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Relationship between age of waste and natural electric potential generation in Sanitary Landfill

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Resumen

Los métodos geofísicos constituyen una herramienta efectiva para determinar alteraciones en las propiedades físicas de los ambientes geológicos, como son los suelos y aguas subterraneas influenciados por contaminantes. Este trabajo consistió en el análisis del potencial eléctrico natural obtenido en zanjas que contienedesechos sólidos con tiempo de confinamiento controlado. La interpretación de los resultados indica una correlación entre el tiempo de confinamiento de los residuos y el aumento de las variaciones de voltaje. Los datos sugieren que el potencial eléctrico resulta predominantemente de el fenómeno de potencial de oxidación/reducción, siendo el potencial del flujo insignificante. A través del análisis estadístico de los datos se estimó ocho años para volver a las características de una zona ausente de residuo, tiempo estimado para la descomposición de la mayor parte de la materia orgánica contenida en los residuos enterrados.

Palabras clave: zanja, potencial espontáneo, materia orgánica, descomposición, oxidación.

Abstract

The geophysical methods are effective tools for determining changes in physical parameters of the geological environment, as soil or groundwater in the presence of contamination. This work consisted on analyzing the natural electric potential obtained over domestic solid waste ditches with controlled closure dates. The interpretation data suggest the generation of electric potential predominantly through the redox phenomenon, as opposed to the flow potential phenomenon. The statistical data analysis indicates a correlation between residence time of the waste and growing variations of voltage. In addition highlights that eight years are required to achieve the reported values for the area with absence of waste, time estimated for decomposition of most organic matter contained in the buried waste.

Key words: ditch, self-potential, organic matter, decomposition, oxidation.

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Introduction

There is a growing need to adapt the application of direct and indirect investigative techniques for use in environmental studies, due to the large amount of synthetic compounds or petroleum products for final use or as raw materials for other industries, spillage or leakage risk during transport and manipulation of these compounds, in addition to undue leaks or discharges of effluents and solid or liquid waste generated during industrial processes, domestic and urban activities.

Detection of changes in physical properties caused by the percolation and residence of contaminants in soils and rocks is the object of study of geophysics applied to environmental studies. The contrast between assessed areas and surrounding areas with natural characteristics to the physical parameter measured, allows 2D and 3D delimitation of potentially contaminated areas.

Studies aimed at analyzing and understanding the behavior of these compounds in the geological environment are necessary and essential, from the perspective of physical and chemical changes due to the presence and interaction with the environment, climatic seasonality, oxygen availability, physical-chemical conditions and others. These changes result in the reduction of compounds toxicity in many cases.

However, in some cases, the release of metals possibly contained in mineral constituents or compounds may occur, as well as a possible increase of toxicity by compounds generated from the degradation of initial contaminants.

Understanding the modifications of physical properties as for the presence of contaminants in geological environment is essential to geophysics application and interpretation in environmental studies.

Measures of self-potential (SP) can promote means of detection and relative quantification of contaminants in groundwater. Baker and Cull (2004) applied the method in the valley of King river – Tasmania, to evaluate the presence of metals from tailings of the Mt. Lyell sulphide mine located nearby. The contours of electric potential were consistent with hydraulic potential estimated by piezometers, factor that assisted on the refinement of groundwater flow model and understanding the pressure gradients observed in drillings.

In Mota *et al*. (2004) study, self-potential and electro resistivity methods were applied to evaluate the granitic massif structure underlying Póvoa de Lanhoso – Portugal landfill. The results allowed the definition of low resistivity zones correlated with negative values of self-potential, which indicates impacted areas by contaminants from the landfill.

In this research line, Nimmer and Osiensky (2002) made self-potential and resistivity measurements in surface and in drilling holes to assess the flow of a salt plume in a partially fractured basalt in Idaho – United States. The results indicate that self-potential allows additional details about the plume dynamics in a complex environment, in relation to artificial electric field techniques, which in some surveys were insensitive to contaminants presence.

These cases quoted above corroborate the hypothesis of self-potential generation by the flow of electrolyte solutions in porous and fractured aquifers, represented in these cases by contaminants from the landfill and saline solution.

