EVAPORATION PHENOMENON AS A SUSTAINABLE SOLUTION FOR LANDFILL LEACHATE TREATMENT

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SUMMARY: One of the main environmental risks of using landfill as waste destination is the leachate produced, which is the result mainly of the rainwater percolation through the waste mass. Among the main emerging techniques of leachate treatment is evaporation, which consists in the elimination of the liquid fraction of leachate, resulting in a solid concentrate. The aim of the present study was to implement and monitor the performance of a natural evaporation technology. A pilot scale evaporator using a high specific surface panel was designed to evaluate the use of this technology in the treatment of landfill leachate, which can be implemented where traditional systems are not technically or economically feasible. The results obtained during the experimental period (January to September, 2008) showed a daily average evaporation rate superior to 26 L/m^2 of panel. Although raw leachate used in the assays was very toxic, the resulted concentrate was tested non toxic to *Daphnia magna*. Statistical analysis showed that the main environmental variables in evaporation were solar radiation, wind speed and air temperature.

1. INTRODUCTION

Sanitary landfill is one of the most used techniques in the world for urban solid waste destination. To avoid risks to the surrounding environment the waste material is safely confined and isolated.

Wang *et al*. (2002) indicated that the municipal landfill leachate has been one of the major problems for the environment because of high organic, inorganic and heavy metal content and toxicity characteristics. Therefore, once extracted from the landfill, the leachate produced must be treated before being discharged into the environment. Operationally, leachate treatment is both a very difficult and expensive process.

These difficulties are mainly due to the characteristics of the leachate produced which depend upon many factors like precipitation, environment temperature, landfill age, waste composition nature content, absorbent capacity of the waste, depth of the landfill, compaction and permeability. U.S. EPA (1995) reported that leachate composition and strength vary from landfill to landfill and even within a given landfill. These aspects imply on variations in the characteristics, concentration and volume of the effluent produced.

Plenty of techniques can be used for leachate treatment although must consider a wide range of possibilities, in order to assure an efficient treatment despite the variations in the characteristics of the effluent to be treated.

Among the main emerging technologies for leachate treatment, natural evaporation may offer the potential to eliminate the liquid fraction (one of the two major by-products of landfill operations), converting in a concentrated residual the original leachate.

The objectives of the present study were to design, develop and monitor a pilot scale evaporation treatment unit for the treatment of landfill leachate. The concentrate toxicology was also evaluated in order to identify the risks of the operational conditions and subsequent environmental risks of this technology. The assays were developed in south Brazil and the results were associated with the main climatic variables, in order to evaluate the performance of the evaporator according to the local climatic conditions.

2. FUNDAMENTALS OF LEACHATE TREATMENT

2.1 Landfill leachate characteristics

Sanitary landfill leachate are concentrated liquids, characterized initially by acid pH, high values of COD (Chemical Oxygen Demand) and BOD (Biochemical Oxygen Demand) and the presence of toxic compounds (Qasim and Chiang, 1994). During the percolation of water through the waste mass, various chemical and biological reactions occur. As a result of these reactions, organic and inorganic compounds are formed in the waste mass and transferred to the leachate produced, which need to be removed from the landfill and treated (McBean *et al*., 1995).

Overall, young leachate, produced during the first 3-4 years of operation of the landfill, present organic matter readily biodegradable, therefore these liquids tend to be acid due to the presence of volatile fatty acids. The pH in this phase varies between 6 and 7 and BOD (10.000-20.000 mg/L) and COD (20.000-40.000 mg/L) concentrations are elevated when compared to those found in domestic effluents or even in older landfill leachate (McBean *et al*., 1995).

After 4-5 years, leachate characteristics tend to change, presenting values of pH between 7 and 8. These changes occur as a result of the depletion of the biodegradable organic matter and the production of gases. Other parameters also tend to stabilize and the values of BOD and COD, initially elevated, are reduced to rates around 500-3000 mg/L and 50-100 mg/L, respectively (McBean *et al*., 1995).

