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# COMPACT CONSTRUCTED WETLAND FOR SHOWER GREY WATER TREATMENT FOR REUSE IN WATER CLOSETS

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**Abstract:** Constructed wetland systems have stood out for their efficiency for the treatment of wastewater. However, they usually have large dimensions, which can make it unfeasible in urban areas. The objective of this work is to evaluate if a compact constructed wetland system can treat the grey water from the shower, in order to reuse the treated water in sanitary toilets. For this purpose, a field system with easily available materials was built, and samples of grey water and treated effluent were evaluated. The system could remove organic matter (removal of BOD and COD equal to 89% and 84%, respectively), color (96% removal) and turbidity (70% removal). Thermotolerant coliforms were not detected in the majority of the samples. With the exception of turbidity (70% removal) and solids (67% removal), the other results are according to the limits of the quality parameters of the reference documents. It is important to consider an initial period until stabilization is reached and maintains constant and a greater organic matter removal. This also happens after system maintenance, when usually a superficial layer of sand is removed. This maintenance was necessary after 16 weeks of operation; thus, it is important that users are aware of this task when choosing this system.

**Keywords:** Constructed wetland; grey water; water reuse; sustainability.

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## INTRODUCTION

To mitigate or to eliminate environmental impacts, decentralized strategies have been used as an alternative to centralized systems which require resources and time to be executed. In residential typology, the reuse of grey water can be an alternative for saving potable water, contributing to a sustainable urban water cycle.

Wastewater originated from the use of tanks, washing machines, showers and sinks is called grey water. Although usually also classified as grey water, water from the kitchen sink is, generally, not considered for reuse due to the high concentration of organic matter and oils.

Despite the variability, because of the regional habits and characteristics, the shower is responsible for the biggest part of residential water consumption in Brazil, as presented by different authors (Sautchuk *et al.* 2005; Fiori, Fernandes & Pizzo 2008; Barreto 2008) which makes it a potential source of wastewater for reuse.

Grey water must not be stored or used without treatment, even it has superior quality compared to domestic sewage, it contains organic matter, nutrients and microorganisms that will deteriorate its quality over time.

The constructed wetland system (CWS) is also called the root zone; flooded built; and cultivated bed. It is a treatment system that can be used in an integrated manner with the environment. It is characterized as natural technology since it uses natural or semi-natural means for treatment. The intense biological activity, which is higher in natural treatment systems, transforms part of the pollutants into substances and nutrients that are used in natural processes.

After the passage of the water through the roots, the substrate and the microbial community, there is an improvement in water quality through biological, chemical and physical processes

The substrate is composed of filter material, which may be sand; gravel; bamboo; tree bark; among others.It is an important element of the system, as it acts as a filter for larger particles, and serves as a support for plant roots (macrophytes) and the microbial community where the biofilm develops. It is also the main element in defining the shelf life of a CWS.

In addition to filtering through the substrate, roots easily assimilate organic matter for their own development. It should also be noted that evapotranspiration occurs through plants and when the water flow is superficial; and these two processes can represent significant water losses in the system.

The CWS can be classified according to the direction of the flow, vertical, horizontal and hybrid. There are systems that have the water outlet above the substrate level, where the water slide is apparent, which are named flooded. This factor is decisive for choosing the type of vegetation.

The roots of macrophytes act on the absorption of water and other elements (organic matter, nutrients, etc.) which are necessary for plants development. There is a great variety of species that can be used in CWS, which can be classified, according to Barreto (2011), as:

- floating: the foliage floats on the water surface; roots may or may not enter the substrate, but are usually found in surface flooded CWS;
- rooted or free submergent: develop submerged and may or may not attach to the substrate; develop in oxygenated media with low turbulence.
- emergent: roots are attached to the substrate and their leaves develop out of the water; are common in subsurface flow CWS.

Tropical countries, such as Brazil, have great potential for using CWS; High temperatures increase the level of evapotranspiration, and increase microbiological activity, increasing treatment efficiency.

Because CWS is a natural system, it is possible to add CWS to the local landscape using regional plants. Due to the low operating and maintenance costs, CWS are suitable for private gardens or public parks (Masi *et al.*, 2010).

The applicability of CWS for different types of buildings is shown in the literature, from single family homes (Yu *et al.*, 2015); clubs; universities (Masi *et al.*, 2010) and even small communities, for treating wastewater for reuse and obtaining a better effluent's quality for disposal.

CWSs are generally designed in large dimensions. To enable the use in urban areas, due to space limitations, compact constructed wetland systems (CCWS) are an option. To increase efficiency and achieve quality indicators for non-potable water reuse, CCWS needs to link other technologies of treatment such as recirculation and aeration and/or complementary treatment such as disinfection, especially when the direct of treated effluent with users is a possibility.