Measures of self potential and redox potential (Eh) were used in the works of Naudet *et al*. (2003) and Naudet *et al*. (2004) to study the evolution of a contaminant plume from a landfill. The results show that the electric potential progressively decreases in the aerobic zone, increases dramatically in the redox front and finally reaches the standard of the study area when achieve the oxidation zone. There is a high correlation between measurements of self-potential and redox potential in the profile.

The previously mentioned works, in contrast, indicate the possible generation of natural electric potential by degradation processes of the organic compounds accumulated in solid waste landfills.

This study evaluates the results of applying self-potential method at a domestic organic waste landfill, arranged in trenches with different closing dates. The relationship between time of closing trenches, decomposition of organic waste and variations of voltage measured by geophysical method, allow estimating the time necessary to geochemical stabilization of the area.

Methodology

The self-potential method is characterized by natural electric field accuracy readings, without any electric current injection circuit or generation of electromagnetic field (Orellana 1972). The advantage lies in the simplicity of involved instrument and versatility of data acquisition into small areas, in addition to the variability of the physical parameter as measured in the geological environment. The main disadvantages associated with the method are the need of connecting cables between reading sensors and the equipment, use of non-polarizable electrodes, besides the high susceptibility to noises produced by electrical systems such as transformers, grounding and engines, elements that may hinder tests in large or urban areas.

Contrasts of self-potential results in variations of temperature, pressure gradient, porosity, fluid migration, variation of resistivity and soil humidity (Corwin 1990). As for the generation process, self-potential can be classified as electrochemical potential, electrolytic and mineral. The mineral potential arises due to geochemical redox reactions in an ore body, corresponding to the galvanic cell defined by Electrochemistry.

From the analysis of the main current theories, Sato and Mooney (1960) proposed a mechanism for the origin of self-potential, within the phenomenon of mineral potential. This mechanism involves a reaction between two electrochemical cells, present simultaneously in two different locations in an ore body. Normally, one cell is above and another below the phreatic level and are interconnected by ore body. These two cells are opposite in nature, an anode and a cathode, with reactions involving gain and loss of electrons. Above the phreatic level oxidation reactions occur, while below reduction takes place.

The potential differences generate natural currents that arise due to redox potential differences of the surrounding solution through contact between the edges of the ore body. The dissolved substances around the upper body are in relative state of oxidation and reduction below the phreatic level, these relative differences in the degree of oxidation are revealed in different Eh values and result in electric current flow in the presence of an electronic conductor, in this case represented by the ore body.

The reduced electrons from the lower portion are conducted to the oxidized upper portion through the ore body, in this way the lower portion is relatively oxidized opposite to the upper, relatively reduced. In this mechanism, the ore body does not participate directly in the electrochemical reactions, otherwise, would be consumed during the process. This acts only as a mean of transporting electrons chemically inert.

Corry (1985) and Nyquist and Corry (2002) works analyzed Sato and Mooney (1960) proposal and raised some incongruent questions in the proposed model:

Width: according to this model, values greater than 800mV are not possible based on the Eh potential of sulfides, whose maximum amplitude of the anomaly generated between the poles of geobattery in relation to the reference electrode is only 400mV. However, several studies of sulfide bodies have reported values of 1000mV or more (Gay 1967).

Loss of the positive pole: This model requires positive and negative poles. Measures of self-potential in surface, subsurface and drill hole in ore bodies show negative anomalies relative to the reference electrode located near the body.

Groundwater level: There are no references in this model regarding anomalies of self-potential in ore bodies completed dry or wet or over sulfides, characterized by central conductor not inert.

Stability: direct measures of self-potential anomalies associated with sulfide bodies are stable for decades and, presumably, during geologic time. However, the model does not explain how the geobattery does not discharge or values do not fluctuate in the face of seasonal fluctuations of the phreatic level and the consequent seasonal variations in chemical composition of groundwater.

Such authors suggest that the arrangement of pairs of electrodes only measure the difference of potential between the electrode on the anomaly and the reference electrode.

In a galvanic cell electric current flow doesn't occur unless the electrodes are set in environments with potential differences. This way self-potential would be generated between electrodes connected by a cable and not by an ore body, from the closed circuit between a relatively more oxidized zone and another more reduced.

The electrochemical potential can be originated by biodegradation processes in soil or rock context with organic matter, present in landfill. These materials are frequently recovery by successive layers of soils after filling dispositions cells. Such context allows the predominance of physical and chemical reduction conditions in waste, responsible for stimulating a proliferation of anaerobic microorganism colonies.