Bidoni and Povinelli (1999) indicate even greater values of BOD in landfill leachate, around 30 to 150 times greater than those of domestic effluent, which vary from 200 and 300 mg/L. These authors also specify that landfill leachate present high concentrations of ammonia nitrogen, soluble in water and toxic beyond certain concentrations.

Clément and Merlin (1995) enlighten that studies carried through by various researchers with 89 samples of leachate indicate that ammonia, usually found in high concentrations in these liquids, was described and the main compound to attribute toxicity to the effluent. The study carried through by Clément and Merlin (1995) showed that ammonia concentration in landfill leachate varying from 100 to 1000 mg/L are toxic to duckweed (*Lemna minor*) at a pH of 8. The same concentrations at a pH of 5 were shown to be considerably less toxic.

2.2 Main leachate treatments

Landfill leachate treatment techniques can be physical, chemical and biological processes, which are usually used in combination. Air-stripping, adsorption, membrane filtration are major physical leachate treatment techniques (Amokrane *et al*., 1997; Bohdziewicz *et al*., 2001; Morawe *et al*., 1995; Trebouet *et al*., 2001), coagulation, flocculation, chemical precipitation, chemical and electrochemical oxidation techniques are the common chemical techniques for landfill leachate treatment (Amokrane *et al*., 1997; Ahn *et al*., 2002; Chiang *et al*., 2001; Lin and Chang, 2002; Steesen, 1997; Marttinen *et al*., 2002). Di Palma *et al*. (2002) used evaporation and reverse osmosis for the treatment of industrial landfill leachate.

Due to the complex nature of leachate characteristics and increasingly rigorous treatment standards, it is difficult to treat this effluent in a single and traditional process. More complex systems can be applied but they present disadvantages concerning for example the availability of physical area and associated costs.

Kargi and Pamukoglu (2003), Koh *et al*. (2004), Wang *et al*. (2002) and Rivas *et al*. (2003) successfully applied combined processes; coagulation-flocculation + biological treatment; photochemical oxidation + activated sludge; Fe(III) chloride coagulation+photo-oxidation; and ozonation alone for treating landfill leachate (Baig *et al*.; 1999; Kuo, 1999; Silva *et al*.; 2004; Steensen, 1997). In literature, combined chemical and biological treatment of landfill leachate has also been investigated.

Among the recent techniques developed for leachate treatment is forced evaporation, in which leachate is evaporated through heating, usually using thermal energy from the landfill gas (LFG) produced. Many technologies are being studied and some of which already developed and in operation that allow, through forced evaporation, the combined treatment of both of the main by-products of a landfill, LFG and leachate. The original effluent results in a sludge that can be deposited directly in the landfill, as long as authorized by the environmental organs (Roe *et al*., 1998).

Another emerging technology for effluent evaporation is natural evaporation with panels, function of local climatic conditions and the enhancement of the contact area between air and liquid, enhancing the evaporation phenomenon. This technology is currently used in real scale in the treatment of various agro-industrial effluents and, in the work here presented, studied in a pilot scale unit for landfill leachate treatment.

2.3 Natural evaporation with panels

Water evaporation was first used by Phoenicians, Romans and Chinese to obtain salt from seawater. Large bowls were filled with seawater and natural evaporation occurred through solar and wind action, leaving behind dry salt (Fink and Hart, 2001).

In more recent times natural evaporation has been used also for treating domestic and other types of effluents. Bondon *et al*. (1994) developed a research using evaporation to treat winery agro-industrial effluents. The system operated through evaporation panels that enhanced the contact area between liquid and air. They initially worked with a trial experiment using 2 evaporation panels, resulting in an average daily evaporation of 1,18 m^3.

With these encouraging results, a real scale unit was implemented initially with 6 panels and is responsible for treating the whole effluent produced yearly by a winery located in the south of France.

In the meantime, the study developed by Duarte and Neto (1996) presents an alternative for the treatment of pig slurry through natural evaporation. Due to the characteristics of the effluent, a pre-treatment was necessary to separate the solid from the liquid fraction, in order to avoid the obstruction of the panel and the sprinklers used.