No studies were found on the use of CCWS for the exclusive treatment of gray water in the journals published by Brazilian scientific associations related to this theme until 2018 December. There were only studies where CCWS is used as a post-treatment sewage after reactors, such as the study presented by Costa *et al* (2018).

A systematic mapping of CCWS journals articles published in English on three international databases (Web of Science, Scopus and Engineering Village), conducted according to Dresch, Lacerda & Júnior (2015), resulted in 15 papers with different typologies and associated systems (**Table 1** and **Table 2**).

**Table 1.** Characterization of the selected CCWS in the international data bases

| Article | Source | Tipology | Linked technology | |
|---|---|---|---|---|
| | | | Upstream | Downstream |
| 1 | Gross *et al.* (2007) | Vertical with recirculation | --- | Chlorine disinfection |
| 2 | Gross *et al.* (2008) | Vertical with recirculation | | |
| 3 | Sklarz *et al.* (2009) | Vertical with recirculation | | UV Disinfection |
| 4 | Frazer-Williams *et al.* (2008) | Vertical | --- | Aeration |
| 5 | Munavalli e Pise (2012) | Vertical | Tank and Sand Filter | Vermicomposting |
| 6 | Paulo *et al.* (2006) | Vertical | Grease Box | --- |
| 7 | Paulo *et al.* (2009) | Horizontal and Vertical | Sedimentation tank | --- |
| 8 | Paulo *et al.* *(*2013) | | Grease Box | |
| 9 | Jokerst *et al.* (2011) | Horizontal and Flooded | --- | --- |
| 10 | Masi *et al.* (2010) | Horizontal | | |
| 11 | Masi *et al.* (2010) | Horizontal | --- | Sand Filter and UV disinfection |
| 12 | Masi *et al.* (2010) | Horizontal | Grease Box | --- |
| 13 | Masi *et al.* (2010) | Horizontal | UASB Reactor | |
| 14 | Frazer-Williams *et al.* *(*2008) | Horizontal | --- | Aeration |
| 15 | Ran, Agami & Oron (2004) | Flooded Horizontal | Sedimentation tank | --- |

UV – Ultraviolet; UASB – Upflow Anaerobic Sludge Blanket

**Table 2.** Performance of the selected CCWS in the of international data bases

| Article | COD | | | BOD | | | TSS | |
|---|---|---|---|---|---|---|---|---|
| | Initial* ($mgO_2/L$) | Removal** (%) | SAR ($g/m^2d$) | Initial* ($mgO_2/L$) | Removal** (%) | SAR ($g/m^2d$) | Initial* (mg/L) | Removal** (%) |
| 1 | 839 | 81.0 | 423.7 | 466 | 99.0 | 235.4 | 158.0 | 98.0 |
| 2 | 230 | 80.4 | 92.9 | 105 | 99.0 | 42.4 | 158 | 98.1 |
| 3 | | | | 120 | 95.0 | 36.4 | 90.0 | 90.0 |
| 4 | 82 | 80.9 | | 20 | 93.1 | 36.4 | 26.0 | 88.0 |
| 5 | | | | 115 | 85.0 | | | |
| 6 | 571 | 47.8 | 41.7 | | | | 109.1 | 84.3 |
| 7 | 646 | 88.0 | 65.5 | 435 | 95.0 | 44.1 | 120.0 | 92.0 |
| 8 | 748 | 95.2 | 90.7 | | | | | |
| 9 | | | | 86 | 92.0 | 1.0 | 171.0 | 73.0 |
| 10 | 190 | 98.0 | 110.0 | 91 | 90.0 | 52.7 | 54 | |
| 11 | 82 | 81.7 | | 20 | 92.0 | | 26.0 | 87.8 |
| 12 | 120 | 79.2 | 105.0 | 51 | 80.4 | 44.6 | 42.5 | 58.6 |
| 13 | 470 | 98.0 | 40.0 | 276 | | 23.5 | 148.0 | |
| 14 | 748 | | 40.0 | | | | | |
| 15 | 298 | 67.5 | 32.6 | 142 | 70.6 | 15.5 | 64.9 | 77.7 |

*Quality of the upstream effluent, **Removal percentage, SAR – Superficial application rate.

The efficiency obtained with the vertical flow are superior to those of the horizontal flow, always with the proper dimensioning. Combination of recirculation or aeration is effective in achieving high levels of contaminant removal. The advantage of this technology is the effectiveness in different contaminant concentrations, as presented by Gross *et al.* (2008).

