3rd INTERNATIONAL WORKSHOP
ADVANCES IN CLEANER PRODUCTION

"CLEANER PRODUCTION INITIATIVES AND CHALLENGES FOR A SUSTAINABLE WORLD"

Performance Analysis of High Efficiency Thickeners to Supensions of Leachate

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Abstract

Leachate is a dark liquid generated by the degradation of waste, potentially polluting. Usually contains high concentrations of suspended solids, heavy metals and organic compounds. Characterize the flakes from a process of coagulation-flocculation of slurry is essential for calculations in thickeners, as well as identifying the optimum operation conditions, such as type of coagulant, concentration and pH. In this study, after determining the optimal conditions of flocculation were determined the diameter of the flake, the density of the floc, density of the supernatant and porosity of the flake using the method of Bailey and Ollis (1986), as well as some parameters obtained from batch sedimentation tests as average speed of sedimentation, and speed of Stokes using the equation of Richardson and Zaki modified . Using this results the flocs can be modeled using techniques proposed by França et al. (1999) and the results are validated by experiments.

Keywords: *Leachate, Floculation, Sedimentation.*

1 Introduction

The leachate is a dark liquid with a nauseating odor that has high concentrations of organic and inorganic compounds. This slurry results from the degradation of domestic residues deposited in a dump which allows the slurry to percolate into the ground thus contaminating water sheets (Hamada et al., 1993).

The composition of the dark liquid is influenced by some factors such as type and composition of the domestic residue, density, disposal chain steps, depth, humidity, temperature and pre-treatment.

1.1. Treatment systems

Among the possible leachate treatment systems, the distinguished ones are photo-electrochemical, by membranes, biological and coagulation-flocculation (Renou et al., 2008, Labanowskia et al. 2010, He et al., 2007, Aziz et al., 2007)

According to Betazzoli et al. (2010), the photo-electrochemical process consists of percolating the solution to be treated through an electrolytic reactor where the anode, coated with metallic oxides, stays under the incidence of UV radiation. This process has shown a good efficiency, where the degradation speeds are of a higher order of magnitude when compared with other processes. Tests conducted with the leachate indicated a reduction of 75% in the color after 5 hours of treatment and a reduction of 20% of the organic load. The odor completely disappeared after 3 hours of treatment.

Filtration with membranes can be used with a biological treatment Ozturk et al. (2003). This treatment revealed appropriate for fresh leachate. However it proved to be expensive and it requires higher pressures.

The aerobic biological treatment (Kargi and Pamukoglu, 2003) was carried out in an aeration tank, with further passage in a post-cure using coagulant agents. Three coagulant agents were been used, namely, aluminum sulphate, ferric chloride and calcium oxide for the reduction of DQO and nitrogen. The larger quantity of DQO removed was 76% after 30 hours of operation.

In accordance with Tatsi et al. (2003), a coagulation-flocculation treatment was used where an stabilized leachate named "old" and "cool" leachate was used. In this work a jar-test using as coagulant agents the aluminum sulphate, the ferric chloride and both of them together were used. Some polyelectrolytes were also tested. The ferric chloride was the coagulant agent which presented the best results, with a reduction up to 80% of DQO with dosage of 2,0 g/L and pH 10,0 in stabilized leachate. With respect to aluminum sulphate agent, the best results were achieved with pH between 4,0 and 7,0, dosages from 0,5 to 1,5g/L for the stabilized leachate. It was noticed that the pH adjustment and the addition of the polyelectrolyte are significant in the alkaline range. The use of two coagulant agents together did not show good results.

Tests with different dosages of coagulant agents in different values of pH were carried out by Cammarata et al. (1994), and this treatment proved to be efficient, indicating reasonable removals of DQO (40%) with ferric chloride and (25%) with aluminum sulphate at pH values of 4,0 to 4,5 and the dosages between 400 and 500 mg/L. The use of coagulant agents together with polyelectrolyte did not contribute to improve the quality of the treated effluent.

A study was carried out through experiments testing the best conditions of pH, flocculant concentrations and the best set of coagulant agents and polyelectrolyte (Bila et al., 2005). Aluminum sulphate showed the best result among the products used with excellent range of pH between 4,5 and 5,0 and with an excellent dosages between 700 and 950 mg/L.

