

PILOT-SCALE MODELS OF TREATMENT OF LANDFILL LEACHATES COMBINED WITH URBAN WASTEWATERS IN A FACULTATIVE LAGOON

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ABSTRACT

This study set out to determine the potential for treating leachates in combination with wastewater at Facultative Lagoons, a device normally used for treating raw wastewaters. Pilot-scale models were used to simulate leachate treatment and disposal in a Facultative Lagoon (FL), combining 2.4 L/hr of raw wastewater with a leachate mixture (comprising both young and old leachates), in concentrations of 4%, 6%, and 10% (v/v). The solution of leachate mixture in raw wastewater was then fed into the two pilot-scale models (M1 and M2). The following parameters: concentration of algae; chlorophyll *a*, *b* and *c*; faecal coliforms (FC); and heavy metals, were analyzed in all the three component stages: the unmixed wastewater; the old and young leachate mixture; and the combined wastewater-leachate mixture.

As a 10% dilution was found not to impede correct functioning of the Model Facultative Lagoon, the same concentration was tried out using urban wastewaters from the University Wastewater Treatment Plant (UWTP).

Interval values of BOD₅ and COD in the wastewater and in the leachate mixture were 45-875 mg/L and 307-5.763 mg/L respectively, and results showed that a 10% concentration of leachates combined with wastewater does not upset the system of biological treatment. None of the mixtures affected the population of algae. Maximum removal efficiency of BOD₅ was 75%, and 35% for COD, therefore leaving a BOD₅ level of less than 25 mg/L in the effluent from the FL. The removal of BOD₅ and COD from the UWTP was greater still, 86% and 64%, respectively. FC and heavy metal concentrations: As (0.007 mg/L), Cd (0.02 mg/L), Cu (<0.01mg/L), Cr (0.04 mg/L), Hg (0.00027 mg/L), Ni (0.15 mg/L), Pb (0.098 mg/L), CN (0.0213 mg/L) and Zn (0.05 mg/L), were all below the maximums established by the Mexican Federal Regulation for Re-use of Wastewater in Agricultural Irrigation (NOM-ECOL-001-1996).

KEYWORDS

Pilot-Scale Models; Landfill leachates; wastewaters; facultative lagoon.

1 INTRODUCTION

Every day the Bordo Poniente Sanitary Landfill receives approximately 12,000 tons of urban waste originating from Mexico City. In this and any landfill, infiltration, precipitation and migration of water through the landfill produces a leachate containing varying quantities of undesirable, even toxic, organic and inorganic substances [1].

The leachates generated in a landfill are mainly of two types: 1) Old leachates (older than five years) the physical-chemical characteristics of which give a Biochemical Oxygen Demand/Chemical Oxygen Demand (BOD_5/COD) ratio of less than 0.1, indicating the leachate is stabilized; and 2) Young leachates (in cells less than one year old) the BOD_5/COD ratio of which is 0.35, indicating the leachate is biodegradable and responsive to biological treatment [2]. Given that leachates are produced in large quantities and are highly toxic, they must be treated. The toxicity requires that studies must first be made as to the rates at which leachates can be poured directly into any biological treatment system without causing perceptible alterations either to the system itself or to the environment.

Some bibliographical reports indicate that leachates with a COD of 10,000 mg/L can be treated in a 5% solution by volume of leachate to wastewater, without causing negative effects to the treatment processes or to effluent quality [3]. Another study treated leachates with a COD of 37.67 mg/L and a BOD_5 of 13.82 mg/L, in a system of activated sludge with a leachate to wastewater proportion of 1.5% (v/v). The result was a highly efficient removal of biodegradable organic material and ammoniacal nitrogen [4].

Referring to a landfill in Quebec, Zaloum and Abbott, (1997) reported that the Facultative Lagoons where wastewaters are treated are also used to treat leachates from the sanitary landfills in the area. Raw leachates accumulate at the base of the landfills from autumn to late spring, and are treated in the Lagoons during the summer months. Semi-continuous discharge from the treatment system at the Facultative Lagoons then takes place from early spring to late autumn, when the treated leachates meet Regulations for solid waste [5].

