Landfill leachate treatment: one of the bigger and underestimated problems of the urban water management in developing countries

C. Madera, Viviana Valencia-Zuluaga

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C. Madera* and Viviana Valencia-Zuluaga**

* Sanitary and Environmental Engineering Area, University of Valle, Calle 13 # 100-00 Edif. 343, Cali, COL
(E-mail: cmadera@univalle.edu.co)
** Cinara, Research and Development Institute in Water Supply, Environmental Sanitation and Water Resources Conservation, University of Valle, Calle 13 # 100-00 Edif. 341, Cali, COL
(E-mail: vivalezu@univalle.edu.co; vivalezu@yahoo.com)

Abstract

The main method for solid waste disposal in Latin America has been the dumping. In Colombia there are many dumping places and several sanitary landfills without leachate treatment or some working improperly, being them stored in artificial ponds or discharged directly into the water bodies and causing damage in the ecosystems and human health. Treatment selection for leachate is hard due to the variability of this liquid since depends of several factors like the dump location and the waste's age and composition. Researchers indicate the effective treatments for young leachates are the biological technologies and for old leachates are the physicochemicals. This study pretend to evaluate the phytoremediation by constructed wetlands of heavy metals of leachate from Presidente landfill, based in Buga, Valle, Colombia. A factorial experiment design will be developed with two vegetal species and two support mediums. The leachate will be characterized and the main rizosferic microorganisms populations will be identified.

Keywords

Developing countries, treatment, discharges, contaminants, management.

INTRODUCTION

Problem

The landfilling is an attractive method for the municipal solid waste management due to economic considerations (El-fadel et al., 2002), so it is especially for developing countries like Colombia. Solid waste disposal is carry out in several ways, as landfills, controlled dumps and, in the worst cases, open-pit dumps with environmental problems as water (surface and underground) and soils contaminated. This method of solid waste disposal leads to one of the hardest problems to solve: leachate management, thought as collecting, treatment and disposal.
In Colombia, like in many developing countries, the dumping is the main method of solid waste disposal. The number of landfills, controlled dumps and open-pit dumps is not well identified and is less known the situation regarding the leachates treatment. The Procuraduría General de la Nación (2003) indicates that approximately, the 65% of the existing dumps are open-pit dumps and the 78% of the dumps do not have leachate treatment. The other hand, the Pan American Health Organization (2005) indicates that the national average of final disposal in landfills is about 51%, but in small communities (less than 40.000 habitants) the 60% of the wastes are

disposed in open-pit dumps and there is no information about leachate treatment. Due to the dumping places are relatively far from urban centres, the problem of leachate management is not seen and therefore is underestimated by population and the municipalities, affecting the environment and human health in the short, medium and long term.

Leachate characteristics

Leachates are the result of the biochemical decomposition of the solid waste's organic or biodegradable part, under aerobic and anaerobic conditions, plus the percolation of rain water through the wastes. This liquid filtrates into the wastes dragging and dissolving some materials that make it toxic and contaminant. The leachate generated in any kind of dump place is the aggregate of water, microorganisms and dissolved and suspended substances of the wastes (Justin and Zupancic, 2009; MINAMBIENTE, 2002; Collazos, 2001; Kiely, 1999; Tchobanoglous *et al.*, 1994). Leachates are characterized by dark colour, bad smell and high organic and nitrogen loads; its treatment is difficult because also contents heavy metals, humic substances and recalcitrant compounds (Monje y Orta de Velásquez, 2004; Zouboulis *et al.*, 2004; Kamenev *et al.*, 2002; Karrer *et al.*, 1997).

Leachate treatment

The right leachate treatment strategy is not easy to define due to the high variability in its composition and characteristics that depend of several variables like the place of the dump and the age of the wastes. Around the world, many researchers had dedicated to study the most effective processes for leachate decontamination and in this way can find and chose the appropriated technology for its treatment depending on its characteristics. Young leachates have a high biodegradability due to the high ratio BOD_5/COD, contrary to the old ones, which have a low ratio and therefore a low biodegradability. Consistent with this, Kang and Hwang (2000) and Ding *et al.* (2001) indicate the biological treatments have shown to be very effective for young leachates, while for old or partially stabilized leachates, researchers like Ntampou *et al.* (2005), Rivas *et al.* (2004), Tatsi *et al.* (2003) y Trebouet *et al.* (2001) indicate the most effective way to treat them is with physicochemical processes.