Recirculation enhances CCWS efficiency, making a smaller area better utilized: Articles 1, 2 and 3 show removal rates of 90% or higher.

Solids removal is directly linked to water appearance and the user's acceptance. The vertical typology achieved the highest removals of TSS. Horizontal systems, flooded or not, have lower percentage of organic matter removal than the vertical systems, because the higher filtering capacity of the vertical typology, especially when associated with recirculation.

The removal of solids is, in the majority, higher in vertical typologies. It is observed that the concentration of solids, on average, of the initial effluent in the vertical typology was higher and the performance was superior, especially in the studies with recirculation.

The association of technologies increases the contaminant's removal, mainly when recirculation and aeration are used. Passing through the filter material several times and contact with oxygenated environment promotes a fast degradation of contaminants and the retention of dissolved particles. However, the disadvantage is the energy demand, which increases the installation and operation costs related to pumping.

The major advantage of watering garden and ornamental plants with non-potable water is that low amounts of organic matter and nutrients can be beneficial to plants and have better results than adding artificial products.

Different typologies can be used for the effective treatment of grey water. In addition to the quality parameters presented, it is necessary to consider the ease of construction, the aesthetic factor and other aspects to select the typology to be used.

There is evidence of reduced organic matter and suspended solids that in some cases resemble systems with long hydraulic retention or a more complex treatment. In general, CCWS are placed on the ground with some sealing. It can also be installed in suspended structure, acting as a wastewater treatment module where effluent is pumped through the top of the CCWS.

This work evaluated if the grey water from the shower, treated by a CCWS, can be reused for flushing toilets.

## METHOD

Based on the literature review, a vertical recirculating CCWS was chosen, combining with ozone disinfection. The system under study was installed in a single-family residence, which has a bathroom used by two people.

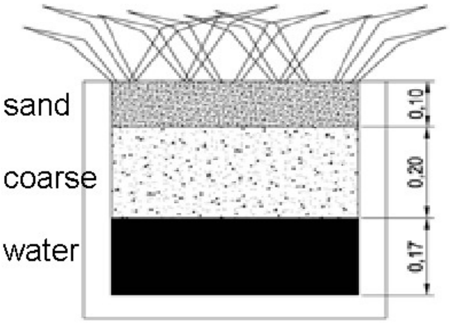
The disinfection system does not require any replacement or handling of chemical products and there is no risk to the users. In addition, ozone layers is environmentally sustainable as they eventually transform into oxygen, improving effluent quality.

Based on studies of Gross *et al.* (2007, 2008), Sklarz et al. (2009) and Yu *et al.* (2016) we have constructed a CCWS. Since space was limited and we wanted to use easily available materials, a polypropylene box for the CCWS wrap was chosen, with a volume of 176 L (0.43m x 0.87m x 0.47m). The CCWS was composed of a 0.10m layer of thick sand (D10 = 0.051 and Cnu = 5.88) at the top and a layer of 0.20m of gravel 0. To increase the water storage capacity, a stainless-steel grid was placed to separate the gravel layer from the exclusive layer of water at the bottom (Figure 1).

Initially, there was a survey about the daily consumption of water in the shower (source of grey water) and in the toilet of the house (where the treated non-potable water would be used). This survey was conducted through interviews, measurement of flow rates and duration for bathing for 3 days.

For the sizing of the system, an evapotranspiration loss of 10% was considered, resulting in 120.6L / day for reuse. This value is higher than the other studies. For example, in Kantawanichkul, Kladprasert & Brix (2009) it was equal to 6%.

The top of the CCWS is at ground level for aesthetic and space saving reasons. This option allows the system to be used as part of the residence's garden. Local plants were taken from the margin of a river near the residence for better adaptation (**Fig. 2**). Many mature and rooted plants were placed at the top of the CCWS. The macrophytes used are classified as emerging, and species Polygonum SPP, very common in river and margins. Reservoirs with 30- and 20-liters were used (**Fig. 3**).



Schematic

Polyethylene box Stainless grid

Coarse layer of 0.20m Sand layer of 0.10m

**Fig. 1** Elements of the CCWS.

(a) (b)

**Fig. 2** Macrophytes: (a) on the river margin (b) placed in the CCWS.

**Fig. 3** Grey water reuse reservoirs: (1) 20L; (2) 30L.

The ozone generator started automatically by a timer, in cycles of 15 minutes after 45 minutes. The generator injects ozone into the reservoir, which is dispersed by a diffuser stone.

