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Treatment of mixed leachate type I and type III by filtration and chemical oxidation

Tratamiento de lixiviados mezclados tipo I y tipo III mediante filtración y oxidación química

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Summary: In Riobamba city from Ecuador, for more than thirty years solid urban waste was placed in an open dump, without gas and leachate control. In 2016, the landfill was technically closed and an emerging cell with the characteristics of a sanitary landfill was built nearby. The Environmental Health and Hygiene Management Department of the Riobamba Municipal Decentralized Autonomous Government monitors leachate generation, recording 19.24 m3/day of young leachate (Type I) from the emerging cell and 5.78 m3/day of mature leachate (Type III) from the old landfill. The two types of leachates are mixed in the main collection pipe that reaches a storage pool that receives 25,02 m3/day. The results of the physical-chemical analysis determine that the values of the parameters are outside the permissible limits. Turbidity is >1000 NTU (Nephelometric Turbidity Unit), and the concentration of suspended solids is 1200 mg. L^{-1} and iron 135,85 mg. L^{-1}. Calcium (1223 mg. L^{-1}) and manganese (356,15 mg. L^{-1}) were also evaluated, as these minerals are related to the 162000 mg.L^{-1} of hardness. For the treatment of the mixed leachate, two phases are proposed: a) physical treatment by downward filtration in a granular bed to reduce the concentrations of suspended solids, and b) chemical treatment by oxidation using sodium hypochlorite. Laboratory results showed a 96.40% decrease in the concentration of suspended solids. Turbidity stabilized at 65 UTN. Iron, calcium, and manganese concentrations decreased by 95.60%, 96.28%, and 50.60%, respectively.

Keywords: Municipal Solid Waste, Leachate, Filtration, Oxidation.

Resumen: En la ciudad de Riobamba- Ecuador, por más de treinta años los residuos sólidos urbanos se depositaron en un botadero a cielo abierto, sin un control de gases y lixiviados. En el año 2016 se ejecutó el cierre técnico del botadero y en las inmediaciones se construyó una celda emergente con las características de relleno sanitario. La Dirección de Gestión Ambiental Salubridad e Higiene del Gobierno Autónomo Descentralizado Municipal de Riobamba monitorea la generación de lixiviados registrando y 19.24 m^3/día de lixiviado joven (Tipo I), generado de la celda emergente y 5.78 m^3/día de lixiviado maduro (Tipo III), provenientes del antiguo botadero. Los dos tipos de lixiviados se mezclan dentro de la tubería matriz de recolección que llega a una piscina de almacenamiento en la que se recepta 25,02 m^3/día. Los resultados de los análisis físico-químico determinan los valores de los parámetros se encuentran fuera de los límites permisible. La turbidez es >1000 UTN (Unidad de Turbidez Nefelométrica), la concentración de sólidos suspendidos es de 1200 mg.L^{-1} y de hierro 135,85 mg.L^{-1}. A demás se evaluó el calcio (1223 mg.L^{-1}) y manganeso (356,15 mg.L^{-1}), por ser minerales que se relacionan con los 162000 mg.L^{-1} de dureza. Para el tratamiento del lixiviado mezclado se propone dos fases: a) tratamiento físico por filtración descendente en lecho granular con el objetivo de reducir las concentraciones de sólidos suspendidos, y b) Tratamiento químico por oxidación utilizando hipoclorito sódico. Los resultados de laboratorio determinaron una disminución del 96.40% en la concentración de los sólidos suspendidos. La turbidez se estabilizó a 65 UTN. Las concentraciones de hierro, calcio y manganeso disminuyeron en 95.60%, 96.28% y 50.60% respectivamente.

Palabras Clave: Residuos Sólidos Urbanos, Lixiviado, Filtración, Oxidación

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I. Introduction

In Riobamba city (Chimborazo-Ecuador), for about thirty years solid urban waste was placed in a landfill located in San Gerónimo de Porlón, 10 km from the city center. Inadequate waste management caused serious environmental problems due to odor emissions, leachate generation, and the presence of vectors. The Ministry of Environment and Water of Ecuador (MAAE), in 2014 agreed with the mayors to conduct studies for the definitive closure of the dumps nationwide. In 2016, the technical closure of the landfill was completed, and attached to this site on a 30000 m2 plot of land, an emerging cell was built with the characteristics of a sanitary landfill designed to receive 110 tons/day of solid waste.