The biologic technologies that had been investigated and used for leachate treatment are: UASB, stabilization ponds, activated sludge, trickling filters, biodiscs and SBR (Robinson, 2005; Agdag and Sponza, 2005; Veenstra, 2000; Kennedy and Lentz, 2000); in the other hand, the physicochemical technologies include cogulation-floculation-sedimentation, membrane processes (reverse osmosis, micro and ultrafiltration), ammonia stripping and advanced oxidation processes (Monje y Orta de Velásquez, 2004; Zouboulis et al., 2004; Veenstra, 2000, Piatkiewicz *et al.,* 2001; Ushikoshi *et al.*, 2002; Zhang *et al.*, 2005; Wang, 2003). Besides these methods, the techniques for the leachate treatment include also methods as recirculation through the wastes and aspersion over the land (Caicedo, 1992).

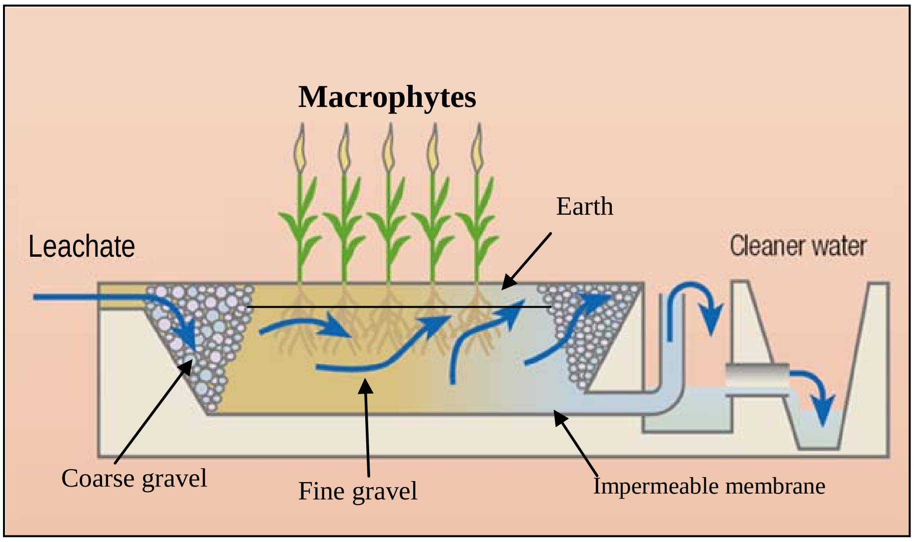
The physicochemical and advanced biological systems are being implemented for leachate treatments with high initial inversion and operation costs, reason why its implementation in developing countries has been limited (Chiemchaisri *et al.*, 2009). Taking this into account and due to the landfill leachate treatment problem is urgent to solve, there is a need of work with systems more flexible and low cost both in investment and operation and maintenance; in this vein, natural systems have began to be investigated since early 90´s as leachates treatment alternatives (Renou *et al.*, 2008; Vymazal, 2009).

Leachate phytoremediation

Constructed wetlands are natural systems whose use for leachate treatment is relatively new; the leachate treatment with wetlands can also be called leachate phytoremediation, where the principle of the treatment is to "use the potential of the natural or actively managed soil–plant system to detoxify, degrade and inactivate potentially toxic elements present in the leachate" (Jones *et al.*, 2006). A constructed wetland consists of a gravel bed as a support media on which different kind of plants grow. In this case, the leachate passes through the substrate, and it is purified by the activity of the bacteria attached to the gravel, plant roots and soil mainly (UNEP, 2003). Figure 1 shows the main features of a sub-surface constructed wetland (SSCW).

Constructed wetlands are characterized by its facility in operation and maintenance, and low cost as well as its adaptability and major stability in tropical environments; its use has shown the reduction of several contaminants such as heavy metals, which have remained in the plant roots or in the support medium, however, the role of the plants into the elimination processes is being widely discussed and researched, in order to find the mechanisms of the contaminant degradation, sequestration or entrapment, especially of the heavy metals (Cd, Pb, Hg, Cr, Cu y Zn), recalcitrant organic substances (humic and fulvic) and complex substances such as phenols, benzene and toluene (Barceló and Poschenrieder, 2003).

Between the mechanisms involved into a wetland for the transformation or removal of the contaminants are: sedimentation, precipitation, chemical transformation, adsorption, ionic exchange in the plant, substrate and detritus, death because of predators, natural death of microbiote, break, transformation and assimilation of nutrients and contaminant by plants and microorganisms (Vymazal, 2005).