Recirculation occurs continuously, triggered by a level sensor, which avoided the pump to operate without water. When started, the pump filled reservoir 1, connected to reservoir 2. After filling reservoir 2, a flow was directed to the top of the SCWC. Recirculation produces oxygenation by contact with air and filtration by passing through the substrate and roots. If it exceeded the top level of the SCWC, the effluent flew to the sewage collector. The sewer pipe was protected from sunlight by a metallic blanket.

Grey water from the shower entered in the bottom of the polyethylene box to increase the flow velocity of the box drain. If this entry was from the top, the flow would be slow and would cause the rise of the water level. The first dilution of grey water occurs in this lower reservoir, under the stainless-steel grid.

When reservoir 1 is fulfilled, a second dilution occurs. A 1 HP centrifugal pump was used to pump the water to the reservoir 1 and to recirculate.

Reservoir 1 had two outputs, the first for reservoir 2 and the second for top of CCWS. In reservoir 2, where the ozone disinfection was performed, there was an outlet to the toilet flush reservoir.

When pumped to reservoir 1, the effluent returned to the top of the CCWS, starting the process again. The use of two reservoirs was necessary to protect the ozoned effluent to have contact with the microbial community from CCWS. In reservoir 2 there was, again, dilution and ozonation, which promote an improvement of effluent quality and eliminate any coliforms presented. The Entry into R2 was at the top to prevent the return of effluent to R1.

The system was operated for twelve months, starting in January 2018 and water quality evaluation bagan in October 2018, after the adaptation period and operational problem solving.

Samples were collected at two points of the grey water reuse system: INPUT - inside the bathroom, while taking a shower, using a bucket under the shower; and OUT - at the exit from the treatment system. Samples were collected in the OUT point about 10 min after the beginning of the shower.

The samples were placed in 0.5 L PET bottles, sanitized with sulfuric acid and distilled water and stored in the refrigerator for a maximum of four hours before the tests.

The parameters to evaluate the grey water and treated water samples were pH, turbidity, conductivity, color, Chemical Oxygen Demand (COD) and total suspended solids (TSS), fixed suspended solids (FSS) and volatile suspended solids (VSS). Thermotolerant Coliform and Biochemical Oxygen Demand (BOD) tests were performed only once a month.

All methodologies followed the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). For the analysis, the means and standard deviations of the obtained results were calculated and the KrusKal – Wallis test with a significance level of 5% was also used to evaluate the statistical difference between the values of each parameter. **Table 3** presents the non-potable water quality parameters used as reference, considering the reuse for toilets flushes, because there is no regulation of this kind of water reuse in Brazil.

## RESULTS AND DISCUSSION

The CCWS system improved the grey water quality of the shower, although some of the variables were above the reference documents (**Table 2**) for reuse.

**Table 4** presents the estimated water consumption for bathing and flushing toilets in the residence, which had one bathroom and two inhabitants.

The estimative presented in **Table 4** shows that the grey water from the shower (134.4L/day) is sufficient for the toilet flush (102.0 L/d).

**Fig. 4** to **Fig. 10** are box–plot graphs of the results obtained of pH, conductivity, color, turbidity, total, volatile and fixed suspended solids, and organic matter in terms of COD and BOD. The samples were INPUT (grey water from the shower) and OUTPUT (reservoir 2 outlet - non-potable water, after passing through the CCWS and disinfection system) from the field-installed grey water reuse system.

Eighteen (18) samples were collected. Data from samples 1 to 4 were not considered in the calculation of averages and system performance evaluation since, during this period (from July to September 2018), three

**Table 3** Quality parameters of non-potable water for reuse purposes.

| Parameters | I | II | III |
|---|---|---|---|
| pH | 6 a 9 | 6 a 9 | 6 a 8 |
| BOD ($mgO_2/L$) | | <10 | |
| Turbidity (uT) | < 2 | < 2 | < 5 e < 2 for more restrictive uses |
| TSS (mg/L) | | <10 | |
| Coliforms (NMP/100mL) | <500 | <200 | Absence |

**I** - SAUTCHUK et al. (2005), water quality standard for flushing toilets

**II** – USEPA (2012), for residential treatment system for restrictive internal and non-restrictive external use

**III** – ABNT (2007).

**Table 4** Water consumption estimation of the residence.

| Parameter | Value |
|---|---|
| Number of baths per habitant per day | 1.2 |
| Average bath time (min) | 7.0 |
| Average shower flow (L/min) | 8.0 |
| Total water consumption in the bath (L/day) | 134.4 |
| Total number of toilet's flush per day | 15.0 |
| Volume of toilet flush (L/flush) | 6.8 |
| Total water consumption in toilet's flush (L/day) | 102.0 |

CCWS maintenances were performed. These maintenances momentarily influence the system and must be considered by the user. The discussion about maintenance is presented in the operation and maintenance item.

