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Hydrodynamic evaluation of a bench-scale evapotranspiration tank (TEvap) subjected to flow rate variation

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Abstract: The evapotranspiration tank (TEvap) is an alternative system to septic tanks for the decentralized treatment of domestic sewage. The hydrodynamic evaluation aims to better understand the behavior of the system in relation to the flow, providing important information about the physical properties involved in the dynamics of liquids in the system. This work aimed to analyze the hydrodynamic behavior of a bench-scale TEvap system in the face of flow variation. A bench-scale model was used, with dimensions of 0.15 m wide, 0.50 m long and 0.25 m high, containing a useful volume of 10.74 liters. It was observed that the system presented a more satisfactory performance with the lower flow rate, while the increase in flow rate tended to result in a higher mixing and dispersion index within the system.
Key words: TEvap; hydrodynamics; hydraulic efficiency

1 Introduction

The evapotranspiration tank (TEvap) is a system used to treat domestic wastewater in a decentralized manner, and can be a single-family solution or even used in hotels or restaurants, in which case it is an interesting alternative due to its potential to be, in addition to a wastewater treatment system, an object of landscape harmony (Pamploma; Venturi, 2004).

This system was first presented in Brazil by Pamploma and Venturi (2004), however over time it has been the object of study, undergoing changes that aim to improve the behavior and performance of the system.

Figure 1 shows a diagram of how TEvap works, where the influent material enters the system through the anaerobic chamber, where anaerobic digestion of the organic matter that entered occurs. The material is then directed to the CDW layer that surrounds the anaerobic chamber and, through an ascending process, passes through the layers of gravel, sand and soil, where it is filtered. Finally, the water and compounds present in this medium can be absorbed by plants or evaporated (Galbiati, 2009; Gomes; Vuitik; Ribas Döll, 2023; Rocha, 2020).

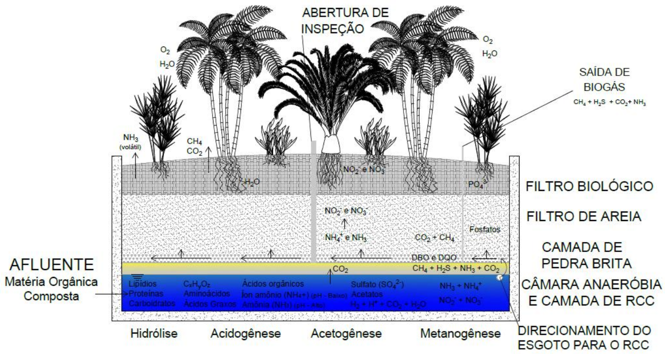

Figure 1. TEvap operation diagram

Source: Gomes and Ribas Doll (2022)

The dimensioning of a system is one of the main pillars to guarantee its good development and operation. In the case of TEvap, Galbiati (2009) was the first author to give more emphasis to this issue, establishing a methodology that has served as a basis for several works in recent years.

Another work that stands out is Rocha (2020) who highlights the importance of controlling the system's construction methods, which also play a very important role in ensuring the system's good development.

Paulo and collaborators (2013) highlight the importance of more in-depth studies considering longer sampling times for a better understanding of the efficiency of evapotranspiration, sludge formation and also methane generation, to allow a more efficient evaluation of the system.

The hydrodynamic evaluation of a system involves many important steps, so the delimitation of methodological aspects of the test to be carried out is important to achieve effective results that represent the system reliably (Ferreira Filho, 2021).

The hydrodynamic test can be performed in a system by injecting a tracer at the system inlet and monitoring the concentration of this material at the outlet, so that the concentration curve, over time, at the system outlet can be analyzed mathematically in order to obtain data such as hydraulic retention time (HRT) and dispersion index in the system (Levenspiel, 2000).

Thus, hydrodynamic assessment is another very important pillar in the operation of a system such as TEvap, as it is necessary that the system assembly ensures that its dimensioning represents the practice reliably, and thus preserves the efficiency designed for the system.

The present work aimed to investigate the hydrodynamics of the evapotranspiration tank at different flow rates, analyzing the impact of the increase in flow rate on the TDH, hydraulic efficiency, longitudinal dispersion and dead volume of the system.

2 Methodology

The work consists of the analysis of the hydrodynamic efficiency of an evapotranspiration tank system on a bench scale. The following topics will first describe the experimental apparatus, the object of study of this article; the experimental procedure, on which the test was based; then the tracer material used in the hydrodynamic test; and finally the mathematical analyses performed for interpretation and analysis of the data obtained during the test.