Using a UASB pilot-scale reactor, Fueyo *et al.* (2003) carried out an anaerobic degradation of leachates mixed in different proportions with urban wastewater. The treatment systems applied are the same as those used for wastewater, but the characteristics of each leachate need to be considered separately [6].

In many cases Facultative Lagoons are used as a pre-treatment step prior to some form of biological treatment in a municipal facility. However, although a considerable amount of research has been carried out into the biological treatment of leachates, few real-scale studies on the utilization of Lagoons for leachate treatment have been reported in the literature [7].

Others studies have evaluated the quality of leachates in landfills of different ages, but the reported ranges of variation of all the leachate components are particularly wide, and the long-term trends are sometimes contradictory [7, 8].

The study being reported here set out to determine the potential for treating leachates in combination with wastewater at Facultative Lagoons, a device normally used for treating wastewaters alone. Pilot-scale models were used to simulate leachate treatment and disposal; and treatment efficiency was assessed by analyzing the concentrations of algae and of chlorophyll *a*, *b* and *c*, the parameters used to measure effluent control and quality.

2 MATERIALS AND METHODS

2.1 Design of the pilot-scale model

Pilot-scale models were used to simulate leachate treatment and disposal in a Facultative Lagoon (FL), combining 2.4 L/hr of raw wastewater with a leachate mixture (comprising both young and old leachates), in concentrations of 4%, 6%, and 10% (v/v). The solution of leachate mixture in raw wastewater was then fed into the two pilot-scale models (M1 and M2). The following parameters: algae concentration; chlorophyll *a*, *b* and *c*; faecal coliforms (FC); and heavy metals, were analyzed in all the three component stages: the unmixed wastewater; the mixture of old and young leachates; and the combined wastewater-leachate mixture.

The design of the model was based on the control of a laminar flow regimen. Each tank had drains that permitted the entrance and exit of water without provoking turbulence. Two identical models were constructed (M1 and M2): leachates were added to model M1, whilst model M2 served as the control receiving only FL wastewater. Both models where the two treatments were carried out had tanks of 200 L capacity, and each was fitted with a system of continuous agitation. *Figure 1* shows the characteristics of the pilot-scale model as it was used during the study. To monitor progress, every 48 hours throughout the experiment samples of wastewater were taken for laboratory analysis from the Facultative Lagoons that lie about 1.5 km from Texcoco Lake. Samples of leachate from the Bordo Poniente Landfill were also taken. Each leachate sample was constituted in the following way. Samples were taken from 12 points distributed around the Landfill. These 12 samples were then mixed together giving one sample representative of the entire Landfill. Each sample-taking exercise was carried out in triplicate.

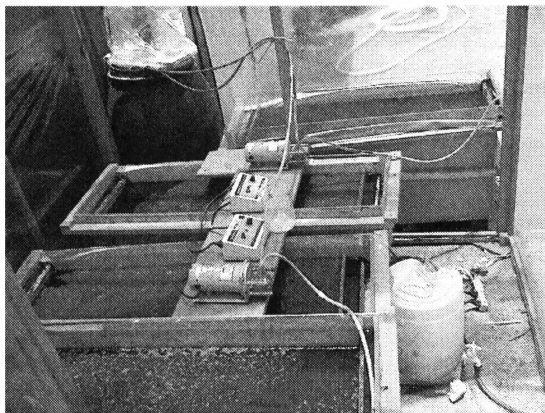


Figure 1. Characteristics of the pilot-scale model.

The pilot-scale reactors were first filled with wastewater from the Churubusco Channel and inoculated with 60 L containing algae and sludge obtained from the Texcoco wastewater treatment plant. Fresh untreated wastewater was then fed in, ensuring the BOD₅ and COD remained at 45 mg/L and 307 mg/L, respectively. The inflow was maintained at 2.4 L/hr,

determined beforehand to be the ideal flow volume. Frequent monitoring was carried out to ensure these parameters were maintained. Over the experimental period of 30-60 days, the percentage of BOD₅ removal was found to remain constant. The reactors were therefore considered stabilized, and the process moved on to the next step.