The action of microorganism in organic matter occurs by three successive stages (Themelis & Ulloa, 2007; Barlaz *et al*., 2002). In principle, fermentative bacteria hydrolyze the complex organic matter into soluble molecules, which in turn are converted by acid forming bacteria to simple organic acids, carbon dioxide and hydrogen; the principal acids produced are acetic acid, propionic acid, butyric acid and ethanol. In the third stage, methane is formed by methanogenic bacteria, either by breaking down the acids to methane and carbon dioxide, or by reducing carbon dioxide with hydrogen.

The contrast between reduction in waste and oxidation in geologic substratum results in similar conditions to electrochemical cell, in intensity measurable by geophysical instruments.

Study area

The Cordeirópolis landfill is located at km 4.5 of Cássio Freitas Levy highway (Cordeirópolis-Limeira highway), Cordeirópolis city, São Paulo State, Brazil (Figure 1). The city has about 17,000 inhabitants, with an economy based on the production of ceramic tiles and the cultivation of sugar cane. The daily production of domestic solid waste is approximately $6m^3$.

The study area is a trench-type controlled landfill, for disposal of domestic solid waste only. The operating system consists in 5 m deep trenches, 4m wide and 80m long, for directly disposal of waste on the soil and subsequent coating with a soil layer of 1m.

This area has 48.400 m^2 available for waste disposal, starting with activities in 11/2001 and life expectancy to 20 years. The physical structure of the landfill is devoid of electric power distribution systems.

The topography of the area is fairly flat, with average slope of 0.5 % in southeast direction and altitude between 660m and 659m. The landfill is surrounded by sugar cane cultivation.

The substrate is constituted by clay soil with 10m thick, and above by a body of diabase with 15m thick. Below there are fine sandstones and siltstones belonging to Tatuí Formation. Groundwater level is located at an average depth of 50m, with flow direction to the southeast, both determined using vertical electrical sounding (Moreira *et al*, 2009). Field tests of saturated hydraulic conductivity revealed average values of 10^{-4}cm/s for the soil. There are no wells installed in the area or any other environmental monitoring systems.

In this area 241 readings of self-potential were made through the fixed base arrangement, distributed in regular mesh of the acquisition, with start of recent ditch (extreme NW) from oldest ditch (extreme SE). The base electrode was fixed upstream of groundwater flow, precisely at the landfill access gate (Figure 1).

The acquisition was performed in two steps:

- First step: voltage readings in square mesh of 20m x 20m, for a broad characterization of the area.

- Second step: readings taken just about the ditches with closing date in December, between 2001 and 2007, with 5m spacing between readings. This step objective was to determine a possible relationship between the decomposition of buried waste and voltage variations over time.