2.1 Experimental apparatus

The experimental apparatus, which aims to simulate a Tevap, was assembled using a glass box with 4 mm thick walls and a rectangular shape. The system represents a laboratory scale reduced by 6.8 times the real scale for an inhabitant and has external dimensions of 0.15 m wide, 0.50 m long and 0.25 m high.

The box was filled with layers characteristic of TEvap, being allocated in ascending order (Figure 2): construction and demolition waste (CDW), with 7.3 cm and 2.9 liters of volume, gravel, geomembrane (to avoid the decharacterization of the layers by the dragging of the flow), sand and soil.

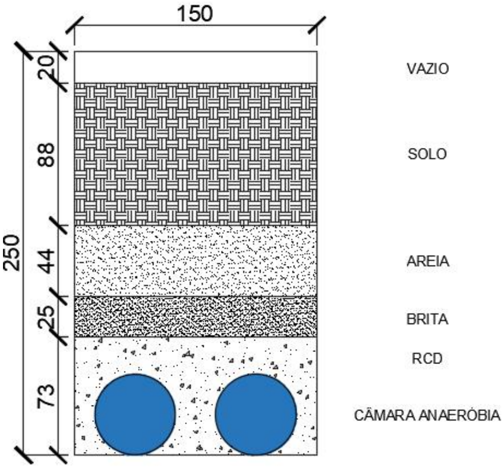

Figure 2. Layers that made up the experimental apparatus

The height and volume characteristics of the layers of the experimental apparatus are presented in Table 1, where the total volume is the three-dimensional volume of the layer, without considering the spaces occupied by the materials that make up the respective layers, and the useful volume considers the volume of the layer that can be occupied by the liquid medium.

Table 1. Characterization of the experimental apparatus

Layer	Height (cm)	Volume total(cm³)	Useful volume (L)
Anaerobic chamber	5,0	1.920,30	1,41
RCD	7,3	3.291,46	2,59
British	2,5	1.784,85	0,66
Sand	4,4	3.141,34	1,51
Alone	8,8	6.282,67	3,07
Empty	2,0	1.500,00	1,50
Total	25	17.920,62	10,74

2.2 Experimental procedure

The experimental procedure of the test followed that proposed by Levenspiel (2000). The test performed was of the step type, in which a tracer material is introduced into the system and its concentration at the system exit point is analyzed over time.

Thus, in this step-type test, the tracer material is injected into the system continuously. This type of test has the advantage of reducing the effects of adsorption of the material in the support medium as well as the advection and countervection effects that can occur in the pulse-type test, when the tracer is injected into the system in the form of a pulse (Levenspiel, 2000).

The experiment aimed to analyze the hydrodynamics of the system at different flow rates. Thus, the experimental procedure of the hydrodynamic test was carried out at four different flow rates that were selected based on the proposed system operation that was presented in the work of Gomes and Ribas Doll (2022). The four test conditions are shown in Table 2.

Table 2. Experiment operating conditions

Flow Condition	(ml/min)	Theoretical TDH (min)
1	15	560,98
2	20	420,74
3	40	210,37
4	80	105,18

Before starting the experimental procedure, the system was cleaned by injecting distilled water and monitoring the electrical conductivity (EC) at the system outlet. Initially, a considerably high EC value was observed, but over the course of the weeks, it was possible to observe its decrease until stabilization at an average value of 12 μC/cm², over a period of 5 days. The same cleaning procedure was performed between the operational stages, aiming to avoid contamination of one phase by the next phase.

For each condition, samples were taken from the system outlet at a 30-min interval. The EC was analyzed using a conductivity meter (MS Tecnopon, model mCA 150), which performed measurements in μS/cm at 25°C; and the device was calibrated daily.

2.3 Tracer material

Sodium chloride was used as a tracer material, for which a concentration curve of the material was constructed based on the EC of the solution, and the concentration curve was made using a concentration range of 0 to 0.5 gL^{-1}, obtaining conductivity values according to Figure 3, where the equation of NaCl concentration in water by EC is also shown.