When aluminum sulphate and ferric chloride concentrations are smaller than 500 mg/L the tests do not indicate significant alterations in the quality of the supernatant, when using polyelectrolyte or bentonite. The biodegradability of landfill leachate using the air stripping procedure followed by coagulation/ultrafiltration (UF) processes was studied and the single coagulation with ferric chloride increased the BOD/COD reduction (Pi et al., 2009)

1.2. The Sedimentation

The sedimentation is a solid-fluid separation technique based on compounds density differences; where the removal of solid particles from a liquid is caused by gravity action. This process presents lower cost and has greater operational simplicity.

The procedure of the batch sedimentation test is rather simple. A sample of slurry is collected in a graduated cylinder and is kept under observation. The height of the free surface from the bottom of the cylinder is first registered. The test has to be conducted under isothermal conditions. At the outset, the particles settle at their maximum hindered settling velocity and the rate of sedimentation will be constant.

In this work, the flakes generated in the process of leachate coagulation-flocculation was characterized, with the aim of using the results in a future project of a treatment system of the leachate generated in Aracruz-ES.

2 Methodology

2.1. Flake´s formation

The best flocculation conditions with an optimum coagulant agent, as well as optimized concentration, pH of the leachate, mixer rotation and time of mixture was defined using a classic jar-test.

2.2. Flake´s characterization

The average flake diameter determination was carried out with an optical microscopy, where a scanned photo of the flake was treated with software of image analyses.

The density determination was carried out using the method of Bailey and Ollis (1986), where the volume of flakes is estimated. The method consists in separating a solid from the fluid phase with a well-established centrifugation procedure, in order to guarantee the non-rupture of the flake that could cause the expulsion of the intra-flocular water.

The porosity calculation was also carried out using the method of Bailey and Ollis to estimate flake volumes. With Eq. (1) it is possible to determine the porosity (ε).

$$\varepsilon = \frac{V_c}{V_c + V_s} \tag{1}$$

The flakes’ sphericity calculation was carried out on the basis of the work of Mohsenin (1970), which determined the degree of sphericity of an ellipsoid through Eq. (2).

$$\phi = \frac{\sqrt[3]{abc}}{a} \tag{2}$$

Where, b and c are the diameters of the three axes of an ellipsoid.

To determine a flake diameter the Michaels and Bolger (1962) method was used. First, the average density and diameter of the flakes, as well as the Stoke´s settling speed and the degree of particles flocculation in each suspension were needed. This calculation was carried out from the curve of initial concentration and its respective initial sedimentation speeds which were obtained with batch sedimentation tests.

For the calculation of terminal settling speed a simple system of equations was used, which constituted of Richardson and Zaki equations (Eq. 3) which were modified for the addition of the parameter k, that is the degree of particle’s flocculation.

To calculate a Stoke´s velocity the equation 4 was used where the flake density is calculated with the equation 5.

$$v = v_{t\infty}\left(1 - kC_0\right)^n \tag{3}$$

$$v_{t\infty} = \frac{d_{fl}^{\,2}(\rho_{fl} - \rho_f)g}{18\mu} \tag{4}$$

$$\rho_{fl} = \rho_f + \frac{(\rho_s - \rho_f)}{k\rho_s} \tag{5}$$

In the equations, v represents the flake sedimentation velocity, $v_{t\infty}$ is the terminal flake velocity, k is the degree of particle flocculation, C0 is the initial suspension concentration, d_{fl} is the flake diameter, ρ_{fl} is the flake density, ρ_f is the fluid density, μ is the fluid viscosity, ρ_s is the dry solid density and g is the gravity acceleration. In accordance with França et al. (1996) it is possible to use the factor n= 4,65 in Eq. (3).

