Comparative performance between two decentralized wastewater treatment plants in pilot scale for treating low strength wastewater

Comparative performance between two decentralized wastewater treatment plants

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Performance comparison between Anaerobic/Aerobic Baffled Reactor and Horizontal Subsurface Flow Constructed Wetlands (AABR and HSCW) was investigated. In this study, both systems were operated, in parallel, from the same source of domestic low strength wastewater, considering that the wastewater has low organic load (0.06 - 0.61 KgCOD.m^3.d^{-1}). Results showed that, the AABR and HSCW achieved 78±9% and 82±9% of Chemical Oxygen Demand (COD) average removal rates, 70±18% and 74±12% of Biochemical Oxygen Demand (BOD_5) average removal rates and 85±17% and 83±16% of Total Suspended Solids (TSS) average removal rates, respectively. Comparing both systems used in this study, the AABR showed to be as efficient as the HSCW in organic matter removal (COD and BOD_5) and TSS and the statistical test (significance level of 0.05), showed no significant difference between each other, in terms of organic matter removal and solids. The Total Coliforms and *E.coli* removal rates, in the AABR, were 2.0 log units and in the HSCW was 3.0 log units and *E.coli* was 2.5 log units. The AABR operation cost per capita was U$ 0.86 per month and the HSCW was US $ 0.16 per month.

Keywords
Anaerobic/Aerobic baffled reactor; Horizontal subsurface flow constructed wetlands, sanitary wastewater, energy cost

INTRODUCTION

Wastewater treatment is essential to ensure public health and environment's quality. Unmanaged wastewater can be a source of pollution, a hazard to the health of human populations and the environment alike. Unfortunately, billions of people in the world do not have access to adequate wastewater treatment systems, consequently, discharging large volumes of untreated wastewater into surface waters. About 80%–90% of all wastewater generated in developing countries is discharged directly into surface water bodies (UN Water, 2008).

The situation of sanitation in Brazil is equally problematic, being demonstrated by the number of cities without any kind of wastewater treatment. According to the Brazilian Institute of Geography and Statistics (IBGE, 2008), 52.2% of the 5.507 Brazilian cities are fit into this calamitous situation of lack of sanitation. Most of these cities discharge wastewater directly into water bodies without proper treatment, thereby undermining the quality of potable (Tonetti *et al*. 2010). Due to the growing concern about the quality of the environment and water resources, researchers have been dedicated to search for alternatives that may meet the needs of developing countries and poor areas wastewater treatment, such as the Decentralized Wastewater Treatment (DEWASTS). DEWATS are more appropriate for low-density communities and varying site conditions and are more cost-effective than the conventional practices (Jamshidi *et al.* 2014). There are different types and configuration of DEWATS, such as, septic tanks, anaerobic baffled reactors, anaerobic filters, anaerobic and facultative pond systems, constructed wetlands.

Anaerobic baffled reactors (ABR) have been reported as a promising solution in domestic wastewater treatment (Yu, Lu & Wu, 2014, Aqaneghad & Moussavi, in press) and other types of wastewater (Thanwised *et al*. 2012) This system is a modification from the conventional UASB, but with multiples vertical baffles or chambers, in series and individuals, incorporating the advantages of it and phase separation (Manoj & Vasudevan, 2014). In the ABR the liquid flows downward and upward through the chambers, ensuring greater contact of the effluent with the biomass present in the lower part of the reactor (Sarathai, Kootattep & Morel, 2010)

Gopala Krishna, Kumar & Kumar (2009) achieved removal rates of 90% for COD in a eight chamber ABR treating low-strength soluble wastewater (COD ≈ 500 mg/L). Bodkhe (2009) used a modified ABR in order to achieve 84% of COD removal and 87% of BOD_5 removal, treating municipal wastewater at a HRT of 6 hours. Pirsaheb *et al.* (2015) studied the performance of an ABR, treating baker's yeast wastewater. The system was capable to achieve removal rates of 95.13%, with influent COD of 15.000 $mg.L^{-1}$. Silva *et al*. (in press) reported a maximum COD removal rate of 92% with the average removal of 78% in a three chamber ABR, with an additional aerobic chamber, treating low strength domestic wastewater with four different HRTs. These results shows the ABR potential to treat different kinds of wastewater.