Leachate was collected from the lateral channels alongside each macro-cell of the Bordo Poniente Landfill, and a leachate mixture was created taking two parts by volume of stabilized leachate (old) with an average BOD₅ of 160 mg/L, plus one part by volume of young leachate with an average BOD₅ of 680 mg/L. This leachate mixture was progressively introduced into the M1 model, starting with 4%, followed by 6% and then 10% by volume (v/v) of leachate to wastewater in phases I, II, and III, respectively.

As the 10% dilution was found not to impede correct functioning of the Model Facultative Lagoon, the same concentration was tried out using urban wastewaters from the University Wastewater Treatment Plant (UWTP).

2.2 Physical-chemical characterization and microbiology of the wastewater and leachate samples from the FL and the UWTP

The following physical-chemical parameters were analyzed in both the leachates and influent: pH, temperature, electrical conductivity, turbidity, colour, alkalinity, Total Solids, Total Volatile Solids, Total Suspended Solids, Suspended Volatile Solids, Total Dissolved Solids, Ammoniacal Nitrogen, Nitrates, Total COD, BOD₅, Heavy Metals (Cr, As, Cd, Cu, Hg, Zn) and micro-organisms (faecal coliforms, algae, chlorophyll *a*, *b* and *c*).

2.3 Evaluation of the Operation of Both Models (Pilot-Scale)

Operation of both models, M1 and M2, was carefully observed both at start-up and during the actual treatment process. Particular attention was paid too

- a) How the system functioned with regard to the most important variables of the treatment process, i.e. BOD₅ and COD
- b) Because the Facultative Lagoon system functions due to the presence of algae, specific studies were carried out to determine the diversity and quantity of algae in the experimental models. Chlorophyll determination was made using the Azov spectrophotometer method [9], and the algae count involved the Sedgwick-Rafter technique [2].
- c) Faecal coliform totals were calculated using the Most Probable Number (MPN), and Membrane Filtration (MF) methods
- d) Dissolved Oxygen was analyzed using the electrometric method (YSI), the values taken in the aerobic zone of the models
- e) Heavy metals were analyzed with the atomic absorption method (EPA 6010B), using an Inductively Coupled Plasma Atomic Emission Spectroscope
- f) The pH was monitored using a potentiometer (Coker-Palmer, Model 05669-20)
- g) The final analysis made was of how ammonia is eliminated, or disappears, from the leachates.

3 RESULTS AND DISCUSSION

3.1 Results of the physical-chemical characterization and microbiology of wastewater and leachate samples from the FL and the UWTP

The results of the physical-chemical characterization of metals and microorganisms in the leachate and influent taken from the FL and UWTP are shown in *Table 1*. As can be seen, the pH in the samples was slightly alkaline: pH 7.9 for the leachates, pH 8.0 for the FL, and pH 8.3 for UWTP. Analysis of the leachates produced the highest concentrations of electrical conductivity (16.8 Ms/cm), turbidity (233 NTU), colour (888 U.C) and suspended volatile solids (150 mg/L).

The COD (5,763 mg/L) and BOD₅ (875 mg/L) values in the leachates were much higher than those detected in the wastewater samples from the FL and UWTP. The FL samples gave a result of BOD₅ at 45 mg/L, which is very low, while the UWTP samples gave BOD₅ concentrations above 64 mg/L.

Table 1. Physical-chemical characterization and microbiology of leachates, FL wastewater and UWTP wastewater.

Parameters	Units	Average value (leachates -old+young-)	Average value (FL)	Average value (UWTP)
pH	-	7.9	8.0	8.3
Temperature	°C	14	19	18.3
Electrical Conductivity	Ms/cm	16.8	2.29	1.98
Turbidity	NTU	233	165	130
Color	U.C.	888	427	390
Alkalinity (CaCO ₃)	mg/L	14.3	8.6	8
Total Solids	mg/L	15.6	1,530	920
Total Volatile Solids	mg/L	3,000	1,090	858
Total Suspended Solids	mg/L	160	110	127
Suspended Volatile Solids	mg/L	150	50	68
Total Dissolved Solids	mg/L	15,520	91,000	995
Ammoniacal Nitrogen	mg/L	887	50	33
Nitrates	mg/L	112	12	5
Total COD	mg/L	5,763	307	234
BOD ₅	mg/L	875	45	64
Chromium	mg/L	2.4	0.01	0.02
Arsenic	mg/L	0.07	0.005	0.007
Cadmium	mg/L	0.43	0.022	0.01
Koper	mg/L	0.19	0.0175	0.002
Mercury	mg/L	0.08	0.00035	0.001
Zinc	mg/L	0.44	0.056	0.07
Fecal Coliforms	MPN/100 mL	ND	3.5X 10 ³	7X10 ¹
Chlorophyll "a"	mg/m ³	ND	335.77	---
Chlorophyll "b"	mg/m ³	ND	58.99	---
Chlorophyll "c"	mg/m ³	ND	59.92	---
Algae	algas/mL	ND	1.5 X 10 ⁴	---