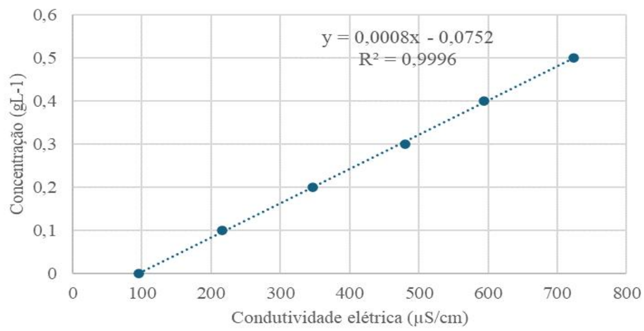

Figure 3. NaCl concentration curve by electrical conductivity

To carry out the experiment, a concentration of 0.2 g/l was used, seeking to obtain results that could be interpolated into the curve, with greater precision.

2.4 Mathematical analysis of data

For the mathematical analysis of the results, the proposal by Vuitik (2017) was followed, where the concentration curve was first normalized by time, with a Boltzmann-type adjustment, and with the feed flow rate, and the E. curve was calculated, which can be used to obtain the detention time and the variation of the E curve, which indicates the dispersion of the distribution. Then, three main metrics were used to evaluate the hydrodynamics, namely:

- Longitudinal dispersion, to then classify the dispersion of the fluid in the system, which can be low, moderate or high dispersion (Levenspiel, 2000).

- Analysis of hydraulic efficiency (λ), where N is the number of perfect mixing reactors in series; TDHm is the average hydraulic retention time (obtained in the test) and TDHt is the theoretical retention time (Godinho et al., 2018).

- Analysis of the reactor's dead volume (Vm), considering the total volume (Vt), average TDH (TDHm) and theoretical TDH (TDHt) to calculate the active volume (Va) (Godinho et al., 2018).

Table 3 presents the mathematical formulas used for each highlighted variable analyzed.

Table 3. Variables studied

Mathematical formula	Highlight variable
$\sigma_\theta^2 = 2\frac{D}{uL}$	Longitudinal dispersion (PD)
$\sigma_\theta^2 = 2\frac{D}{uL} + 8\left(\frac{D}{uL}\right)^2$	Longitudinal dispersion (LDS)
$\lambda = \frac{TDH_m}{TDH_t}(1 - \frac{1}{N})$	Hydraulic efficiency
$V_a = V_t \frac{TDH_m}{TDH_t}$	Active volume
$V_m = V_t - V_a$	Dead volume

Finally, the Person correlation coefficients obtained in relation to the variation of the metrics mentioned were calculated with the variation of the real TDH observed for each condition, in order to indicate in which of the conditions the system presented the best hydrodynamic operating condition.

3 Results

Table 4 first presents the theoretical TDH values, which consider the theoretical useful volume of the system and the operating flow rate, and then the real TDH, obtained by the test, noting that for the first two tests, the real values are greater than the theoretical ones, while in the last two scenarios the opposite occurs. The same table also presents the longitudinal dispersion values, both for small dispersion (PD) and for large dispersion (GD) and finally the number of perfect mixing and series reactors (N).

Table 4. Results of TDH, dispersion and number of perfect mixing reactors in series found

Flow rate (ml/min)	Theoretical TDH (min)	Actual TDH (min)	D/uL		N
			PD	GD	
15	560,98	942,25	0,03581	0,03177	13,96
20	420,74	610,14	0,45958	0,23628	1,088
40	265,75	126,71	0,49557	0,24852	1,009
80	132,88	78,03	0,21291	0,13740	2,348

Table 5 presents the hydraulic efficiency data, a variable that indicates the development of the reactor, making an analysis of the system that relates the ratio between the theoretical TDH and average TDH with the number N. In addition, the active and dead volume found for each scenario is also presented, which often indicate that the actual volume of the reactor can be considered active and useful for the system.

Table 5. Results of hydraulic efficiency and active and dead volumes found in the tests

Flow rate (ml/min)	Hydraulic efficiency	Active volume (mL)	Dead volume (mL)
15	1,559	14.133,76	-5719,06
20	0,117	12.202,70	-3788,00
40	0,004	4.012,14	4402,56
80	0,337	4.941,21	3473,49

Table 6 shows the values of the Person correlation coefficient obtained in relation to the variation of the variables with the variation of the real TDH observed for each condition. Thus, it is possible to analyze whether the increase in flow, and consequently the decrease in TDH was correlated with the variation of the parameters analyzed.

Table 6. Person correlation coefficient obtained between the variable and the variation of the real TDH

Variable	Person's correlation coefficient
PD	0,504
GD	0,568
N	0,779
Hydraulic efficiency	0,768
Active volume	0,976
Dead volume	0,976

4 Analysis of results

It is worth noting that only one study was found in the literature that proposed to analyze the hydrodynamics of a TEvap system, the study by Silva (2019). However, it is worth noting that in this study the author maintained the fixed flow rate, alternating the heights of the granular layers of his model.