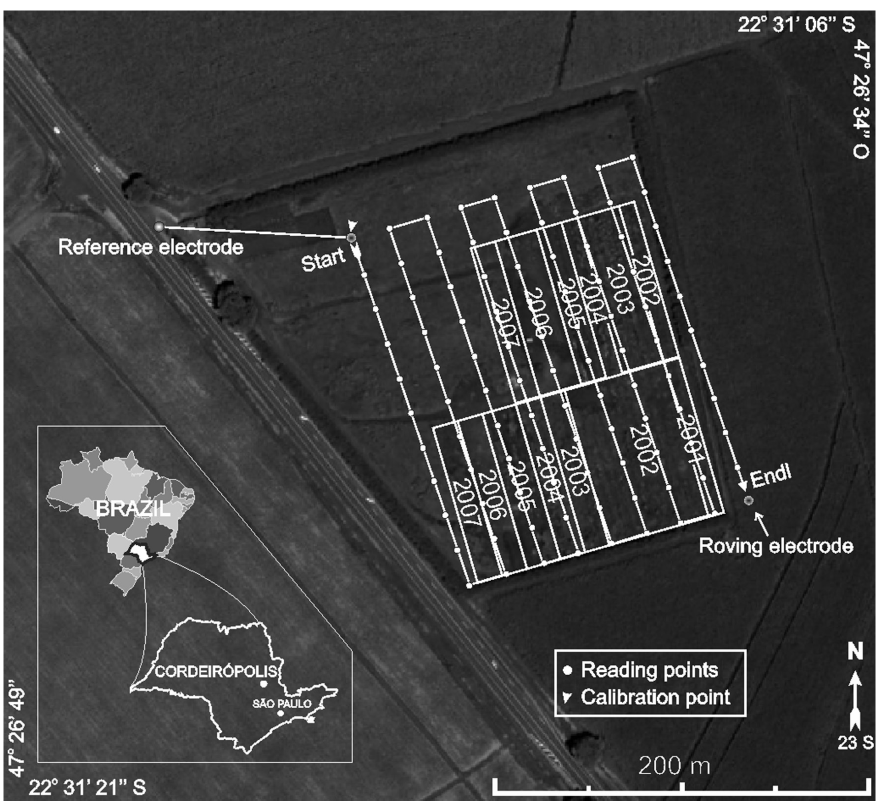

Figure 1. Area of study.

This study used non-polarizable Pb-$PbCl_2$ electrodes characterized by high stability over time (Petiau 2000). The data reduction involved the following proceedings: acquisition of absolute voltage, drift correction between initial and final lines and base tie-in correction, according Corry (1985) and Telford *et al*. (1990).

The obtained data after reduction are presented graphically. The measurements obtained in regular mesh were georeferenced and interpolated in the program Surfer 8.0, by the neighborhood method.

In the neighborhood method, initial groups are established by the highest coefficients of mutual association, for the admission of new members is sufficient to determine which represent the highest association with the elements of a given group (Landim 2004). Hence, the choice of the interpolation method was based in fidelity to the interpolated values and limitations of the surface to the extreme input values.

Results

The self-potential measurements in regular mesh are presented in map, below closure ages of waste ditches (Figure 2).

The acquired data indicate more negative values in the ditches closed between 2007 and 2006 (0mV to 10mV), and widespread occurrence of values between 10mV and 30mV in ditches closed between 2005 and 2004. Measures between 30mV and 70mV occur in ditches closed between 2003 and 2001.

The position of the groundwater level around 50m deep, waste ditches dug up to 5 m deep in clay soil, suggest that the values of self-potential are produced by geochemical activity. The relationship between voltages values increasing positively with increasing time of organic waste degradation contributes to this effect.

Measures below 20mV are practically contained in the ditches limits closed between 2007 and 2006. The trend of increasing positive values in the oldest ditches may be associated with the decrease of available organic matter and consequent geochemical stability. The elevated measurements obtained in the ditches closed between 2003 and 2001 may indicate an advanced stage of degradation.

The generation of leachate and its chemical, physical and microbiological characteristics are related to the decomposition of organic matter present in the solid waste stored in landfills.

The fluids produced in landfills are often acidic, with variations associated with substrate type, climate, waste type, and seasonal variations, among others. From the production of leachate

Figure 2. Self-potential map with closure ages of the ditches.

several changes occur that involve aerobic stages - acetogenic, and anaerobic - methanogenic (Bagchi, 1987; Fang 1995). The pH tends to increase with time since initial acid forms tend to neutralized states, with decrease of chemical oxygen demand (COD) and biological oxygen demand (BOD) (Farquhar 1989; Moreira *et al*, 2009). The total organic carbon content, total fatty acids or ketones and total dissolved solids are high during acetonagenesis and low for methanogenesis, ie decrease with residence time of organic matter (Birks & Eyles, 1997; Meju, 2000).

The self-potential data acquired during the second stage surveys confirm the trend of increased self-potential for recent ditches to old ones (Figures 3 and 4). This increase is possibly associated with increased geochemical stability over the period of organic waste degradation.

Large amounts of water can permeate the bit compressed waste in old landfills, when compared to landfills recently compressed, resulting in a relative low concentration of chemical constituents in leachate of old landfills, with high porosity and permeability (Radnoff *et al*. 1992).

The study area is located in a context of clay soils and low hydraulic conductivity, also associated with the fact of the occurrence of a profound groundwater. In this case, it is likely that the oxygen supply in the ditches of waste occurs by percolation of rainwater in all the ditches, with an increase of atmospheric oxygen, especially in the oldest graves, where the compaction of waste results in the fracturing of the soil cover.

Even further incursions of oxygen result in little geochemical activity due to drastic reduction in the supply of organic matter consumed over the years of the waste residence.