ND = not detected in the analysis

With regard to the metal content in the leachates, only Chromium (2.4 mg/L) was above the limits established in the Official Mexican Norm 001-ECOL-1996 (1.5 mg/L). However, the Chromium concentration diminished favourably as a result of diluting the leachate with wastewater from both the FL and UWTP, and by the natural precipitation of heavy metals. No microorganisms were observed in the leachates when they were analyzed.

Table 2 shows the results of the physical-chemical quality, microbiology and metals present in the leachate-wastewater mixture at 4%, 6% and 10%. These results illustrate the significant

decrease in the leachate heavy metal content when mixed with raw wastewater from the FL and UWTP. The leachates contained Chromium 2.4 mg/L; whereas the combined leachate-FL wastewater mixture gave Chromium 0.105, 0.15, 0.04 mg/L at 4%, 6% and 10% v/v, respectively. As the concentrations of this metal did not interfere with the activity of the microbial community present in the system, the same *Table 2* gives the following average results at the three dilutions: faecal coliforms at 1.5×10^2 , 2.1×10^2 , 1.2×10^2 (MPN/100 mL); concentrations of algae fluctuating from 0.5×10^3 to 1.8×10^4 algae/m; and chlorophyll *a* at 261.57, 123.36, 33.1 (mg/m³) respectively. No micro-organisms were detected in the analysis of the leachates.

Aldana (1998) demonstrated that part of the metals present float to the surface, part are absorbed by phytoplankton, and the rest precipitate out as sediments, the greatest concentration of metals being found in sediment [10].

Table 2. Results of the characterization of treated combined effluent (leachate-wastewater mixture) at 4%, 6% and 10%.

Parameters	Units	4 %	6%	10%
Leachate / wastewater FL				
pH	-	8.6	8.7	8.6
Electrical Conductivity	µmhos/cm	2,546	3,545	4,488
Orthophosphates	mg/L	34	40	39
Total Dissolved Solids	mg/L	1,269	1,779	2,263
Nitrates	mg/L	6.5	9.2	14.3
BOD ₅	mg/L	21	24	26
COD	mg/L	251	353	425
Total Cyanide	mg/L	NE	NE	0.0213
Chromium	mg/L	0.105	0.15	0.04
Arsenic	mg/L	0.006	0.007	0.006
Cadmium	mg/L	0.026	0.027	0.002
Copper	mg/L	0.105	0.150	0.01
Mercury	mg/L	0.003	0.004	0.0008
Zinc	mg/L	0.112	0.141	0.05
Fecal Coliforms	MPN/100 mL	1.5×10^2	2.1×10^2	1.2×10^2
Chlorophyll "a"	mg/m ³	261.57	123.36	33.09
Chlorophyll "b"	mg/m ³	59.72	101.35	26.78
Chlorophyll "c"	mg/m ³	31.6	20.68	157.82
Algae	Algae/mL	0.5×10^3	1.5×10^3	1.8×10^3
Leachate / wastewater UWTP				
COD	mg/L	344	400	433
BOD ₅	mg/L	56	70	78

The average concentrations of the mixtures showed that As, Cd, Pb, Ag, Cu, Ni, Cr, and CN were all below the limits established by the NOM ECOL-001, 1996, for agricultural as well as urban reuse.

In the case of micro-organisms such as faecal coliforms, in the stabilization period bacteria concentration registered 10^4 MPN/100 mL in the influent and 10^3 MPN/100 mL in the effluent, which demonstrates a logarithm in the rate of removal in the cellular concentration of these bacteria. These values persisted throughout the 60 days.