Since 2017, the Directorate of Environmental Health and Hygiene Management of the Municipal Decentralized Autonomous Government of Riobamba has been monitoring leachate generation. The piping system collects 5.78 m^3/day of leachate from the old landfill i.e. mature leachate (LM) and 19.24 m^3/day of young leachate (LJ) generated in the emerging cell. The two leachates are mixed in a matrix pipe and discharged to a storage pool. The environmental problem arose in 2017 when excessive rainfall in the winter months caused the storage pool to collapse and the leachate overflowed into a stream that is part of the Chambo River watershed. To rectify the problem, the leachate was recirculated to the emerging cell.

Leachate in a landfill is the liquid that infiltrates or drains through solid wastes and contains component materials of such wastes that are soluble, partially soluble, or suspended (Salazar and Saavedra, 2009). Leachate is the result of liquid percolation through the waste. This fluid is composed of rain, composition water, and moisture from the waste itself that drains and percolates causing physicochemical and biological reactions and processes (Méndez, Castillo, Sauri, Quintal, Giácoman and Jiménez, 2009).

The environmental impact of landfills is related to gas emissions (CO_2 and CH_4) and liquid effluents or leachates generated by the moisture contained in the waste, decomposition, chemical and biological reactions, and rainwater percolation (Boumechhour, Rabah, Lamine, Said, 2013).

Leachates are composed of organic and inorganic elements that are classified into 4 groups: 1) dissolved organic matter (COD, TOC, VFA, humic and fulvic acids), 2) inorganic micro components (Ca, Mg, Na, K, NH_4^+, Fe, Mn, Cl, SO_4, HCO_3), 3) heavy metals (Cd, Cr, Cu, Pb, Ni, Zn), and 4) Xenobiotic compounds (aromatic hydrocarbons, phenols, chlorinated aliphatics, pesticides, plasticizers) (Kjeldsen, Barlaz, Rooker, Baun, Ledin, Christensen, 2002; Wiszniowski, Robert, Surmacz-Gorska, Miksch, Weber. 2006; Aziz, S.Q., Aziz, H.A.; Yusoff, Bashir, Umar. 2010). Leachates can present in minimal concentrations of borates, sulfides, arsenate, selenate, Ba, Li, Hg, and Co (Ramírez-Sosa, Castillo-Borges, Méndez-Novelo, Sauri-Riancho, Barceló-Quintal, Marrufo-Gómez, 2013).

Leachate contains chemicals, pathogens, organic matter, nutrients, and toxic substances that can cause harm to human health and the environment (Raco, Dotsika, Battaglini, Bulleri, Doveri, Papakostantinou, 2013). Leachates are associated with the contamination of surface and groundwater sources (Pablos, Martini, Fernández, Babín, Herraez, Miranda, Miranda, Martínez, Carbonell, San-Segundo, García-Hortigüela, Tarazona, 2011), therefore treatment alternatives are estimated according to their composition or by type of contaminant (Martínez López, Padrón-Hernández, Rodríguez-Bernal, Chiquito-Coyotl, Escarola-Rosas, Hernández-Lara, Elvira-Hernández, Méndez, Tinoco-Magaña, & Martínez-Castillo, 2014). Determining the quantity and composition of leachate is an important step for the management system (Abu-Qdais, Hamoda, Newham, 1997; El-Fadel, Bou-Zeid, Chahine, Alayli, 2002), and treatment design (Shouliang, Beidou, Haichan, Lians- Heng, Shilei, Hongliang, 2008).