Silva's model (2019) presented a volume approximately 37.2 times greater than that analyzed in this study. However, it is important to highlight that the equivalent flow rate of the system used by the author was close to the lowest flow rate used in this work. Thus, it is highlighted that the results found by the author reflect a situation that can be compared to the situation studied in this work with the lowest flow rate.

The longitudinal dispersion values found in all situations indicate a large dispersion, thus indicating that diffusion in this case may impair the distribution of the liquid in the system, consequently resulting in a less uniform mixture. This result can be explained by the physical composition of the system, since the system has granular layers, which may impair the mixing of the liquid.

However, it is highlighted that the situation that proved to be most efficient in this regard was with the lowest flow rate, indicating that with the increase in flow rate, and the dispersion of the liquid may be impaired, and at lower flows the effect of the granular layers may be softened.

The number N relates the behavior of the system to the number of systems in perfectly mixed reactors (CSTR) that would be equivalent to it, as indicated by Levenspiel (2000). When this value is greater than 30, the system could already be considered with a behavior closer to the plug-type reactor (PFR). For this work, in both cases, lower values were found for the number N, indicating that the TEvap will have a greater tendency to behave like a perfectly mixed reactor, which can be explained by its granular material layer composition that tends to promote mixing between the ascending flows of the system.

Hydraulic efficiency (λ), in turn, had very different behavior in the situations analyzed. Persson and collaborators (1999) created a classification considering the value of λ, whereby for values lower than 0.5 the system would be classified as having low efficiency and for values above 0.75 the system would have good efficiency, and for intermediate values the system would have satisfactory efficiency.

In the situations analyzed, all scenarios indicated low efficiency, with the exception of the lowest flow situation, which presented a value greater than 1. In addition to the analysis of hydraulic efficiency, it is necessary to highlight the dead volume values found in each scenario, where in the first two scenarios negative dead volume values were found. This occurs because the real TDH values found were greater than the theoretical values. This result allows for distrust in the values found, since the most common occurrence is the opposite effect.

However, this situation can be explained by the composition of the soil layer of the system, and the soil used in the system has a considerably finer granulometry and therefore has a considerable ionic capacity (Ernani, 2008) that may have interfered in the experiment, since the trace used (NaCl) dissociates in the medium and may have adhered to the smallest particles of the soil (clay).

The analysis of the Person coefficient showed that for the longitudinal dispersion variables there was no great correlation with the increase in TDH as illustrated in Figure 4, however for the dead volume values there was a considerable relationship, indicating that with the decrease in the TDH value an increase in the dead volume value was observed.

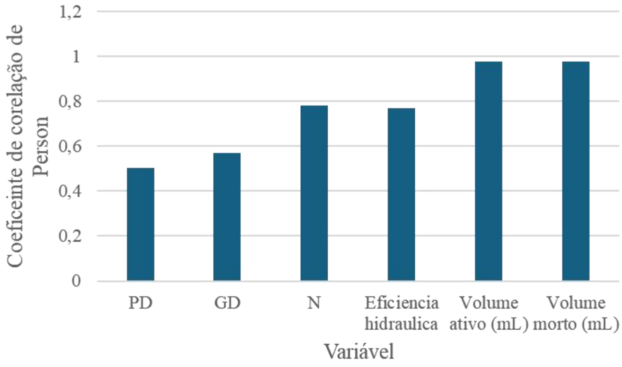

Figure 4. Analysis of Person's coefficient for each variable analyzed

For the number N and the hydraulic efficiency, a considerable correlation was observed, however not as much as in the case of the dead volume, thus it was observed that with the decrease in the TDH there was a decrease in the efficiency value and in the value of the number N.

It is important to highlight that the present work aimed to evaluate the impact of flow variation, however, the variation of other factors can have positive influences on the system, for example, reducing the heights of the layers of granular materials could lead to better liquid mixing conditions.

Furthermore, it is worth noting that the results here provide a perspective on the overall behavior of the system, since the system is composed of several layers. Analyzing the hydrodynamic behavior of the anaerobic chamber, for example, could be interesting, since with its tubular composition it is expected that at this stage of the system the behavior will be similar to that of a PFR reactor, different from that found for the system as a whole.