Duarte and Neto (1996) studied the evaporation process with panels with the intention to supply an alternative solution to the traditional pig slurry treatment for regions where these techniques are economically or technically impracticable, valuing the advantages of local climatic conditions (air temperature, relative humidity and wind speed).

For Duarte and Neto (1996) the studied process had satisfactory results during the trial period, with an average daily evaporation per panel of 2,31 m^3. Besides the important evaporation rate, the system was found to consume 1/10 the energy of the usual treatments, for the same volume treated. The authors emphasized the importance of the evaporation phenomenon as a simple solution to deal with complex environmental issues.

3. EXPERIMENTAL STUDY

3.1 Apparatus

The experimental pilot (Figure 1) was implemented based on the studies of Bondon *et al*. (1994) and Duarte and Neto (1996), adapting it to the characteristics of landfill leachate and to the resources available. The pilot unit was located in the UFSC campus in Florianopolis, Brazil.

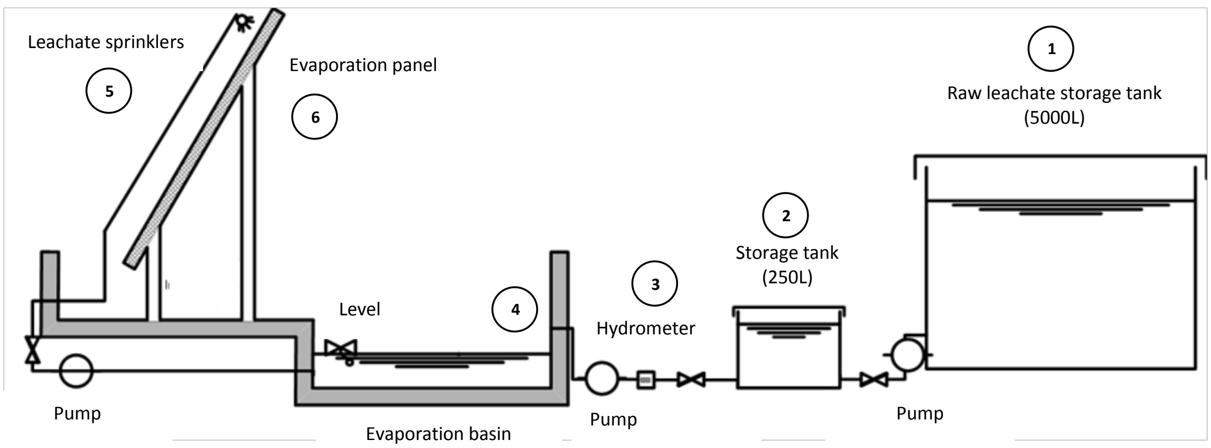

Figure 1. Scheme of the experimental evaporation system.

Raw landfill leachate was stored directly onto a storage tank (5000 L) (1) and pumped to a smaller storage tank (250 L) as level variation occurred (2). As the liquid entered this smaller tank it was filtered in order to avoid the entrance of parts (pebbles, rocks, etc.) that could damage the evaporation system (pumps, sprinklers, panel, etc.).

The 250 L tank fed the evaporation basin (4), where evaporation of the liquid occurs. As the level varies in the evaporation basin the pump is activated, feeding the system. The hydrometer (3), located between the storage tanks and the evaporation basin, measures the leachate volume fed into the system.

From the evaporation basin leachate is pumped to the 4 tri-directional rotating sprinklers (5), which distribute the liquid on the whole panel surface (6). The panel is in polypropylene, similar to a beehive structure, with dimensions of 1,0 x 3,5 x 0,3 m (base x height x width). The panel was placed in the direction of the prevailing wind, which in Florianopolis is from Northeast (NE) and leaned, on its width, to an angle of 60° with the horizontal line. Therefore, the panel, which develops an area of approximately 200 m^2 of exposure, occupied a projected area on the ground of about 2 m^2.