## pH

The pH factor is essential for wastewater treatment, because it influences microbial metabolism and existing chemical substances. **Fig. 4** presents the box plot with the measurements. The value of the pH of the OUTPUT sample (7.7 ± 0.6) is significantly higher than the INPUT (6.7 ± 1.3) (Kruskal-Wallis 5%). This is probably due the use of personal hygiene products such as soaps and shampoos, which tend to have a pH in the range of 4.5 to 6.5 lower values were found in the INPUT samples.

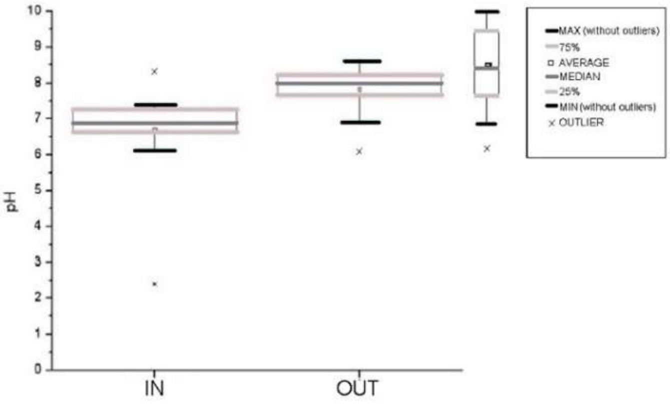
The lowest value (pH = 2.4) in this same sample (INPUT) probably occurred by the use of some cleaning product for bathroom sanitation.

However, even with the pH variation of the INPUT sample it is verified that the value of the final effluent did not change much. There is no direct dependence between them, due to all reactions that occur in the treatment. Moreover, the effluent mixed with the stored water also helps to maintain the neutral pH. In spite of the hygiene products and the organic matter decreases the pH, the final effluent did not change and none of the values of this parameter in CCWS OUTPUT resulted in a value out of the limits showed in Table 2 (between 6.0 and 8.0 or 9.0).

## Conductivity

Electrical conductivity (EC) values did not show any statistical difference between the INPUT and OUTPUT samples (KrusKal-Wallis 5%); even the average OUTPUT (793 ± 277 µS/cm) being 18% higher than the INPUT (670 ± 577 µS/cm). It can be seen that treatment, by transforming organic matter into inorganic matter, tends to increase EC (**Fig. 5**).

**Fig. 4** Box-plot graph of pH values.



The materials retained in the substrate contributed to an increase of the effluent EC values at OUTPUT. There are no limits established for this parameter in the reference documents used, however, it is important to consider it, as high EC values are harmful when water is intended for irrigation (USEPA, 2012) or toilet flush.

## Color and turbidity

As color and turbidity are correlated with parameters, their removals were similar (**Fig. 6** and **Fig. 7**). There was a statistical difference between the INPUT and OUTPUT values (KrusKal – Wallis 5%) for both parameters. The products used in bathing and to clean the bathroom added color and turbidity to the effluent. The solids attached to the body and bath area surfaces also increase the value of these parameters.

Color and turbidity removals were higher in the last samples, which represents the efficiency of the system was increasing over time. This is due to different factors, including the reduction of voids over time, as the high organic load applied to CCWS accumulates in the top of the sand layer, between the pores, assisting in filtration. In addition, the community of microorganisms contained in the substrate expands and, by natural selection, those that best suit the available effluent conditions tend to grow and increase the system's ability to remove pollutant material.