The obtained values on the reference line are relatively less variable and higher than those acquired on the waste ditches. In contrast, the values obtained on the ditches have a tendency of increase or decrease towards the end of the line, respectively referring to the ditches in 2007 and 2003. Relatively higher values in the central portion of the lines are presented by the measurements obtained on the ditches in 2002 and 2001.

The measurements on the 2007 ditch present relative lower values, with extreme measures between -1mV to 28mV. The ditches in 2006, 2005 and 2004 present higher values, with extremes measures between 20mV and 48mV.

Statistical analysis of self-potential average values measured on the waste ditches indicates the period of 8 years to return to the natural values, from the first year of closure (Figure 5).

Due to the low permeability of the landfill soil, it is likely that the electrical potential measured reflects almost exclusively the redox potential of the organic matter contained in the buried waste, as described in papers by Naudet *et al*. (2003), Naudet *et al*. (2004) and Moreira *et al*. (2011), to the detriment of electrical potential generated by the flow of inorganic solutions in porous and fractured aquifers, such as the work of Baker and Cull (2004), Mota *et al*. (2004), Nimmer and Osiensky (2002).

In this sense, the estimated period for return to the natural values of electric potential must indicate the time required for consumption of organic material from rapid decomposition. In a context of domestic solid waste, this organic material is represented mainly by food debris, oils and vegetal and animal residues, in addition to oil derived products and greases on a smaller scale.

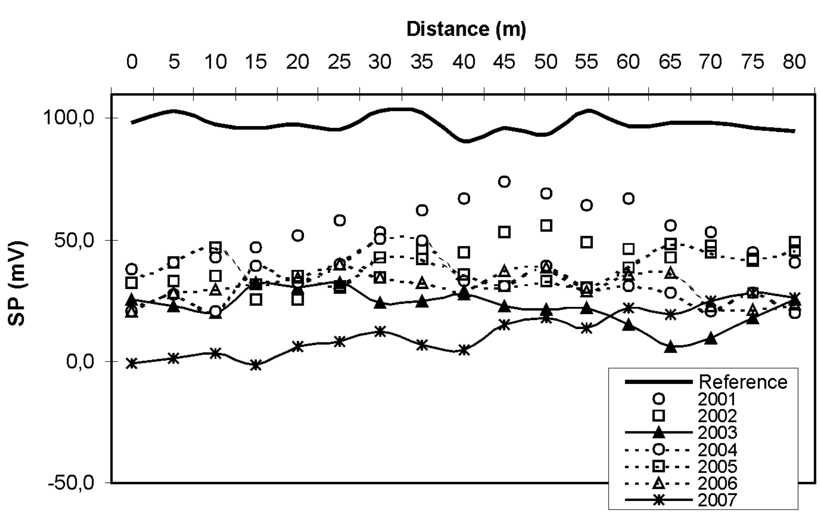

Figure 3. SP measures obtained over the ditches.

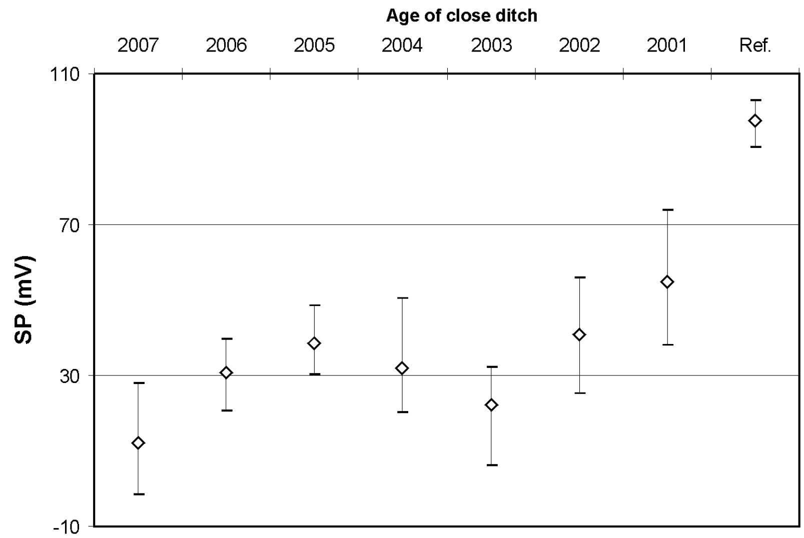

Figure 4. Mean and extreme values of SP for the second stage surveys.