Due to the inclination of the panel (60°), part of the leachate percolated through the panel structure, where evaporation occurred, and the exceeding part of the liquid returned, through gravity, to the evaporation basin for recirculation.

3.2 Experimental procedure

3.2.1 Evaporation in the experimental system

The water balance of the process considered the natural evaporation of the environment, precipitation and the volume of leachate fed into the evaporation system. With these components it was possible to esteem the evaporated volume fraction attributed to the presence of the evaporation panel.

The monitoring of the experimental pilot was carried through daily, from January to September 2008. Natural evaporation was measured through a Class A Pan evaporimeter, the amount of rain in the period was supplied through a meteorological station located next to the experimentation area and the leachate volume was measured through the hydrometer located before the evaporation basin.

The resulting evaporation in the system was related with the main climatic variables in the region in order to determine which of these components have the most influence in natural evaporation with panels.

3.1.2 Raw leachate and concentrate toxicity

The acute toxicity test allows to evaluate the toxicity of a sample on a determinate aquatic organism, exposing it to various concentrations of this sample, in a short period of time (usually 24-48h). The results are expressed in Median Effective Concentration - EC(50), which represents the concentration in which 50% of the exposed population survives the sample in a determinate period of time (Brentano, 2006).

For each test 500 ml of raw leachate and concentrate in the evaporation basin were collected. For each sample 5 dilutions were prepared with volumetric precision in geometric progression, common ratio 2. Each dilution was carried through in duplicate in test tubes containing of approximately 25 mL of the solution, with 20 organisms (*Daphnia magna*) tested per dilution.

After 24 and 48 hours the number of immobile organisms was counted and from this information the EC(50) was calculated. The Dilution Factor (DF) of the sample was also calculated, and it represents the first of a series of dilutions of a sample in which acute toxic effects are no longer observed in the organisms tested (no immobile organisms).

4. RESULTS AND DISCUSSION

4.1. Evaporation in the experimental system

Table 1 presents the monthly evaporation in the experimental pilot. Besides the rain volume in the system and the leachate volume evaporated, both natural and the panel evaporation are specified, as well as the contribution of each to the total evaporation in the period.

Table 1. Experimental pilot evaporation results.

Period	*Rain. [m³]*	*Leachate volume [m³]*	*Natural evaporation (E_N) [m³]*	*Panel evaporation (E_P) [m³]*	*Total evaporation [m³]*	*Contribution*	
						E_N [%]	*E_P [%]*
January 2008	2,65	6,66	0,71	8,60	9,31	8	92
February 2008	1,59	0,85	0,55	1,89	2,44	23	77
March 2008	2,31	0,39	0,64	2,06	2,70	24	76
April 2008	1,22	1,44	0,58	2,08	2,66	22	78
May 2008	0,16	1,25	0,66	0,75	1,41	47	53
June 2008	1,60	0,11	0,54	1,17	1,71	32	68
July 2008	0,22	2,23	0,56	1,89	2,45	23	77
August 2008	1,15	0,92	0,51	1,56	2,07	25	75
September 2008	2,69	1,16	0,51	3,34	3,84	13	87
Total	*13,58*	*15,01*	*5,26*	*23,34*	*28,59*	*18*	*82*

The total volume evaporated in January represents nearly 33% of the amount evaporated during the whole trial period. Other than being the month with the highest temperatures during the experimental period, this volume may also be attributed to the type of sprinkler used initially, which emanated very small droplets that were frequently dispersed in the surrounding environment in days of elevated wind action. Seen this dispersion, sprinklers were changed and 4 tri-directional rotating sprinklers were adopted for the rest of the trial period.

During the trial period the total evaporation was of 28,59 m^3, equivalent to an average evaporation of approximately 111 $L.day^{-1}$.

Considering the accumulated evaporation in the period, and average of 82% of it is attributed to the evaporation panel. However, the contribution of natural and panel evaporation in the system is uneven throughout the period. In the months with highest air temperature and solar radiation the panel contributes in more effective. In contrast, in months in which climatic conditions are less favorable for evaporation the panel has a similar evaporation rate as natural evaporation (Figures 2 and 3).