**Fig. 5** Box-plot graph of EC values.

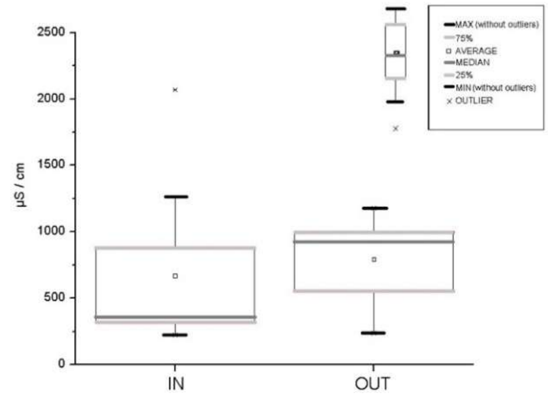


**Fig. 6** Box-plot graph of color values.

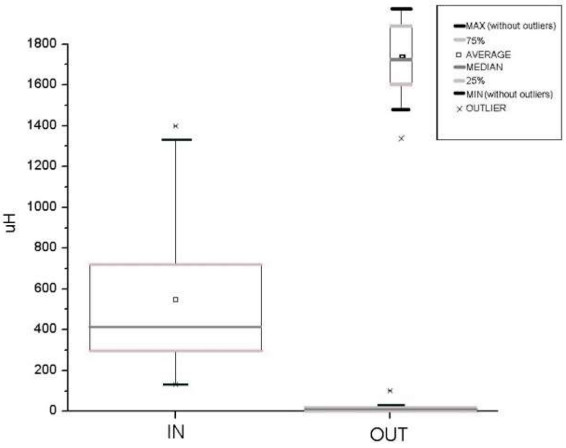
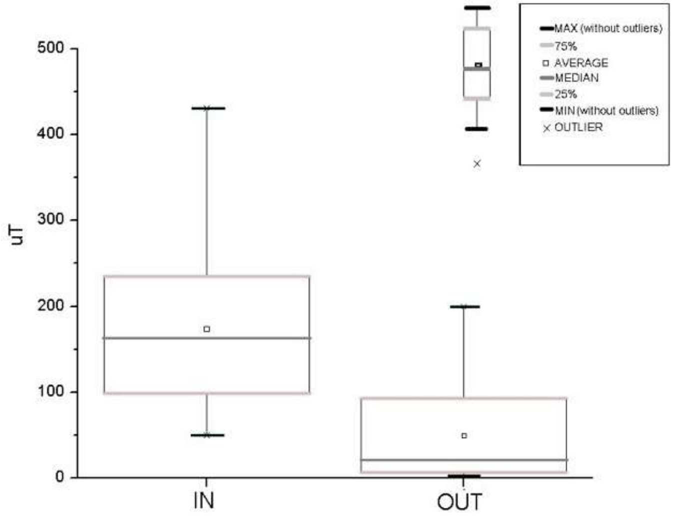


**Fig. 7** Box-plot graph of turbidity values.



The average color removal from the effluent was 96% in total, and the mean INPUT was 549 ± 370 uH and the average OUTPUT was 21 ± 30 uH. The average removal of the first half of the collections (5 to 12) was 93% and, the second (13M to 16T), it was 99%, confirming the improvement of system performance regarding this parameter over time.

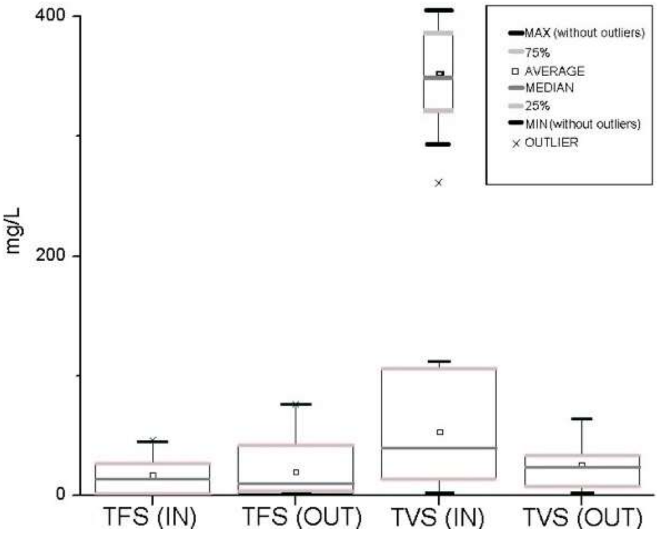
An improvement over time can also be seen in turbidity values. The average removal of the first half of the collections (5 to 12) was 49%, and in the second half (13M to 16T), the removal reached 91% (Figure 14). In total, the SCWC showed a 70% turbidity removal, with an average INPUT value of 174 uT ± 99 and, at OUTPUT, 50 uT ± 62.

If just considered the second half to calculate the average of color and turbidity OUTPUT values, it is even lower: the color OUT equals to 3 ± 2 uH and turbidity to 11 ± 12 uT. These values were below the reference limits used (**Table 3**). Thus, it is evident that the system is efficient in removing these two components, however it is necessary to consider an adaptation time. In addition, in the period when the pump was changed, it was found that there was excessive pressure in the recirculation and a drag of sand to the reservoirs R1 and R2. Therefore, the use of a proper pump may result in better performance.

**Suspended solids**

Solids represent both inorganic and organic materials suspended in the effluent. Therefore, volatile suspended solids (organic) (VSS) and fixed suspended solids (FSS) (inorganic) values were measured. All values are shown in **Fig. 8**. The mean values of TSS at INPUT and OUTPUT were, respectively, 1550 ± 2343 mg/L and 661 ± 699 mg/L, thus there was a 57% reduction. The mean value of VSS was 1362 ± 2351 mg L at INPUT and 447 ± 738 mg/L at OUTPUT, a reduction of 67%. In addition, the ratio of VSS to TSS (VSS/TSS) for INPUT and OUTPUT was 88% and 68% respectively, indicating that most solids were organic. This data shows that CCWS uses some of the organic matter for plant growth.