Other DEWAT that has been received great attention is the Constructed Wetlands (CW), since their high pollutant removal efficiency, easy operation and maintenance, low cost, good potential for water and nutrient reuse, tolerance to high variability, and function as significant wildlife habitat. (Kadlec & Wallace, 2008). CWs has gained popularity in the last four decades as an alternative to conventional treatments and it is considered as a cost-effective and sustainable way for wastewater treatment (Wu *et al.* 2014). Based on the water flow regime and the type of macrophyte growth. CWs may be classified into three groups: free water surface flow, subsurface flow, and hybrid systems (Vyzamal, 2007).

In subsurface flow CWs, the wastewater is transferred through the filtering media, flows in the porous section (substrate) in a horizontal or vertical path, and contaminants are removed mainly by physical mechanisms, such as filtration or sedimentation, and biochemical interactions, such as microbial degradation (Shelef *et al*. 2013).

CWs development has received great attention, and has also been significantly applied, nowadays, in treatment of several kinds of wastewater, for example in Kynkäänniemi *et al*. (2013), Trang & Brix (2014). In domestic wastewater treatment, Zurita *et al.* (2009) investigated the use of four commercially valuable ornamental species in two types of subsurface flow wetlands in a tropical area in Jalisco, Mexico. The removal rates for the horizontal subsurface flow CW were: 77.9% for BOD_5, 76.3% for COD and 82 % for TSS.

Within this context, the aim of this study was to compare the performance of two types of decentralized treatment systems, an Anaerobic/Aerobic Baffled Reactor (AABR) and a Horizontal Subsurface Flow Constructed Wetlands (HSCW) in the treatment of low strength wastewater from an University campus.

MATERIALS AND METHODS

The feed used in this study was a low strength wastewater collected in UNESP- Univ. Estadual Paulista located in Bauru, Sao Paulo-Brazil, with approximately daily flow of 7.300 $L.d^{-1}$. The characteristics of the inlet, with the minimum and maximum values, were as follows: Chemical

Oxygen Demand (COD): 105-381 mgCOD.L^{-1}; Biochemical Oxygen Demand (BOD_5): 36-162 mgBOD_5.L^{-1}; pH: 6.8–7.5; Total Suspended Solids (TSS): 6-130 mgTSS.L^{-1}; Temperature: 24-28°C, Ammonia Nitrogen: 19-89 mgN-NH_4^+.L^{-1}, Organic load: 0.06-0.61 kgCOD.m^{-3}.d^{-1}.

The pilot plants were comprised of a major common preliminary treatment, composed by screening, settling tank (5.500 L) and equalization tank (2.200 L.). After the common sections the treatment was divided in two different and separated secondary treatments, composed by an Anaerobic/Aerobic Baffled Reactor (AABR) and Horizontal Subsurface Flow Constructed Wetlands (HSCW). Before each secondary treatment, the effluent was pumped to two different steps, the AABR effluent was pumped to a storage tank and the HSCW to a mechanical screen.

The AABR system used in this study consisted of four vertical and cylindrical chambers being 3 anaerobic and 1 aerobic, with a total hydraulic volume of 817 L. The area used for the construction was 2x3 m. and it was designed to treat the wastewater produced by 20 people. The AABR was operated during 203 days, the Total Hydraulic Retention Time (anaerobic+aerobic) varied between 33 and 8.25 hours, and the flow varied between 0.4 L.s^{-1} to 1.6 L.s^{-1}, treating 115 L.d^{-1}per capita, using the maximum flow (1.6 L.s^{-1}). The AC was aerated through two air microporous diffusers (pore of 10 μm), disposed on the bottom of the chamber (75 mm of base diameter and 70 mm high), connected to an air compressor, with the flow controlled by a air flow meter, calibrated to a flow of 5 L.min^{-1}. The AC had an area on the top, filled with bamboo rings (*Bambusa vulgaris*), to microbial support. After the chambers, it was installed a laminar settling tank (80 L), with plastic inner plates disposed in a 60º angle, relative to the horizontal (Figure 1).