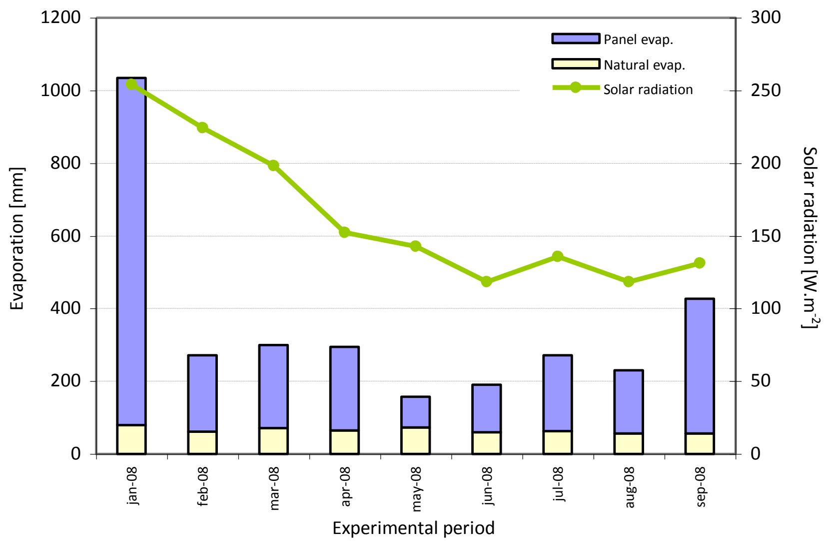

Figure 2. Monthly accumulated evaporation and average solar radiation in the period.

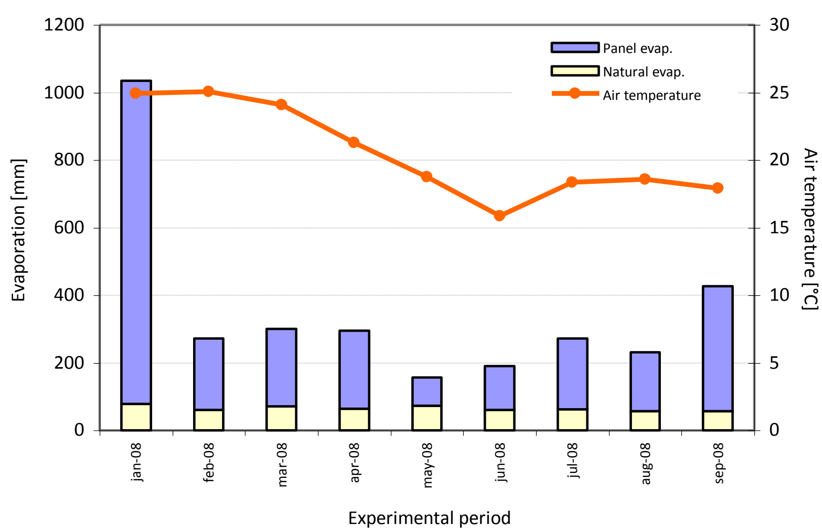

Figure 3. Monthly accumulated evaporation and average air temperature in the period.

Of the total volume evaporated, 15,01 m^3 represent the elimination of leachate, the remaining volume (47%) was due to the elevated rain rate in Florianopolis in the period. The average landfill leachate evaporation rate in the system was of $58L.day^{-1}$.

The statistical analysis (Kendall Tau's non parametrical test) of the data showed that the main climatic variable in natural evaporation with panels is wind speed, followed by solar radiation and air temperature. Relative humidity, which resulted non significant in the statistical analysis, vary in an inverse proportion with evaporation. Therefore, regions with lower relative humidity may be more indicated for the implementation of this technology.