3.2 Results of BOD₅ and COD behaviour

The raw wastewater used evidenced a low BOD₅ concentration of 45 mg/L. This is due to the significant length of open sewer along which it travels before reaching the Texcoco wastewater plant, during which time part of the organic matter is transformed. However, at all experimental levels (after 60 days), with leachate mixtures of 4%, 6% and 10%, overall BOD₅ removal efficiencies were 71, 84 and 110 mg/L respectively. As a result of this low organic load, as shown in *Figure 2*, the M2 model had a mean removal efficiency of only 28% for the entire operation time studied.

The biodegradation constants K_d of the experimental models were: M1 (0.42/d) and M2 (0.34/d). These values are similar to K_d (0.35/d), the value obtained at the Texcoco wastewater treatment plant. These results confirm that the incorporation of leachate had no effect on the biological process.

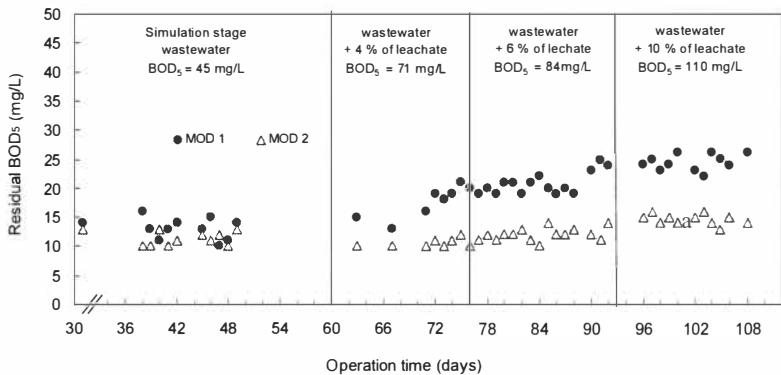


Figure 2. Residual BOD₅ during the Stabilization of the Models and at each stage of the study: M1 with leachates and M2 without leachates.

COD values increased from 219 mg/L to 711 mg/L with the addition of leachates in a 10% solution (see *Figure 3*). However models M1 and M2 maintained a steady level of COD removal during the whole experiment period, in other words, with and without the contribution of leachates. Over a period of 60 days, the pilot models demonstrated a constant COD removal of 35%. In a series of tests using wastewater typical of the UWTP, the average result showed greater removal of COD at 64%.

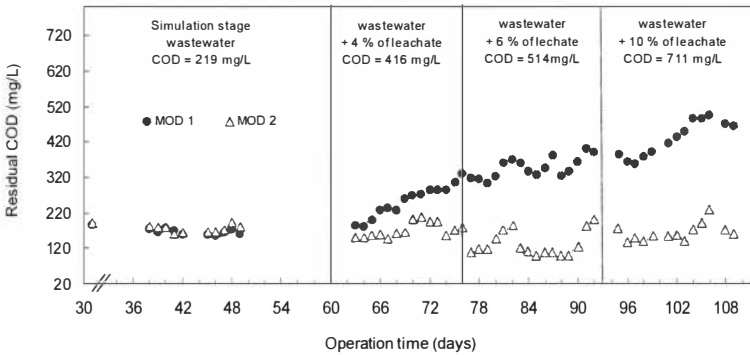


Figure 3. COD removal in Stabilization Lagoon Models: M1 with leachates and M2 without leachates.

3.3 Behaviour of the microbial communities

The types of algae present in the FL and in models M1 and M2 were: *Microsistis* sp., *Merismopedia* sp., *Euglena* sp., *Scenedesmus* sp., *Chlorella*, *Diatomeas* and *Anacystis* sp. Of these, *Anacystis* sp. was the dominant species, and it formed colonies of micro-organisms surrounded by a mucous substance, in which the gases trapped in the aggregates caused it to float to the surface.

The biological process in the Facultative Lagoons occurs principally due to algae and bacteria. The algae assimilate nutrients and carbon dioxide, and generate oxygen. The bacteria consume oxygen, organic material and biomass, and generate carbon dioxide. The presence of algae is indispensable for the development of the aerobic process.