**Fig. 8** Box-plot graph of solids values.



The average value of the FSS at OUTPUT was 17% higher than the INPUT, from 183 mg/L to 214 mg/L, and the FSS/TSS ratio increased from 12% to 32%. This increase is believed to be due to the excessive pressure exerted by the pump to recirculate the effluent. When reservoirs R1 and R2 were already full, all flow was sent to the top of the CWSS at a speed that may have drag sand to the OUTPUT. Sand, as it is an inorganic solid, mainly altered the FSS.

The high rate of solids at OUTPUT were the biggest problem encountered in the system under study. The reduction in the organic part of the solids and other factors such as color and turbidity demonstrate that CCWS with recirculation can achieve better results.

Comparing the results with the limit values contained in the reference documents (10mg/L), the values found are above those indicated. These high values can be a problem for users due to aesthetic requirements and also, when accumulating in the coupled box, possibly cause malfunctions. There are also health risks to users as pathogens may adhere to suspended solids. In addition, they may hinder the action of the disinfectant agent.

The operational problem caused by system pump replacement (better described in the system operation and maintenance item) influenced solids results. Inorganic solids values show that there was a transport of filtering material to the OUTPUT, which indicates that the treatment potential of the proposed system is higher than that achieved in this study.

**Chemical oxygen demand and biochemical oxygen demand (COD and BOD)**

The organic matter values in terms of COD and BOD of the samples collected in this study are shown in **Fig. 9** and **Fig. 10**. The removal of organic matter in terms of COD was 84%, with INPUT and OUTPUT average values, respectively, of 604 ± 298 $mgO_2/L$ and 84 ± 58 $mgO_2/L$ (with significant difference - KrusKal – Wallis 5%).

**Fig. 9** Box-plot graph of COD values.

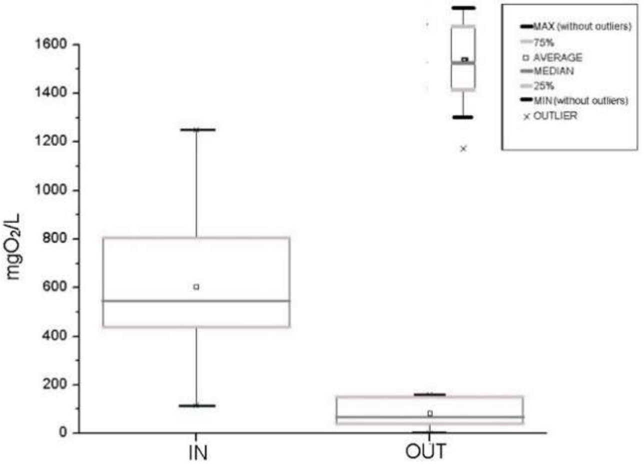
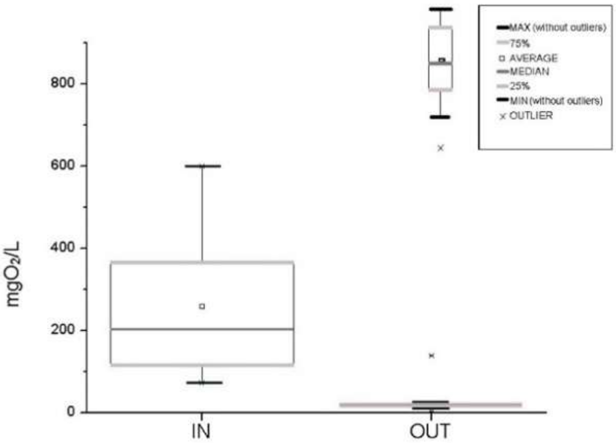


**Fig. 10** Box-plot graph of BOD values.



The BOD values in the INPUT and OUTPUT average were, respectively, 239 ± 218 $mgO_2/L$ and 17 ± 8 $mgO_2/L$ and the mean removal 89%. These results show that recirculation is efective in degradation of organic matter.

These organic matter concentrations in terms of BOD in the OUTPUT samples were higher than the limits found in Table 2 (10 $mgO_2/L$). In addition, considering these values and the estimated water consumption for the bath in the home (134.4L, Table 3.1) the surface application rate (SAR) results in 177.2 $gCOD/m^2day$, which is also higher than all SAR of the studies in **Table 1.**

Although, the percentage of removal of CCWS was high, it turns out that the OUTPUT values for BOD values were slightly higher than the limits given in the reference documents (10 $mgO_2/L$) (**Table 3**).