Knowing the total volume generated yearly in a landfill and based on the local climatic conditions, it is possible to implement a leachate treatment using natural evaporation with panels. According to Bradfer (2006), real scale units should foresee an emergency basin with the capacity to store from 30 to 50% of the volume produced yearly in order to operate safely in periods not favorable for evaporation. Bradfer (2006) also quotes that, in this type of system, the installation of panels can be gradual, adding more panels to the plant as the production of effluent increases.

4.2 Raw leachate and concentrate toxicity

Acute toxicity tests revealed elevated toxicity of raw leachate (Table 2) and the absence or low toxicity for the concentrate in the evaporation basin (Table 3).

Table 2. Acute toxicity results on raw leachate.

Test number	*1r*	*2r*	*3r*	*4r*	*5r*	*6r*
pH	8,51	8,84	8,72	8,90	9,13	8,75
EC(50)	5,25	10,27	5,83	4,41	3,97	3,34
DF	32	16	32	32	64	64

Table 3. Acute toxicity results on the evaporation concentrate.

Test number	*1c*	*2c*	*3c*	*4c*	*5c*
pH	9,02	8,96	8,96	9,09	9,70
EC(50)	100	48,3	6,93	70,71	35,35
DF	0	4	**32**	2	4

Physical-chemical characterization of the samples was carried simultaneously with the acute toxicology tests in order to correlate the results obtained.

Correlating the results of the acute toxicity tests with the physical-chemical characteristics of the liquid allows to attribute, despite not excluding other factors, the toxicity of raw leachate to the elevated ammonia concentration found (above of 1.000 $mg.L^{-1}$), as indicated by the research of Clément e Merlin (1995). The results of the acute toxicity tests with the concentrate from the evaporation basin, where ammonia concentration is considerably lower (varying from 6 to 136 $mg.L^{-1}$) corroborates this hypothesis.

The acute toxicity tests on the evaporation concentrate indicate that, with the exception of test # 3c, the effluent could be discharged in the environment for presenting Dilution Factor (DF) inferior to 8, the maximum limit of acute toxicity for *Daphnia magna* established by the Brazilian State of Santa Catarina's law (Portaria 017/02 of the Environmental Foundation - FATMA) for landfill leachate.

In test # 3c the pH was 8,96, ammonia concentration 22,4 $mg.L^{-1}$ and dissolved oxygen concentration above 7 $mg.L^{-1}$. These values are in line with the other tests carried through with the concentrate and did not show evidence of acute toxicity. The most probable reason for this result was an error during the assay, which should have been repeated but was not possible seen that the remaining sample volume was not enough to carry through a new test.

The constant recirculation of the liquid in the system enhances the ammonia volatilization and the oxygenation of the effluent, favoring the biological process of oxidative degradation of the organic substances present.

The acute toxicity tests revealed that this technology does not represent potential risk to the environment even if concentrating liquids of high pollutant load, as landfill leachate.

5. CONCLUSIONS

The monitoring of the experimental pilot during 9 months allowed to evaluate the technique of natural evaporation with panels through different climatic conditions. Results show that this type of treatment may be interesting and, even having been implemented in a region with elevated rain rate and relative humidity, the average evaporation in the system was 111 $L.day^{-1}$.

Acute toxicological tests conducted on both effluents showed a high toxicity of the raw leachate and low or inexistent toxicity of the concentrate, with the exception o one sample tested. The Dilution Factors of the concentrate were lower than the maximum allowed by the Brazilian state of Santa Catarina's law, which dictates the limits for discharging effluents into the environment (Portaria 17/02 of the Environmental Foundation - FATMA).

The main climatic variable in natural evaporation with panels is wind speed, followed by solar radiation and air temperature. Relative humidity, which resulted non significant in the statistical analysis, vary in an inverse proportion with evaporation. Therefore, regions with lower relative humidity (yearly average of 80%) may be more indicated for the implementation of this technology.

Overall, the experimental apparatus was of simple operation and can be operated and monitored with the technical and human resources available locally in any landfill. The implementation of this technique in small landfills can be explored as an alternative or complementation to the usual leachate treatment techniques, aiming a more efficient and safe management of these effluents.

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