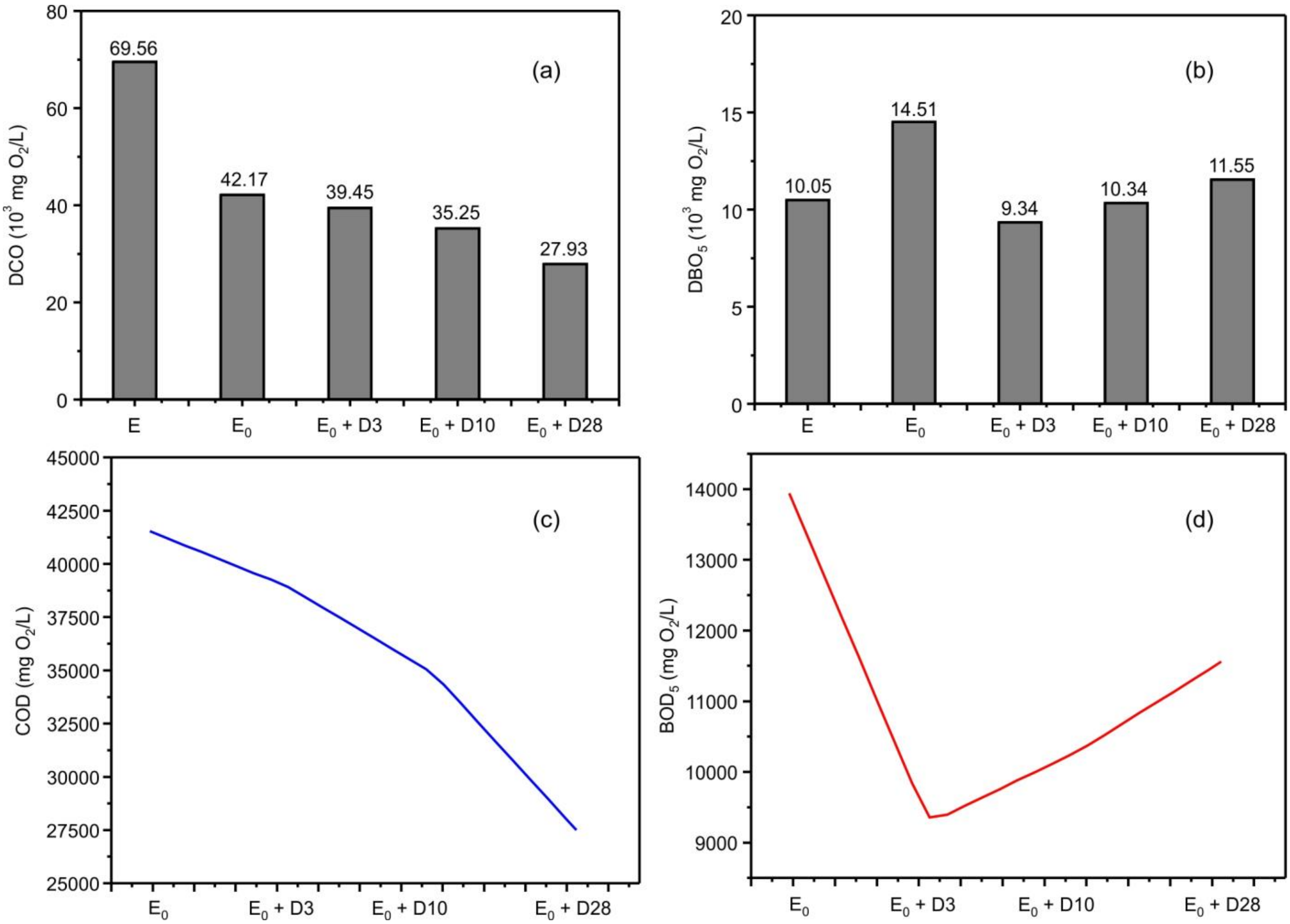

Fig. 4. Effect of the bio-deodorization process on (a and c) COD and (b and d) BOD_5

oxygen (oxidation) to nitrite (NO_2^-). The efficiency of NH_4^+ oxidation (nitrification) increased gradually with increasing duration of aeration and seeding with the bacterial consortium and the removal rate is as high as 62.22% after the 28 days. The reduction (denitrification) of NO_2^- or NO_3^- is significantly influenced by the duration of rearing and seeding. This reaction is performed by chemolithotrophic, autotrophic (strict aerobic) bacteria such as *Bacillus* and *Pseudomonas* [36]. The equation of this process is as follows:

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+ \quad (5)$$

Nitrites and nitrates initially appeared, respectively, at 0.062 mg/L and 4.03 mg/L in leachates and began to decrease throughout the period until they reached 0.003 ± 0.85 mg/L for nitrites and 1.25 ± 0.75 mg/L for nitrates (Fig. 5c-d). This decrease can be explained by the nitrification of nitrites *via* aerobic bacteria, reducing to organic nitrogen (N-Org). The concentration of ammonium (NH_4^+), nitrites (NO_2^-) and nitrates (NO_3^-) has decreased due to the transformation of organic nitrogen into volatile nitrogen elements (NH_3, N_2, *etc*.) that are harmless to the environment. The hypothesis that NH_4^+ is transformed into ammonia NH_3 and then into organic nitrogen is verified by the fact that in a basic environment [37], OH^- ions react with ammonium to produce ammonia. Nitrogen is generated by bacterial digestion and recovered as gas in the final composition of the sludge (fertilizing power).

The reduction of total nitrogen by biodegradation is well documented in the literature and numerous studies indicate that microbial systems can reduce total nitrogen in effluents [38,39] observed a similar reduction in total nitrogen (around 20%) in biological systems using bacteria such as *Pseudomonas* and *Bacillus* for wastewater treatment applications. However, efficiency largely depends on operating conditions, such as dissolved oxygen concentration, temperature and pH. For the mechanism involved in total nitrogen reduction can result from several biological processes, including nitrification and denitrification. Nitrification converts ammonium (NH_4^+) into nitrite (NO_2^-), then nitrate (NO_3^-), while denitrification transforms nitrate into nitrogen gas (N_2), which is released into the atmosphere. Bacteria such as *Bacillus* and *Pseudomonas* are mainly responsible for carrying out nitrification and denitrification.

At the beginning of experiment, the ammonium concentration was very high (4861.23 mg/L). After 28 days, the reduction in ammonium was 62.22%, with a significant decrease by day three, indicating effective oxidation of NH_4^+ to NO_2^- in the presence of oxygen. This process is known as nitrification. Previous research [40] has shown that *Bacillus* and *Pseudomonas* are particularly effective in nitrifying NH_4^+ in water treatment systems. For example, *Pseudomonas* has been described as an actor in nitrification in aeration systems and reduction of 50 to 70% of NH_4^+ have been observed under