To calculate a flake diameter we also use the Coelho and Massarani (1996) methodology was used. It consists in the calculation of the average flakes diameter that isn't in the Stokes regimen through the substitution of Equations 7, 8 and 9 in Equation 6

$$\frac{d_{fl}v_{t\infty}\rho_f}{\mu} = \left[\left(\frac{24}{k_1\left(\frac{C_D}{\mathrm{Re}}\right)}\right)^{0,65} + \left(\frac{k_2}{\left(\frac{C_D}{\mathrm{Re}}\right)}\right)^{1,30}\right]^{1/1,30} \tag{6}$$

With:

$$\frac{C_D}{\mathrm{Re}} = \frac{4}{3}\left(\frac{\left(\rho_{fl} - \rho_f\right)\mu g}{\rho_f^{\,2} v_{t\infty}^3}\right) \tag{7}$$

$$k_1 = 0{,}843.\log\left(\frac{\phi}{0{,}065}\right) \tag{8}$$

$$k_2 = 5{,}31 - 4{,}88\phi \tag{9}$$

Where C_D is a drag coefficient, Re is the Reynolds number, ϕ is a particle sphericity and k_1 and k_2 are adimensionals parameters.

2.3. Sedimentation tests

In order to determinate the expression of the variation of the height of the upper interface with the time, the equation 10 can be used. A rectangular tube with 1,0m of height was used. For the determination of a permeability $K(\varepsilon_s)$ is necessary to define the k_1 parameter, using a Kozeny-Carman equation (11).

$$h = h_o - \lambda\left(t - \frac{1 - e^{-k_1 t}}{k_1}\right) \tag{10}$$

Where:

$$k_1 = \frac{\mu}{K(\varepsilon_{s0})\rho_s\varepsilon_{s0}} \tag{11}$$

$$\lambda = \frac{k_2}{k_1} \tag{12}$$

$$k_2 = \frac{(\rho_s - \rho_f)g}{\rho_s} \tag{13}$$

With the experimental values of h and t, the parameter K_1 is estimated with Equation 10, through adjustment; considering $\varepsilon_s=\varepsilon_{so}$, to determines the value of the permeability, $K(\varepsilon_s)$. A set of experiments is necessary, with different porosities and from a set of values of K e ε_s, to estimate the parameters (α and γ) of Equation 14.

$$K(\varepsilon_s) = (\alpha + \gamma\varepsilon_s)\frac{(1-\varepsilon_s)^3}{\varepsilon_s{}^2} \tag{14}$$

2.4. Thickener prototype experiments

A prototype of a continuous Dorr Oliver thickener with 0,05 m^2 and 1,70 m was built. The suspension was prepared in a tank where the correct amount of flocculant was added. Two peristaltic pumps were connected to the equipment, one to feed the thickener and the other for the removal of the concentrate at the bottom.

The system must be well controlled, the interface kept clear and stable and these conditions maintained for several hours.

The concentration profile in the equipment was determined by samplers located from the bottom to the top of the equipment.

2.5. Activated Carbon Filtration

One of the analyzed parameters was the sample's turbity, which was determined with a spectrophotometer using a 480 nm (Quimis Q - 108D, 340/950 nm), with pure water as reference test. It was decided to check process efficiency by analyzing the effluent color (turbidity) reduction caused by the solid fraction in suspension. The transmittance symbolizes the light beam percentage that passes through the analyzed sample. Although unconventional to this type of procedure, it shows the color intensity of the sample. Then, it was considered that the transmittance accomplished by the method was enough to reduce the efficiency of each stage of the process.

The concentration of some metals was analized by an atomic absorption spectrophotometer.

3 Results and Discussions

First of all, the jar-test was used for the determination of the best conditions of the coagulation-flocculation procedure. Four flocculant agents were tested: namely, ferric chloride, aluminum sulphate, calcium hydroxide and ammonia hydroxide. The aluminum sulphate showed a better visual result. Afterwards, some tests were conducted with pH values between 3 and 8, since in the range of pH between 4,5 and 6 the system stays in a similar form. A pH 6 was used when considering that it was closer to initial pH 8.

Tests for the determination of the best concentration of the coagulant agent were carried out and optimum results were observed in the concentration value of 750ppm. The ideal equipment rotation was of 180 rpm which was kept for 4 minutes and, after that, at a rotation of 40 rpm for 2 minutes.