During the entire experimentation period and in all the tests, elevated concentrations of chlorophyll *a* were found. (Chlorophyll *a* is found in all algae and green plants.) All the tests registered comparatively lower levels of chlorophyll *b*, present in the form of the *Chlorophyceae* and *Euglenophyceae* groups; and slightly lower levels of chlorophyll *c* (compared to *a*) in the form of the *Bacillariophyceae*, *Coscinodiscophyceae* and *Fragilariophyceae* groups. The presence or absence of these different photosynthetic pigments served to distinguish between the principal groups of algae.

Algae identified as *Scenedesmus*, *Microsistis*, *Merismopedia*, *Euglena* and *Chlorella* were all found in a persistent form. These algae play an important role in the purification process at the FL, as the majority of the Lagoon's oxygen is generated by their photosynthetic activity, and they absorb soluble nutrients from the bacterial decomposition of organic matter [11].

Diatomeas, which indicate an advanced phase of treatment, were also observed. Mobile green algae such as *Euglena*, generally becomes dominant when there is limited light penetration, but in the results of this study, *Euglena* formed only part of the mixed algae population without becoming dominant.

Algae are desirable in Lagoons as they generate the oxygen needed by bacteria for waste stabilization.

Chlorophyll *a* is considered a good chemical indicator of phytoplankton biomass. It helps determine the trophic state of surface waters, and determines water quality. Chlorophyll *a* also allows detection of the adverse effects of pollutants on plankton. Despite its variability, chlorophyll *a* is one of the most frequently measured parameters in production studies [11, 12].

Regarding chlorophyll *b* in the leachate mixture at 4%, 6% and 10%, *Figure 4* shows there were no significant differences between model M1 and the M2 control model. This indicates that chlorophyll *b* concentration in the M1 experimental model to which leachate was added, remained the same as in the M2 control model to which no leachate was added.

Chlorophyll *c* behaviour was very similar to that of chlorophyll *b* when 4% and 6% leachate mixtures were prepared. However, when model M1 was operating with a 10% leachate mixture, measurements showed that control model M2 evidenced slightly higher levels of chlorophyll *c*, which follows the pattern found with chlorophyll *a*.

3.4 Behaviour of faecal coliform

The levels of faecal coliforms (see *Figure 5*) in the effluent of both models M1 and M2 registered 10^2 MPN/100 mL. The cellular density of faecal coliforms was thus below the maximum permitted by Mexican standards for treated wastewater destined for irrigation (1000 MPN/100 mL as set out in NOM-001-ECOL-1996). In some cases, the level of faecal coliform matter was also below US norms (200 MPN/100 mL) [13].

3.5 Behaviour of dissolved oxygen

In the case of dissolved oxygen, no differences were observed in any of the experimental phases (4%, 6%, or 10%) when the leachate was incorporated. The values of dissolved oxygen in the aerobic zone of the models remained between 1 and 2 mg/L, which ensured appropriate conditions for metabolism of the system's micro-organisms; and the concentrations of dissolved oxygen (DO) at the surface remained above 2.0 mg/L.

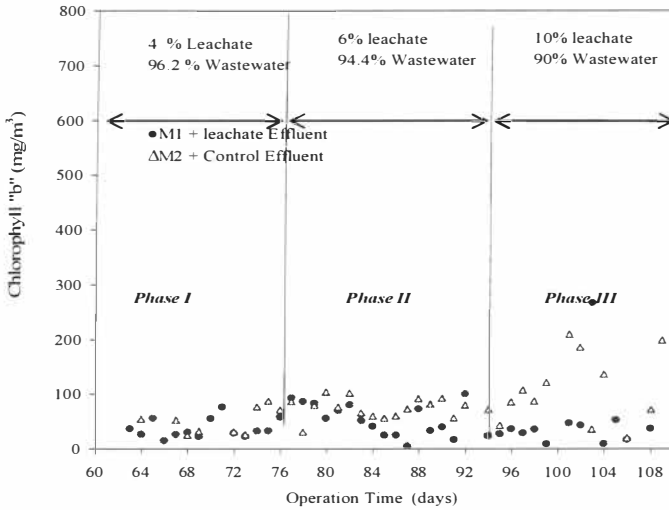


Figure 4. Concentrations of chlorophyll b in leachate mixtures of 4%, 6% and 10%.