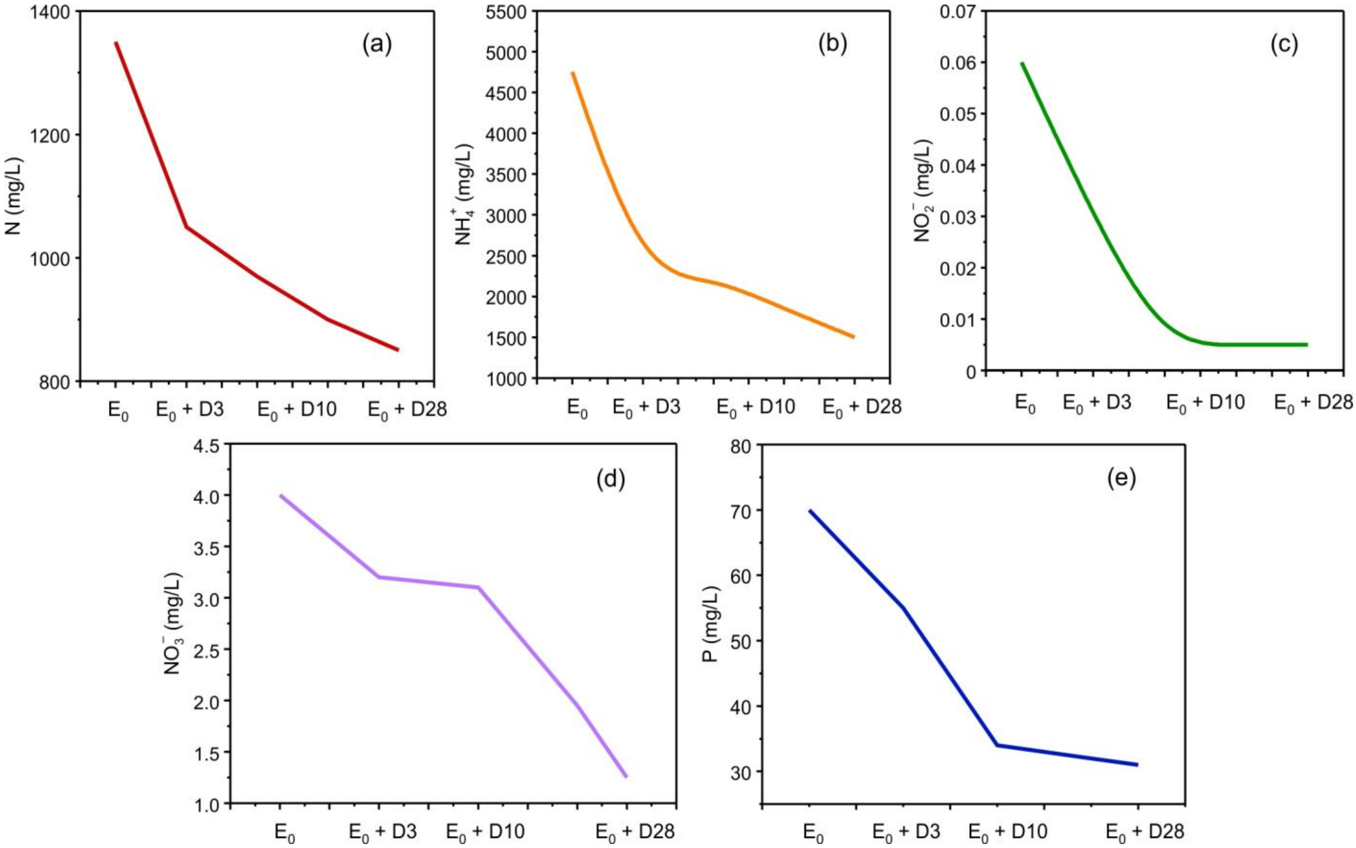

Fig. 5. Treatment process effect on (a) Total nitrogen, (b) NH_4^+, (c) NO_2^-, (d) NO_3^- and (e) total P

optimal aeration conditions. Nitrification is a biochemical process carried out by autotrophic bacteria such as *Bacillus* and *Pseudomonas*, which use oxygen to convert ammonium into nitrite and nitrate. The first step of nitrification, catalyzed by bacteria such as *Nitrosomonas* (or strains of *Pseudomonas*), transforms NH_4^+ into NO_2^-. The NO_2^- is then oxidized to NO_3^- by bacteria such as *Nitrobacter* or other strains of *Pseudomonas*.

Denitrification is influenced by the duration of aeration and inoculation with the bacterial complex. This shows that the presence of denitrifying bacteria, such as *Bacillus* and *Pseudomonas*, plays a key role in reducing NO_2^- and NO_3^- to gaseous nitrogen (N_2), thus reducing the nitrogen concentration in the leachate. Zhang *et al.* [41], observed denitrification rates greater than 60% in systems using *Pseudomonas* strains under aerobic and anoxic conditions. *Bacillus* is also involved in this process, especially in environments where oxygen availability fluctuates.

A study conducted by John *et al.* [42] demonstrates that the residual ammonia concentration in the tanks treated with the microbial consortium (4.8 ± 0.068 μM L^{-1}) was consistently lower than that in the control tanks without bacteria (7.29 ± 0.292 μM L^{-1}). Furthermore, the treatment tanks showed higher residual concentrations of nitrite (6.9 ± 0.59 μM L^{-1}) and nitrate (4.16 ± 0.58 μM L^{-1}) compared to the control tanks (0.28 ± 0.201 and 0.394 ± 0.964 μM L^{-1}, respectively). This indicates the effectiveness of complex in converting ammonia to nitrite and subsequently to the less toxic nitrate form. Notably, these levels never reached toxic thresholds in the treatment tanks, which maintained a high survival rate of 97.2 ± 0.58%. In contrast, the control tanks experienced significant fish mortality due to ammonia toxicity (55 ± 0.25%). This study demonstrates that the microbial composed of *B. amyloliquefaciens*, *B. cereus* and *P. stutzeri* is effective in reducing ammonia, nitrite and nitrate in aquaculture wastewater, making it a promising bioaugmentation agent for mitigating environmental concerns and enabling water reuse in aquaculture systems before discharge into open water.