Thus, it is highlighted that improvements in the system's behavior could be achieved by changes in the system's compliance. Furthermore, the evaluation of the system's hydrodynamics in intermediate stages could lead to a better understanding of where the system tends to present more deficient behavior, which could lead to studies of system adaptations at more specific points.

5 Conclusions

Thus, it is highlighted that the system presented better hydrodynamic behavior with the lowest flow rate, since the dispersion values indicated a better mixing tendency than the other scenarios.

It was observed that with the increase in flow rate, the system tended to present a larger dead volume and a more turbulent flow, indicating that at higher flow rates the system may have worse hydrodynamic behavior.

The tracer used may have influenced the results, since it may have been adsorbed by the soil layer, given that the soil used had fine granulometry, presenting characteristics of a more clayey soil and possibly having a greater ionic capacity.

It is important to highlight the importance of further clarification regarding the behavior of the system operating with biological treatment itself, that is, in order to have more assertive conclusions about the best operating flow rate for the system, it is important to analyze how it behaves for the treatment of domestic effluents at the respective flow rates analyzed.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] ERNANI, Paulo Roberto. Química Do Solo E Disponibilidade De Nutrientes. [S. l.]: Paulo Roberto Ernani, 2008.

[2] FERREIRA FILHO, Sidney Seckler. Princípios, Fundamentos e Processos em Engenharia Ambiental. Santana de Parnaíba, SP: SGuerra Design Ltda, 2021.

[3] GALBIATI, Adriana Farina. TRATAMENTO DOMICILIAR DE ÁGUAS NEGRAS ATRAVÉS DE TANQUE DE EVAPOTRANSPIRAÇÃO. 2009. 52 f. Mestrado - Universidade Federal de Mato Grosso do Sul, Campo Grande - MS, 2009.

[4] GODINHO, Jayson Pereira et al. Comportamento dinâmico e hidrodinâmico de reator tipo UASB submetido à variação de carga hidráulica. Revista DAE, [s. l.], v. 66, n. 209, p. 84–98, 2018.

[5] GOMES, Kaio Gustavo; RIBAS DOLL, Maria Madalena. Startup de um tratamento de águas cinzas domésticas com detergente biodegradável por tanque de evapotranspiração em escala piloto. Ponta Grossa: [s. n.], 2022.

[6] GOMES, Kaio Gustavo; VUITIK, Guilherme Araújo; RIBAS DÖLL, Maria Magdalena. Congresso Brasileiro de Engenharia Sanitária e Ambiental. PROJETO, HIDRODINÂMICA E DESEMPENHO DE UM TANQUE DE EVAPOTRANSPIRAÇÃO PARA TRATAMENTO E DISPOSIÇÃO FINAL DE ÁGUAS CINZAS DOMÉSTICAS, [s. l.], n. 32, p. 10, 2023.

[7] LEVENSPIEL, Octave. Engenharia das Reações Químicas. 3. ed. São Paulo: Bluncher, 2000. v. 1

[8] PAMPLOMA, S; VENTURI, M. Permacultura Brasil. Esgoto à flor da terra: Soluções ecológicas, [s. l.], v. 16, n. 5, p. 18–19, 2004.

[9] PAULO, Paula L. et al. Natural systems treating greywater and blackwater on-site: Integrating treatment, reuse and landscaping. Ecological Engineering, [s. l.], v. 50, p. 95–100, 2013.

[10] PERSSON, J.; SOMES, N. L. G.; WONG, T. H. F. Hydraulics Efficiency of Constructed Wetlands and Ponds. Water Science and Technology, [s. l.], v. 40, n. 3, p. 291–300, 1999.

[11] ROCHA, Gabriel. TANQUE DE EVAPOTRANSPIRAÇÃO PARA TRATAMENTO DE EFLUENTES DOMÉSTICO EM ZONAS RURAIS. 2020. 97 f. Mestrado - Universidade Estadual de Ponta Grossa, Ponta Grossa, 2020.

[12] SILVA, ANDRÉ PHELIPE RODRIGUES DA. Uso de traçadores para avaliação da hidrodinâmica de um tanque de evapotranspiração - TEvap. 2019. 63 f. Disertação (Mestrado) - Universidade Federal de Viçosa, Viçosa MG, 2019.

[13] VUITIK, Guilherme Araujo. EFEITOS DA RECIRCULAÇÃO EM REATORES ANAERÓBIOS COMPARTIMENTADOS. 2017. 130 f. Doutorado - UNIVERSIDADE DE SÃO PAULO ESCOLA DE ENGENHARIA DE SÃO CARLOS, São Carlos, 2017.