The degree of biodegradability of leachate is inversely proportional to its age, with young leachate being more biodegradable and mature leachate less biodegradable (Fatima, Rafiq, Hai, 2012; Ramirez-Sosa et al. 2013). The mature leachate usually has a lifetime greater than 10 years; the concentrations of COD fluctuate in ranges of 1000-2500 ppm and BOD between 70-170 ppm. The young leachate has a lifetime of fewer than 5 years, COD values are usually high in the range of 10000-30000 ppm and DBO_5 between 1000-15000 ppm (Torres-Lozada, Barba-H, Ojeda, Martínez and Castaño, 2014).

To study the variability of leachates Bachi (1994) classifies them into three types: Type I: Young or biodegradable leachates (< 5 years), which are characterized by COD concentrations greater than 20000 mg. L^{-1}, DBO_5 less than 0.5 mg. L^{-1} and heavy metals are found in 2 g. L^{-1}. Type II: Medium or intermediate leachates (between 5 - 10 years), with BOD between 3000 and 15000 mg.L-1, BOD between 0.1 to 0.5 mg. L^{-1}, and no heavy metals. Type III: Old or stabilized leachates (> 10 years), COD is less than 5000 mg. L^{-1}, DBO_5 less than 0.1 mg. L^{-1}, and heavy metals less than 50 mg. L^{-1}.

The leachate color varies between 3000 and 15000 color units (CU), in tones ranging from brownish-brown-grayish when fresh, to a black-viscous color when mature, the odors are highly foul and its physicochemical characteristics, are strongly variable in quantity and quality, making the leachate to be classified as one of the most polluting wastes (Méndez et al. 2009).

The characteristics of the leachate in San Gerónimo de Porlón (Riobamba) correspond to what several authors call "typical" according to the age of the cell. There is a difference of more than 30 years between the old landfill and the current emerging cell, so a mixture of Type I and Type III leachate is being collected.

To comply with Ecuadorian regulations regarding effluent control, the Environmental Health and Hygiene Management Directorate of the Riobamba Municipal Decentralized Autonomous Government commissioned the physicochemical analysis of the leachate to the Center for Technical Services and Environmental Technology Transfer - CESTA (April 2017), determining the following results:

Table 1.

Physical-chemical analysis of leachate generated in Porlón

Parameter	Unit	Result	PLV
COD Chemical Oxygen Demand	mg· L^{-1}	36900	200
Biological Oxygen Demand COD_5	mg· L^{-1}	14700	100
Suspended solids	mg· L^{-1}	1200	130
Organic nitrogen	mg· L^{-1}	499.90	50
Ammoniacal nitrogen	mg· L^{-1}	975	30
Nitrates	mg· L-1	415.68	-
Hydrogen potential	pH	6.90	6 - 9
Free chlorine	mg· L^{-1}	0.01	0.50
Sulfates	mg· L^{-1}	25	1000
Total Phosphorus	mg· L^{-1}	29,10	10
Total hardness	mg· L^{-1}	162000	-
Alkalinity	mg· L^{-1}	12900	-
Calcium	mg· L^{-1}	1223	-
Magnesium	mg· L^{-1}	356,15	-
Iron	mg· L^{-1}	135,85	10
Sodium	mg· L^{-1}	1191	-
Potassium	mg· L^{-1}	2573	-

Note. PLV: Permissible Limit Value

Table 1 shows that the parameters analyzed exceed the permissible limit of the Ecuadorian standard. The objective of the research is to experimentally treat the mixed leachate by granular filtration and chemical oxidation to reduce the concentrations of suspended solids, iron, calcium, and magnesium, the latter two parameters being related to the high concentration of hardness in the leachate.

II. Materials and Methods

The flow of mixed leachate entering the storage pool was monitored and its physical characteristics were identified. The tests for physical treatment of the mixed leachate (granular bed filtration) and chemical treatment (oxidation) were carried out in situ at San Gerónimo de Porlón. (1°39’53”S - 78°35’27” W Riobamba- Ecuador), and the physicochemical analysis of the treated product was carried out at the Environmental Services Laboratory of Universidad Nacional de Chimborazo.