Total phosphorus was present in leachates at an initial concentration of 70.47 mg/L (Fig. 5d). A reduction over the treatment is observed around 55.63 ± 6.2 mg/L for E_0 + D3, 34.14 ± 3.12 mg/L for E_0 + D10 and 30.54 ± 3.02 mg/L for E_0 + D28. This decrease may be due to the consumption of phosphorus by aerobic microorganisms, which appreciate it in their skeleton in the form of PO_4. These results are in agreement with several recent studies demonstrating the effectiveness of these bacterial types in phosphorus bioremediation. Zhou *et al.* [43] showed that *Pseudomonas* fluorescens can remove more than 50% of inorganic phosphorus in less than 10 days in an aerobic system. Similarly, Brown *et al.* [44] observed a significant decrease in phosphorus in *B. subtilis* enriched activated systems, with an elimination efficiency of up to 60-70%. Potential mechanisms by which these microorganisms act on phosphorus include polyphosphate accumulator bacteria (PAOs), *Pseudomonas* spp., store phosphorus in the form of intracellular polyphosphate granules. This process results in a significant reduction of dissolved phosphorus in the medium [45] or a *Bacillus* cells produce extracellular polymeric substances (EPS) that facilitate the passive adsorption of phosphorus to the cell surface or into the biofilm matrix [46]. Phosphorus can be trapped either temporarily or permanently through microbially mediated processes. Certain *Bacillus* species facilitate biologically induced chemical precipitation by increasing the local pH through the production of ammonia (NH_3) or hydroxide ions (OH^-), thereby promoting the formation of insoluble phosphate salts such as calcium phosphate [47]. Furthermore, both *Bacillus* and *Pseudomonas* genera are known to produce phosphatase enzymes (acidic and alkaline), which catalyze the hydrolysis of organophosphorus compounds, releasing inorganic phosphate (PO_4^{3-}) that can subsequently be assimilated by microbial cells [48]. The obtained results show that inoculation of *Bacillus* and *Pseudomonas* promotes an effective removal of phosphorus from leachate. These data are consistent with the recent literature on the biological processes for phosphorus removal and highlight the essential role of these bacterial genera in aerobic treatment systems.

Effect of bio-deodorization process on suspended solids (SS) and electrical conductivity (EC): The relationship between variations in suspended solids removal efficiency, electrical conductivity and seeding time is shown in Fig. 6. In the first phase of leachate pre-treatment (Fig. 6a), large quantities of suspended solids are found around 6990 mg/L, then decrease over the first three days to 4331.4 ± 1213 mg/L and then increase to 5600 ± 1276 mg/L and 6080 ± 1700 mg/L on the tenth and twenty-eighth days, respectively. This is attributable to the remodelling of the sludge at the bottom of the tanks under the effect of aeration. In addition, the electrical conductivity in the leachates was initially 64 360 µS/m and gradually decreased slowly to 52900 ± 10023 µS/m in the treated leachate during the first three days of pre-treatment (Fig. 6b). After this period, it increased to 38640 ± 9098 µS/m for the tenth day and 39725 ± 10129 µS/m for the twenty-eighth day, which may be related to the increase in chloride, sodium and potassium levels in the leachate [34].

Physico-chemical leachate analyses after bio-deodorization: The physico-chemical parameters of the raw leachate effluent after 3 days, 10 days and 28 days of seeding are achieved in Table-2, they represent the average of each addition of the complex. The latter resulted in significant reductions for the main parameters. The COD and BOD_5 were reduced by 27928 ± 10232 mg/L and 11550.3 ± 37841 mg/L, respectively. Total nitrogen was significantly reduced. In addition to these results relating to the reduction of the pollutant load, this pretreatment has enabled considerable observations to be made with regard to pretreated leachates. Aeration allowed, on the one hand, the deodorization of the leachates from the first days and clarified the colour of the leachates. The results were more significant in terms of efficiency, with a reduction in the organic load. The process leads to a reduction in sludge