The best conditions were used for coagulation-flocculation with the aim to creating the flakes. By Bailey and Ollis method they had determined the density of the flake ((ρ_{fl}), density of the fluid ((ρ_f) and porosity of the flake (ε), that were 1,050 g/cm; 1,008 g/cm³ and 0,11 respectively were determined.

Using the batch sedimentation tests (Figure 1) for different initial concentrations of leachate, the degree of flocculation (k) and Stoke´s velocity were determined (vt_∞). In order to carry out the estimation of model parameters, the package ESTIMA (Pinto et al., 1993) has been used, and the results indicated k = 9,58 and vt_∞ = 1,86 cm/s, which were adopted for the described model in Equation 3 and presented in Figure 2. The correlation coefficients matrix of the estimated parameters can be seen below.

$$\begin{bmatrix} 1 & 0{,}94 \\ 0{,}94 & 1 \end{bmatrix}$$

Fig. 1 – Batch sedimentation tests

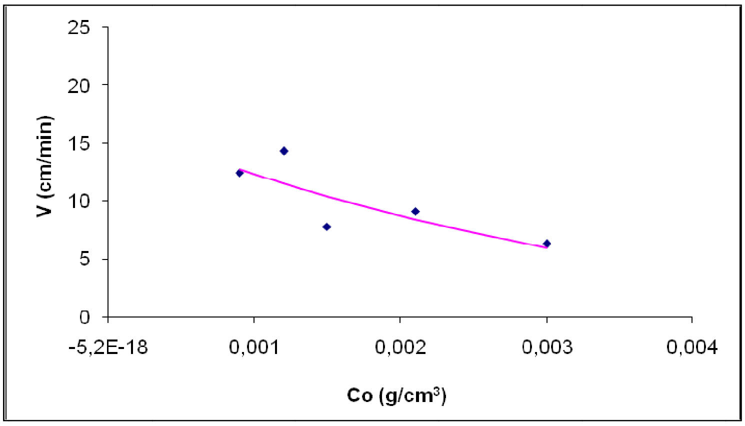

Fig. 2 - Determination of parameters k and vt_∞.

The flake diameter (d_{fl}) was determined experimentally through photographs using optical microscopy after the flocculation of the sample. In Figure 3 it is possible to see the frequencies distribution of the flakes. The average diameter of the flakes collected experimentally was 119 μm. The results with the mathematical models are presented in Table 1.

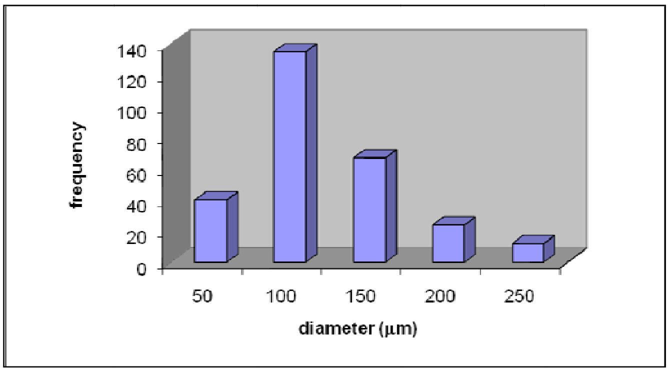

Fig. 3 - Experimental determination of d_{fl}

Table 1 - Results of the mathematical models

Mathematical Model	**Variable**	**Value**
Michaels e Bolger	d_{fl}	117 μm
Coelho e Massarani	d_{fl}	122 μm

For the model of Coelho and Massarani a ϕ = 0,76 was used, which was also calculated experimentally through Equation 2. It is possible to verify that the two diameters found in the mathematical models have closer values.

Upon analysis of the results it is possible to verify that the density of the flake, calculated with the model of Michaels and Bolger (ρ_{fl} = 1,067 g/cm^3), is closer to the value of density which was determined experimentally.

In this study it was also possible to calculate the parameter K(εs). The determination of α and γ was done with the software "ESTIMA" (Figure 4).