Leachate Gaugin

A 90° triangular weir is constructed near the storage pool to measure the incoming leachate flow. The triangular weirs make it possible to obtain precise measurements of the loading heights (H) at reduced flow rates. The Thomson formula was adapted for gauging (Lux, 2010):

$$Q = 1.40\ H^{5/2} \quad \text{Eq.1}$$

Figure 1 shows the 90° triangular landfill located in San Gerónimo del Porlón that serves to measure the leachate flow before being discharged to the storage pool. Triangular landfills allow accurate measurements of load heights (H) at low flow rates. Thomson's formula (Lux, 2010) was adapted for the appraisal:

$$Q = 1.40\ H^{5/2} \qquad \text{Eq.1}$$

Where Q is the flow rate (m^3/s) and H is the water load (m). Three daily measurements of H were performed for a period of one week.

Leachate inflow was monitored at the end of the winter season (June 2017), three times a day (08h00, 13h00, and 16h00) for four weeks. With the data obtained, an average flow rate of 26.50 m^3/day was established.

Physical Treatment Of Leachate

To remove 1200 mg. L^{-1} of suspended solids (permissible limit is 130 mg.L^{-1}), the design of an experimental downflow cylindrical filter with the granular bed was proposed.

Sizing: Equations 2, 3, 4, and 5 (Ordoñez and Pesantez, 2017) were applied for the experimental design of the filter:

$Al = 2\pi rh$ Eq. 2	$A_B = \pi r^2$ Eq. 3
$At = 2A_B + Al$ Eq. 4	$Vt = \pi r^2 * h$ Eq. 5

Where:

Al= Lateral area (cm^2); r= Radius (cm); h= Height (cm); A_B = Base area (cm^2); At= Total area (cm^2); Vt= Total volume (cm^3).

Applying the equations, the dimensions of the experimental filter were obtained as indicated in Table 2:

Table 2.

Dimensions of the experimental filter

Segments	Units	Dimensions
h_t	cm	200
d_t	cm	20
Al	cm	1
To the	cm^2	9424.80
A_B	cm^2	314.16
At	cm^2	10053.12
Vt	cm^3	47124.00

Construction Of The Filter

For the construction of the column-type filter, a PVC pipe of 20 cm diameter (d_t) with a height of 200 cm (h_t) was used. At one end of the pipe, a funnel was incorporated to dose the leachate and at the other end a PVC cover was placed with 25 holes of 1 cm diameter (d_o) and a 1/16" plastic mesh was attached for the drainage of the filtered leachate.

Filter Bed

In the filter, 47124 cm^3 of ¾ (Vt) gravel was placed as a filter bed occupying a height of 150 cm inside the filter, leaving 40 cm for dosing the raw leachate and 10 cm of the free edge.

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Filter Inlet Flow Management

To control the inflow of raw leachate into the system and to collect the output of filtered leachate, flow rate, and filtration rate calculations were performed using equations 6 and 7, respectively (Mott, 1996):

$Q = V / Tr$ Eq. 6

Where: Q= Flow rate (cm^3/min); Volume= cm^3; Tr= Hydraulic retention time (min).

$Vf = Q/At$ Eq. 7

Where: Vf= filtration rate (m/min); Q= Inlet flow to the filter (cm^3/min); At= Total area (cm^2).

Experimentation

Before physical treatment by filtration, the leachate was characterized. One liter of sample was placed in an Inhoff cone and after 45 minutes a minimal amount of sedimentation was observed, so the implementation of a settling tank was ruled out. Approximately 1 cm of cream and foam was recorded on the surface. The creams are a problem for the subsequent treatment stages and should be treated with a grease trap type system. The sample is completely dark, thick, and with an unpleasant odor.

After removing the floating cream, we proceeded to prepare the filtering area by introducing 2 samples of 500 cm3 of leachate into the filter. Once the filter bed was conditioned, 5 samples of 1000 cm3 were gradually introduced, registering a flow rate of 2000 cm3/min. In the process, the average filtration rate was 0.20 cm/min. The average filtration time per sample was 2.50 min. The resulting filtrate liquid was clearer and yellow in color.

Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD_5)

For the design of effluent treatment, it is necessary to know the biodegradability capacity that in theory determines what fraction of the total organic compounds (Gualancañay, 2019). In the degradation of organic matter both COD and DBO_5, increase due to the high content of anoxic or anaerobic bacteria that consume oxygen (Tilley, Ulrich, Lüthi, Reymond and Zurbrügg, 2014).