In the case of COD, the documents used as reference did not have limit values, however, it is important to remember that higher values of this parameter indicate that the effluent will degrade over time. This phenomenon was not observed in the this CCWS, however this is a factor to be considered, because a longer residence time of this effluent, for example, due to a period of non-use of the residence, may cause an unpleasant odor. Even with the excessive pressure of the pump, the system performed well in reducing organic matter.

## Thermotolerant coliforms

The values found for the samples collected in the present study are presented in **Table 5**. Except for one of the samples, all values obtained for the OUTPUT samples meet the limits of the reference documents (<500 NMP / 100mL for complete absence), indicating a good potential for the use of ozone as a disinfectant.

The presence of thermotolerant coliforms in one of the OUTPUT samples is probably due to a momentary failure and may had been solved in the following ozonation cycle. Another possibility would be contamination during sample collection or handling, either due to poor hygiene of the vials where they were stored, or contamination at the time of collection, resulting in a sample that does not represent reality.

In general, the use of ozone as a disinfectant proved to be efficient. In future works it would be interesting to use an electronic trigger to ensure that all water flowing into the reservoir is disinfected immediately and does not have to wait for the timer to trigger. This improved system operation would minimize the health risks of users.

## Operation and maintenance

Because it is a system that uses natural aggregates as a substrate, there is a possibility of clogging over time. In the system under study, after 4 months of operation, surface clogging occurred, which compromised its performance. This clogging time was similar to that observed in studies by Cruz *et al.* (2019), who used a septic tank followed by a sand filter for domestic sewage treatment, taking 16 weeks to have the sand filter clogged, and a solution similar to that applied in this work was also performed.

For maintenance, there is no specific standard for these systems, thus the procedure set out in NBR 13969 (ABNT, 1997) was adopted: after surface drying, manual scraping and removal of surface deposited material, with a small layer of filter material (according to standard, the thickness of the layer to be removed ranges from 0.02 m to 0.05 m) was made; In addition, part of the vegetation was removed and the sand was scraped.

It is a simple maintenance that does not require technical knowledge and/or qualified labor, and the only care is to preserve the roots of the plants. However, in July, one month before the tests, it was necessary to replace the pump with insufficient power, requiring the complete disassembly of the CCWS and specialized knowledge was needed. This maintenance had a strong influence on the initial tests and also on the dragging of the sand by the excess of pressure.

After removal of the material, the spaces were filled again with coarse sand ($D_{10}$ = 0.051 and $C_{nu}$ = 5.88) stored, with the same characteristics as the first installation. Thus, it is important to constantly check the substrate and to have replacement materials when necessary. The material removed can be used in gardens or backyards, provided that the handling of this area is done with gloves, if necessary, it can be disposed of in the residential garbage. The laboratory tests showed a high index of organic matter and other components in the effluent, so it is emphasized that when disposal is necessary, direct contact should be avoided. In this case the disposal was carried out in the garden to contribute as fertilizer to the ornamental plants.

Finally, it should be noted that the CCWS uses accessible materials, and the operation is apparently simple, there is a need for maintenance, which, if not done properly, may impact in the operation. Thus, when the user chooses a system such as the one proposed, the person must be informed of the need for periodic maintenance at periods of not more than 4 months to ensure its proper functioning and proper performance.

## CONCLUSIONS

The grey water from the shower under study had high contamination compounds concentration, showing that the bath water is unsuitable for direct reuse and storage without proper treatment. Although the treated effluent did not meet all parameters of the reference documents (**Table 3**), there was a great improvement in water quality after it. This work represents a breakthrough in CCWS studies for water reuse, showing that even using more accessible materials it is possible to produce water for reuse.

The association of CCWS with recirculation and ozone disinfection was effective: even with grey water contamination compounds concentration was higher than those reported in the literature, the system generated results that resemble larger conventional systems.

The treatment provided by the proposed CCWS is not the most appropriate when the effluent needs to present low values of EC.

The parameter with the lowest performance of the CCWS was the suspended solids (57% removal, on average). In the case of fixed suspended solids, there was an increase in the passage through the system, probably due to the excessive flow of the pump. The volatile suspended solids, which represent the organic part, had a good reduction (67%), indicating that most of the dragged material was sand. Thus, there were no risks to users due to effective disinfection and high removal percentage of organic matter. For the development of future works, it is suggested to consider the installation of plastic substrate in an attempt to reduce the high FSS concentration of treated effluent.

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