3.6 Behaviour of heavy metals

Heavy metal concentrations in the 10% leachate mixture were: As (0.006 mg/L), Cd (0.02 mg/L), Cu (0.01 mg/L), Cr (0.04 mg/L), Hg (0.0008 mg/L), CN (0.0213 mg/L) and Zn (0.05 mg/L). These levels are all below the maximums established by the Mexican Federal Regulation for Re-use of Wastewater in Agricultural Irrigation [12].

Some studies show that metals such as Zn^{+2} assist algae development, whereas Cr^{+6} can diminish the growth of algae and other micro-organisms, although the exact concentration able to inhibit growth has not yet been determined [11]. Concentrations of heavy metals in the Facultative Lagoon were remarkably low in all cases, and therefore, predictably, there would be no influence on algae development.

Table 3. Treated leachate-wastewater quality.

Treatment (mg/L)	pH	TDS (mg/L)	P-PO ₄ (mg/L)	N-NH ₃ (mg/L)	BOD ₅ (mg/L)	COD (mg/L)	Chlorophyll "a" (μ /L)	Fecal Coliforms (MPN/100 mL)
Wastewater								
DOB ₅ = 45	8.9	1065	36	40	12	158	236	6 X 10 ²
COD _a = 219								
4 % (v/v)								
DOB ₅ = 71	8.6	1390	34	36	19	293	140	3 X 10 ²
COD _a = 416								
6 % (v/v)								
DOB ₅ = 84	8.7	1810	38	48	21	362	136	5 X 10 ²
COD = 514								
10 % (v/v)								
DOB ₅ = 110	8.6	2383	43	73	25	468	150	2 X 10 ²
COD _a = 711								

4 CONCLUSIONS

- After 30 days, the pilot models demonstrated constant BOD₅ and COD removals of 75% and 35% respectively. Results of tests using typical wastewater from the UWTP showed superior removal of BOD₅ and COD, at 86% and 64% respectively.
- Recalcitrant leachates mixed in a proportion of 2:1 give a biodegradability ratio of BOD₅/COD 0.14.
- The Facultative Lagoon at the Texcoco plant, using typical UWTP wastewater, is thus a viable alternative for the disposal and treatment of leachate from the Bordo Poniente Landfill, when the leachate is diluted to 10% per volume.
- Facultative Lagoons can also be used as a disposal alternative for stabilized leachates where the main desired effect is dilution.

- The character of the effluent also demonstrated that, during the summer, the effluent could be used for agricultural irrigation as it meets Mexico's Federal guidelines in this regard.
- Algae identified in models M1 and M2 during the stabilization period were: *Microcystis sp.*, *Merismopedia sp.*, *Euglena sp.*, *Scenedesmus sp.*, *Chlorella*, *Diatomeas* and *Anacystis sp.*
- The algae population was seen to respond to the addition of leachates, but the climatic and physical-chemical conditions under which the treatment system operates allow for re-establishment of these organisms.
- Algae are desirable in Lagoons as they generate oxygen needed by bacteria for waste stabilization. In all the treatments in this study, constant concentrations of chlorophyll *a*, *b*, and *c* were found, indicating that the incorporation of leachates at the concentrations studied does not affect the presence of the micro-organisms responsible for treatment in the Facultative Lagoons at Texcoco Lake.
- In all cases, the final levels of faecal coliforms in the effluent of wastewater mixed with leachate were found to be in the order of 10^2 MPN/100 mL. This is below the Mexican maximum for treated wastewater destined for reuse in agriculture (1000 MPN/100 mL).
- The values of dissolved oxygen in the aerobic zone of both models M1 and M2 remained between 1 and 2 mg/L, which ensured suitable conditions for metabolism of the system's micro-organisms. Other parameters such as pH, orthophosphates, conductivity, and TDS showed changes of little significance.
- Heavy metal concentrations in the 10% leachate mixture were: As (0.006 mg/L), Cd (0.02 mg/L), Cu (0.01 mg/L), Cr (0.04 mg/L), Hg (0.0008 mg/L), CN (0.0243 mg/L) and Zn (0.05 mg/L), all of which fall below the maximums established by Mexico's Federal Regulation for the Re-use of Wastewater in Agricultural Irrigation (NOM-ECOL-001-1996).

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