In Table 1, the results of COD and DBO_5 of leachate are outside the permissible limit value due to the high content of refractory organic material resulting from the contribution of Type III leachate.

The relationship between BOD_5 and COD allows a quantitative approximation of the biodegradability of the effluent and allows the establishment of the most appropriate treatment (Hernández, 1992). The K_b coefficient is directly related to the concentration of organic matter present in the effluent, as mentioned in equation 8 (Fajardo, 2005).

$K_b = BOD_5 / COD$ Eq. 8

If, (BOD_5/COD) < 0.2, the effluent is poorly degradable, and the treatment by chemical methods to oxidize the organic carbon; If, 0.2 < (BOD_5/COD) < 0.4, the effluent is moderately degradable and applies for less aggressive chemical treatment; and If, (BOD_5/COD) > 0.4, the effluent is biodegradable and applies for biological treatments.

When applying equation 8, the result of K_b in the raw leachate is 0.398, therefore it can be chosen to apply a chemical treatment.

Chemical Treatment Of Leachate

The filtered product underwent the chemical oxidation process by applying a 5% sodium hypochlorite (NaClO) solution. To dose the solution, a jar test was carried out with 3 samples of 50 ml of the filtered product. It was determined that the leachate changes its chemical structure and is clarified with 6 ml of NaClO, this change is considered as the end of the oxidizing reaction. The physical characteristics improve the light-yellow fluid.

III. Results and Discussion

After the 2-phase experimentation, the physical results are evident. Figure 2 shows the raw leachate sample with a turbidity >1000 NTU. The physical filtration process allows the retention of suspended solids, registering 400 NTU as shown in Figure 3. As the leachate passes through, the filter bed takes on the characteristics of a percolator (cohesive force). The biomass contained in the leachate will thicken and the biological layer attached to the filter material will enter an endogenous state, losing its adherence to the filter material (Tilley, et al., 2014).

When applying the chemical process with 5% NaClO, a second clarification of the leachate is recorded as shown in Figure 4, reaching 65 NTU. The generation of sedimentable solids resulting from the chemical reaction is minimal.

The treated sample was sent to the Environmental Services Laboratory of the National University of Chimborazo (June 2017) for the respective physicochemical analysis. The results are shown in Table 3:

In the chemical process, the pH of the leachate is increased, however, it remains within the permissible limit. The results obtained indicate a decrease of 96.40% in the concentration of suspended solids. Iron, calcium, and manganese concentrations dropped by 95.60%, 96.28%, and 50.60% respectively. The treated leachate stabilized with a turbidity of 65 NTU, which means a reduction of 93.50%.

Fig. 1. Crude leachate sample

Fig. 2. Filtration treatment

Fig. 3. Oxidation treatment

Table 3.

Analysis of leachate after filtration and oxidation

Parameter	Unit	Leachate		PLV
		Raw	Treaty	
Hydrogen potential	pH	6.9	8.5	6 - 9
COD Chemical Oxygen Demand	mg· L-1	36900	42840	200
Biological Oxygen Demand COD_5	mg· L-1	14700	17800	100
Turbidity	NUT	>1000	65	-
Suspended solids	mg· L-1	1200	43.20	130
Iron	mg· L-1	135.85	6.00	10
Calcium	mg· L-1	12023	446.70	-
Magnesium	mg· L-1	356.15	175.70	-

Note. PLV: Permissible Limit Value

IV. Conclusions

In the physical treatment process by filtration, the cohesion forces in the gravel allow the capture of suspended solids, reducing the turbidity of the leachate.

The K_b coefficient of the raw mixed leachate is 0.398, this value indicates that it is moderately degradable, making chemical treatment appropriate.

The application of 5% NaClO promotes the oxidation of minerals and gives way to a second stage of leachate clarification. The oxidation process raises the initial concentrations of COD and DBO_5.

The physical and chemical treatment applied in the research serves as an experimental reference for the treatment of mixed leachate.

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