These parameters and the correlation coefficients matrix of them were obtained using "estimates" and are presented below:

Parameter	**Value**
α	$-4{,}29 \times 10^{-7}$
γ	$2{,}22 \times 10^{-5}$

$$\begin{bmatrix} 1 & -0{,}97 \\ -0{,}97 & 1 \end{bmatrix}$$

$$K(\varepsilon_s) = (-4{,}29x10^{-7} + 2{,}22x10^{-5}\varepsilon_s)\frac{(1-\varepsilon_s)^3}{\varepsilon_s{}^2} \tag{15}$$

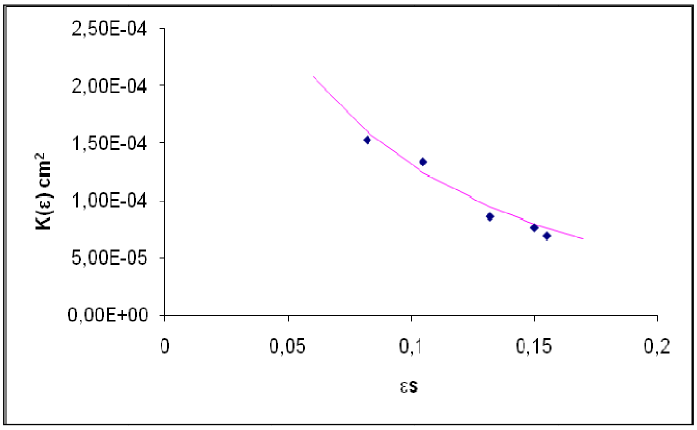

Fig. 4 - Determination of α and γ parameters

Using a continuous prototype (Fig. 5) it was possible to see that the height of the upper interface of sedimentation took three hours for the system to become stabilized, as can be seen in Figure 6.

Fig. 5 - Continuous prototype

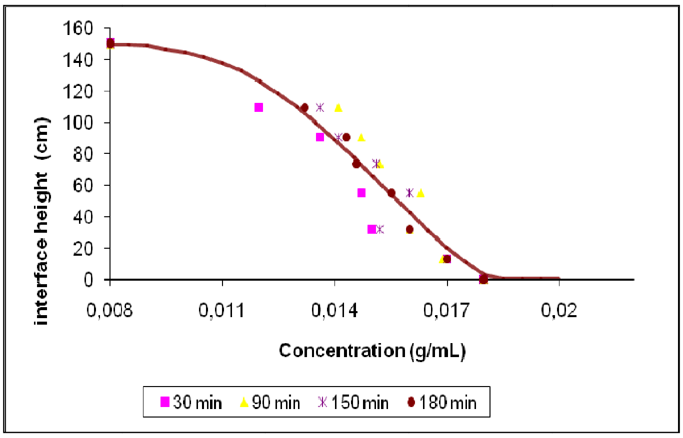

Fig. 6 - Sedimentation time to process stabilization

When an active carbon filter is connected to the sedimentation process, it is possible to get a visually significant result, as can be seen in Figure 7. The turbity was analyzed and its reduction observed after the flocculation-sedimentation (65%) and after filtration with active carbon (85,8%). The principal solubilized compound after and before the treatment can be observed in Table 2.

Fig. 7 – Leachate cleared with coagulation-sedimentation process with a stage of filtration with active carbon

Table 2 - Analysis of several metals after and before the treatment

	Natural Leachate	Coagulation-sedimentation and filtration
Ca (µg/mL)	54,4675	32,2075
Mg (µg/mL)	8,6965	9,1940
Fe (µg/mL)	12,8140	0,1725
Zn (µg/mL)	0,5625	0,4625
Cu (µg/mL)	0,2025	0,1040
Mn (µg/mL)	2,4310	2,1905

4 Conclusions

The generated flakes in this domestic residues leachate treatment process can be shaped by using the proposed techniques, and the results are validated by the described experiments. The average diameter of the flake, experimentally calculated, was of 119 µm, while the density was 1,050 g/cm^3. With these results, possible futures studies can be carried out in high efficiency sedimentation process based on any of the two considered models.

5 Acknowledgements

The authors would like to thank CNPQ - Conselho Nacional de Desenvolvimento Científico e Tecnológico for supporting this research.

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