Source: Adapted from UNEP (2003)

Figure 1: Main features of a sub-surface constructed wetland (SSCW)

Most of the leachates content heavy metals, in this sense, one of the characteristics of the plants for phytoremediation must be the hyperaccumulation. This kind of vegetation is chosen mainly because the physiological potential to tolerate and assimilate toxic substances, its growing rates, the depth of its roots and the ability to degrade and/or bio-acumulate the contaminants in its roots, branches or leaves (Salt *et al.*, 1998; Barceló and Poschnrider, 2003; Llugany *et al.*, 2007).

Some species with good heavy metals accumulation are: Arabidopsis halleri, Thlaspi caurulescens, Thlaspi caurulescens, Thlaspi rotundifolium, Minuarta verna, Thlaspi goesigense, Allysum bertholoni, Berkheya codii, Psycothria douarrei, Miconia lutescens, Melastoma malabathricum (Barceló and Poschnrider, 2003).

Leachate reuse

Leachate reuse for irrigation is a good alternative for the disposal of this liquid; in fact, this option is regarded as suitable for the polishing of pre-treated leachate, as another remediation option (Gray *et al.*, 2005; Haarstad and Maehlum, 1999 cited by Jones *et al.*, 2006). Besides this, leachates have high concentrations of macro and micronutrients such as N, K, Mg, Ca, Zn and B, whence it can work as a fertilizer for some crops such as energy crops; this option can give the possibility of close the loop on nutrients (Justin and Zupancic, 2009; Jones *et al.*, 2006).

Different results have been obtained in the researches with leachate irrigation, some of them showed inhibition of root growth (Wong and Leung, 1989) and other showed no detrimental effects on the irrigated vegetation (Ankers and Ruegg, 1993 cited by Gray *et al.*, 2005) and no excessive accumulation of some compounds which could negatively plant grow or soil properties (Justin and Zupancic, 2009). Nevertheless, it can say that leachate irrigation works under controlled conditions with irrigation plans designs in order to prevent the intoxication plants and the exceeding of the nutrients requirements as well as to minimize damage to the environment (Cheng and Chu, 2007).

METHODOLOGY

Objectives

The main objective of the proposal is to evaluate at pilot-scale phytoremediation of the leachate from Presidente Regional Landfill (Buga, Colombia), using sub-surface constructed wetlands. To meet this objective, it has settled the following specific objectives to develop:

- ✓ To analyze the influence of the variation of vegetal species and support medium on the SSCW performance for leachate treatment with reuse purposes.
- ✓ To analyze the rizosferic ecosystem generated inside the wetlands operated at different vegetal species and support mediums.
- ✓ To propose schemes for leachate reuse.

Picture 1: Presidente Regional Landfill

Material & methods

The pilot-scale research will be carry out at the Presidente Regional Landfill (Cali, Colombia) where solid wastes from 16 municipalities are disposed, receiving an amount of 500 ton/day of solid wastes (in average) and producing an estimated between 2.0 and 2.5 l/s of leachate (Proactiva, 2009).

Actually, the leachates at Presidente Landfill are being stored in several artificial ponds and one part of them is recycled and spreading over the wastes disposed in landfill cells. These leachates are considered as a mixture between young and old leachates.

The research will be conducted for one year. The experimental design will be a factorial one with two factors, each one with two levels (see Figure 2):

- ✓ Factor 1: Vegetal Specie (VS) — Level 1: Native 1; Level 2: Native 2
- ✓ Factor 2: Support Medium (SM) — Level 1: Gravel; Level 2: Sand

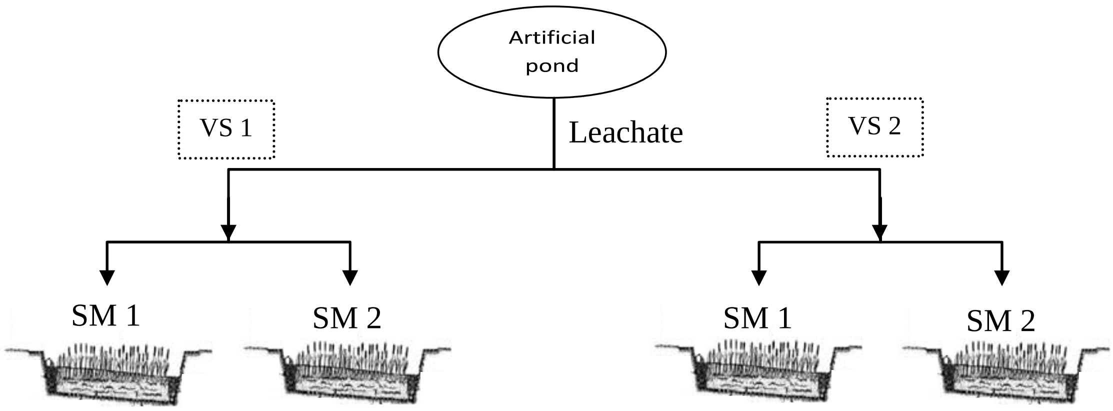


Figure 2: Experimental design scheme

To meet the research objectives, four phases has been raised:

<u>Phase I</u>: In this phase it will be made the recognizing of the researching place (Presidente landfill) and a complete characterization of the leachates to be treated at the wetland units with the aim of determine its polluting power and to set some design variables. The most deep literature review will be done at this phase, including past experiences regarding the treatment of these leachates and characterizations previously achieved. In this stage also an inventory of native plants will be made in order to select the research plants.

<u>Phase II:</u> This phase include the design and the hydraulic check of the wetlands, the inventory and purchase of the required materials for the implementation, and the installation (construction), startup, testing and adjustments of the pilot units. The four units will be operated at the same time in order to get a better statistical analysis comparing the wetlands.

<u>Phase III:</u> After the four units are operating at the required conditions, all the measurements will be made at this phase. To analyze the influence of the variation of vegetal species and support medium on the SSCW performance, the parameters to be measured as response variables are: Total Carbon Organic (TOC), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), pH, Total Suspended Solids (TSS), Oxidation Reduction Potential (ORP), Electric Conductivity (EC), Nitrogen Total Kjeldahl (NTK), Ammoniacal Nitrogen ($N\text{-}NH_3$), Nitrites (NO_3^-), Phosphates ($P\text{-}PO_4^-$), Mercury (Hg), Cadmium (Cd), Lead (Pb) and Chromium (Cr^{+6}).

These parameters will be compared both before and after the treatment at each wetland as well as will be compared among them four.

On the other hand, to analyze the rizosferic ecosystem generated inside the wetlands operated at different vegetal species and support mediums, the main populations of the microorganisms that grows at the plant roots (rizosferic microorganisms) and belongs at the archaea and bacteria domains, will be identified. Besides, it will be made an estimation of the abundance, diversity and richness of the identified populations by the molecular techniques FISH y PCR real time.

Phase IV: Finally, in this phase it will be compared all the obtained results regarding removals of the contaminants and quality of the treated leachates, against the existing national and international standards and guidelines for wastewater reuse. According to this comparison, some direct or indirect alternatives or schemes of leachate reuse will be proposed.

First own experiences with leachate treatment

Considering the leachate has been partially stabilized by the storage in artificial ponds, the physico-chemical treatment was studied as an alternative treatment for the Navarro Landfill leachates (Cali, Colombia). The process investigated was coagulation-flocculation-sedimentation and was conducted at laboratory scale, assessing two coagulants: one conventional ($FeCl_3$) and another potential (Neutraolor). The optimum values of the operating parameters that influence the process were determined for each coagulant and at the same time, the removal efficiencies in physico-chemical parameters of water quality and sanitary interesting parameters were determined. At the end of the research, it was found that the optimum dose, coagulation pH, rapid mixing time (RMT) and slow mixing time (SMT) were about 1600 mg/l, 5 un, 80 s and 10 min for $FeCl_3$, and 294 ml (dil. 1/1), 7 un, 40 s and 5 min for Neutraolor, respectively. The maximum removals obtained in terms of color, COD, BOD_5, Detergents, Cyanides, N-NH_3 and Arsenic were 98.3, 51.7, 84, 70.9, 98.1, 30.1 and 85.6% for $FeCl_3$, and 86.9, 44.6, 97.5, 84.6, 80.4, 58.8 and 85.6% for Neutraolor, respectively.

Due to the average removals obtained for Ferric Chloride and Neutraolor in color (97 and 84%), COD (47 and 44%), BOD_5 (75 and 96%), Detergents (56 and 85%), Arsenic (86 and 86%) and Cyanide (97 and 74%), it was demonstrated that the physicochemical treatment for old leachate is a technically viable and successful option.

The coagulation pH is the most important parameter in the leachates coagulation process; in the case of Ferric Chloride, it was found that the lower pH is, the greater Color removal is. The dose of coagulant is the second most important parameter in the evaluated process, being the mixing times also important but less crucial, especially the SMT.

According to the Color and COD results, it can be said that there is a direct relationship between the removal of these two parameters (the higher is the Color removal, the higher is the COD removal), but this only applies to the physico-chemical treatment of the leachate through the process of coagulation-flocculation-sedimentation with inorganic coagulants such as Ferric Chloride and Neutraolor.

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