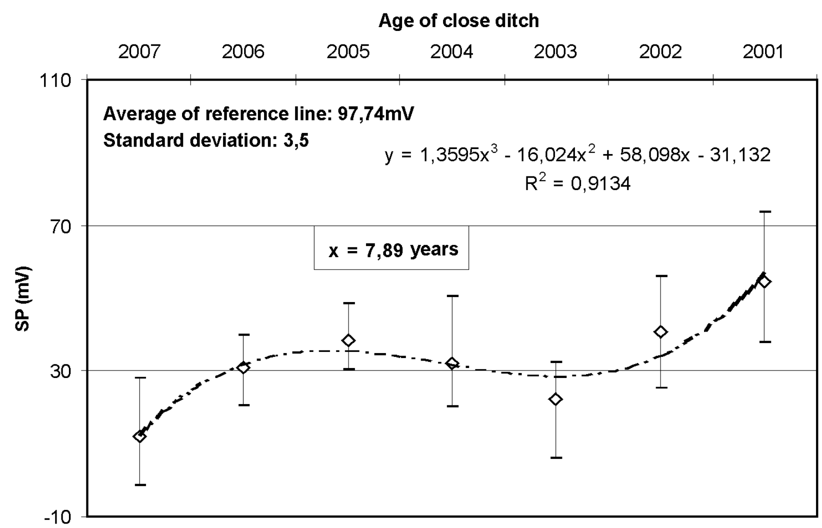

Figure 5. Statistical analysis of the second stage data.

Conclusion

The results show the possibility of applying the self-potential geophysical method in studies of domestic solid waste disposal areas, whether as preliminary studies in areas under the absence of environmental monitoring devices, or as a complementary technique of investigation.

However, the applicability of the self-potential method and the results obtained in this work were made possible due to absence of electrical noise and the small area covered during the survey. The application of this method for studies in urban areas is severely impaired due to the frequent presence of electrical systems in this environment, which generate interference during measurements.

The natural electrical potential measurements indicated a relationship with the decomposition period of the waste, ie gradual increase in the electrical potential concomitant with the increase in the residence period of the waste. The occurrence of values close to zero in the ditch in 2007 and positive values and rising towards the older ditches indicates that the decomposition of organic waste produces electric potential that can be measured by geophysicist instrumental.

Decomposition processes of organic matter described in landfills involve the consumption of organic matter in aerobic and anaerobic stages, with oxygen consumption and generation of sub products such as CH_4 and CO_2. The high oxygen consumption in latest ditches rich in organic matter results in a reducing environment, characterized by values that tend to negative. The decreasing availability of this material produces progressively less reducing conditions, reflected in increasingly positive electrical potential.

The progressive increase of the electric potential values enabled a statistical analysis that revealed the need for about 8 years so that the values measured on the waste ditches are similar to the electric potential of the uncontaminated adjacent area.

This result is indicative of the average period for much of the organic matter consumption contained in domestic waste. However, the decomposition of waste such as paper, plastics and metals require tens to hundreds of years. The possibility of electric potential generation in this case is open to somewhat uncertain future studies.

The predominance of organic matter in the buried waste, existence of a deep groundwater and lack of metallic conductor ore body are elements that do not favor the application of the geobattery model in an attempt to understand the factors that are responsible for the generation of electric potential contrast measured in the study area.

Fixing the reference electrode in the external and topographically elevated area, different of the reading electrode moved to 241 measurement points and preferably fixed over waste ditches submitted to the action of organic matter decomposition processes, are elements that contribute to the understanding of the generation mechanism of natural electric potential in the study area, based on the proposed Nyquist and Corry (2002). In this case, the contrast is generated by the potential difference between the reference electrode and the movable electrode.

The likely predominance of the redox potential in the values generated by the decomposition of organic waste is indicative of the possibility of applying this geophysical method for monitoring areas contaminated by petroleum products.

Even though involving relatively high complexity processes, the decomposition of oil in soils also requires the consumption of oxygen in several degrees, which depend on concentrations of contaminants within a plume of contamination, as suggested by the works of Rabus and Heider (1998) and Thomas and Ward (1989). Therefore, similar results obtained in this work can also be achieved in areas contaminated by petroleum products.

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