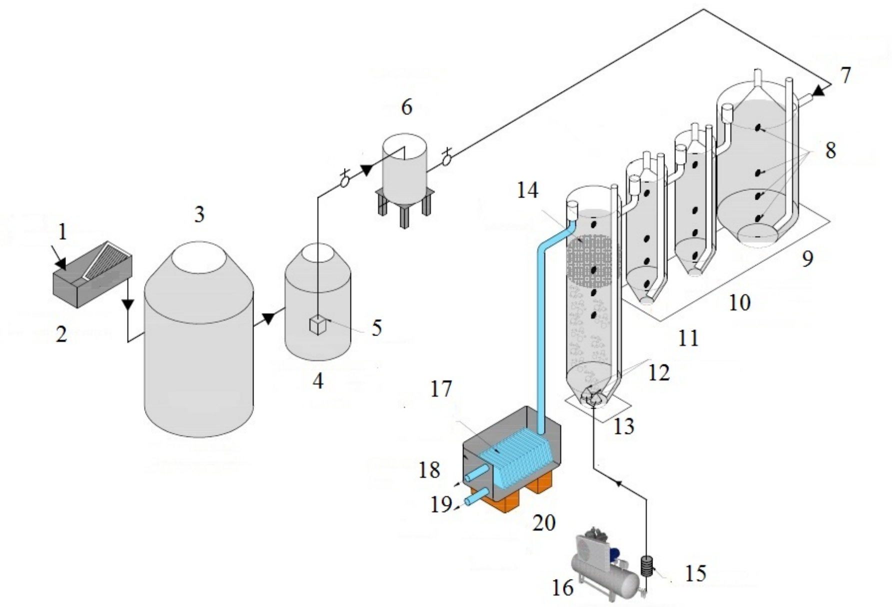

Figure 1. Schematic diagram of the AABR: 1-Raw wastewater; 2- Screen; 3- Settling tank; 4- Equalization tank; 5- Pump; 6- Storage tank; 7- Influent; 8- Chambers sampling points (for the present study, the higher points were used); 9- Chamber 1; 10-Chamber 2; 11- Chamber 3; 12- Air diffusers; 13- Anaerobic chamber; 14- Bamboo rings; 15- Air flow meter; 16- Air compressor; 17- Plastic plates; 18- Effluent; 19-Sludge exit; 20-Laminar settling tank

The HSCW used an area of 9.0 x 4.5 m, also design to attend 20 people. The area was filled with sand (layer of 10cm), gravel (layer of 10 cm), styrofoam beads (layer of 40 cm) and crushed rock (layer of 20 cm). The plant species used was Vetiver grass (*Chrysopogon zizanioides*), and the hydraulic load was 58 L.m^{-2}.d^{-1}. The HSCW was monitored during 63 days, with flow varying from 1.160 to 1.660 L.d^{-1}, treating 117 L.d^{-1} per capita. (Figure 2). This system was initially constructed to attended another research, comprising three beds and had been operated for approximately two years. In this present research, samples were taken only in one bed, multiplying the flow by three.

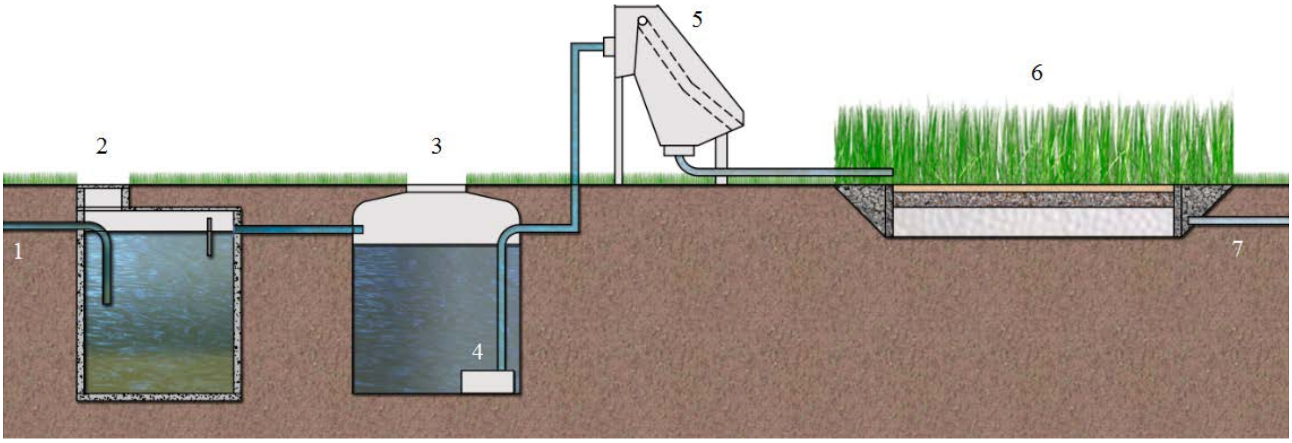

Figure 2. Schematic diagram of the HSCW: 1- Inlet (screened wastewater); 2- Settling tank; 3- Equalization tank; 4- Pump; 5- Mechanical screen; 6- Constructed wetland; 7- Outlet

The samples from the inlet and outlet of the both systems were analyzed for parameters such as a COD (5220-D method), pH (4500- H^+ B method), BOD_5 (5210 D method), TSS (2540 D method), and Total coliforms/E. coli (9221 method) according to the Standard methods (Rice *et al*. 2012). A volume of 2 L. of the inlet and outlet was taken, in the morning, once a week.