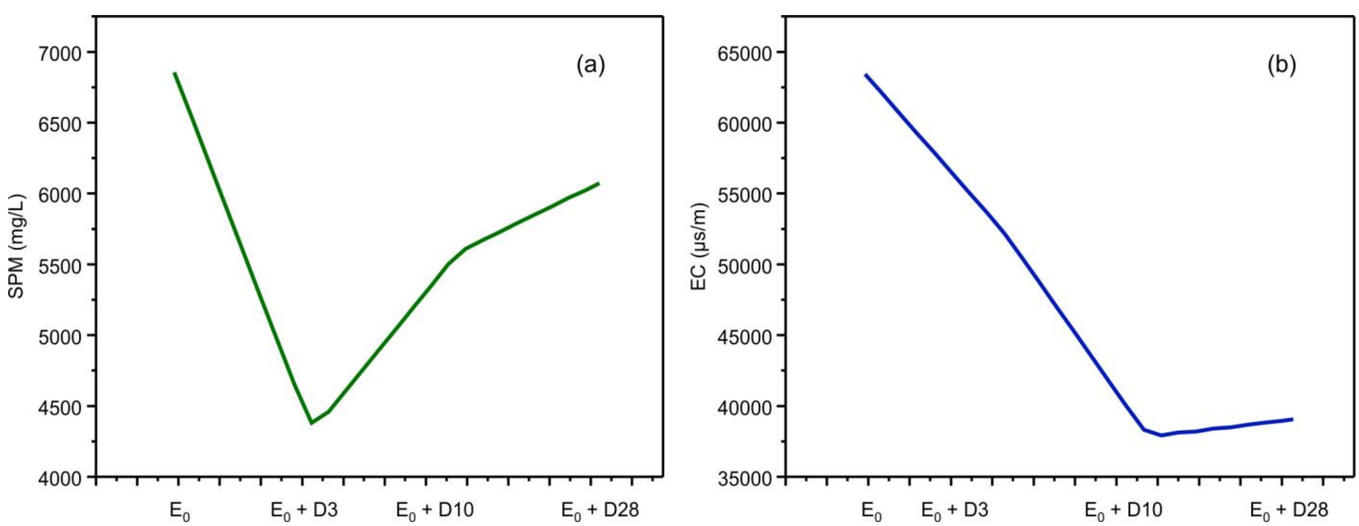

Fig. 6. Effect of the process on (a) suspended matter and (b) electrical conductivity

TABLE-2
CHARACTERIZATION OF LANDFILL LEACHATE BEFORE AND AFTER TREATMENT

	Leachate before treatment		Leachate after treatment	
	E_0	E_0 + D3	E_0 + D10	E_0 + D28
pH	6.14	6.05 ± 0.75	7.7 ± 0.82	8.5 ± 0.98
EC (µS/m)	64360	52900 ± 10023	38640 ± 9098	39725 ± 10129
COD (mg/L)	42172	39453.2 ± 18920	35245.6 ± 15600	27928 ± 10232
BOD_5 (mg/L)	14251	9340 ± 2143	10349.7 ± 3123	11550.3 ± 37841
SS (mg/L)	6990	4331.4 ± 1213	5600 ± 1276	6080 ± 1700
N (Total (mg/L)	1355	1023 ± 576	934.7 ± 320	840 ± 301
NH_4^+ (mg/L)	4861.23	2205 ± 756	2165 ± 934	1533 ± 892
NO_2^-(mg/L)	0.062	0.0333 ± 0.0021	0.0034 ± 0.002	0.003 ± 0.85
NO_3^- (mg/L)	4.03	3.07 ± 0.95	2.83 ± 0.85	1.25 ± 0.75
P (Total) (mg/L)	70.47	55.63 ± 6.2	34.14 ± 3.12	30.54 ± 3.02

volume, which is recirculated to the bottom-mounted VERTEX aeration system. This system ensures continuous agitation of the settled sludge, improving its bioavailability to the introduced bacterial consortium. The ensuing microbial digestion results in minimized sludge accumulation and substantially reduced concentrations of heavy metal contaminants.

Conclusion

In this work, the issue of foul-smelling municipal waste management is addressed. Due to its complex chemical composition, landfill leachate requires extensive treatment before environmental discharge. Identifying effective treatment technologies remains a challenge. In this study, a bacterial consortium was used for the biological deodorization of odorous gases from high-concentration leachate. Based on the outcomes, it can be concluded that raw leachates from the Casablanca landfill were loaded with readily the biodegradable polluting organic matter. To overcome this concern, the deodorization applied by aeration and seeding of the highly efficient *Bacillus* and *Pseudomonas* bacteria, as a pre-treatment, was investigated. This bacterial consortium exhibited outstanding capacity during the removal of individual or mixed nitrogen compounds and the maximum denitrification rates of NH_4^+, NO_2^- and NO_3^- were 69.22%, 99.82% and 46.81%, respectively. The biological treatment of odorous gas from landfill leachate, due to low costs and good results, is the preferred technology for malodorous treatment and it is imperative to promote the spreading application of this technique.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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