Furthermore, data retrieved from the consecutive days during the monitoring period was analyzed to examine the performance of the two systems. The COD, BOD5, and TSS removal efficiencies results from each system were compared using a statistical test Miller & Miller (1993), and it was checked the significant differences between, at a 0.05 significance level.

RESULTS AND DISCUSSION

Table 1 shows the parameters average concentrations in the inlet and outlet of both systems used in this study.

Table 1. Average and standard deviation (S.D.) of parameters concentrations studied in the AABR and HSCW.

Parameters	Units	Inlet*	AABR outlet*	HSCW outlet*
COD	$mgCOD.L^{-1}$	214 ± 63	48 ± 25	47 ± 21
BOD_5	$mgBOD_5.L^{-1}$	85 ± 36	23 ± 11	38 ± 11
TSS	$mgTSS.L^{-1}$	43 ± 28	4 ± 3	10 ± 10
pH	---	7.3 ± 0,2	7.3 ± 0,1	6.4 ± 0,18
Total Coliforms	MPN.100 ml^{-1}	1.52 $x10^7$	2.76$x10^5$	1.42$x10^6$
E.coli	MPN.100 ml^{-1}	3.27$x10^6$	1.01$x10^5$	3.45$x10^5$

*Average ± standard deviation

The inlet concentrations of the analyzed parameters were found to be low for organic matter (Table 1). The wastewater could be categorized as low strength wastewater, according to Metcalf & Eddy (2003). Both systems were operated in room temperature, in mesophilic range (27°C to 30°C). The pH values remained between 6.8 and 7.5 in the inlet, 6.9 and 7.7 in the AABR's outlet and 6.2 and 6.8 in the HSCW's outlet. No significant variation in pH was observed in both systems, being operated in a neutral range.

Organic matter and suspended solids removal

The COD average removal rates of AABR and HSCW are shown in Figure 3 (A, B), the BOD_5 average removal rates of AABR and HSCW are shown in Figure 4 (A, B) and the TSS average removal rates of AABR and HSCW are shown in Figure 5 (A, B).

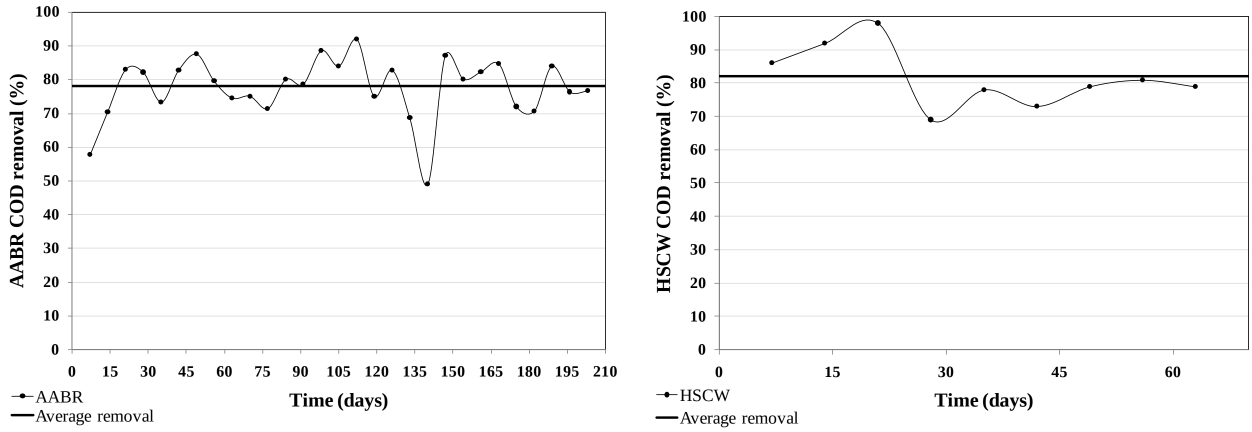

Figure 3. (A) COD removal rates of AABR; (B) COD removal rates of HSCW

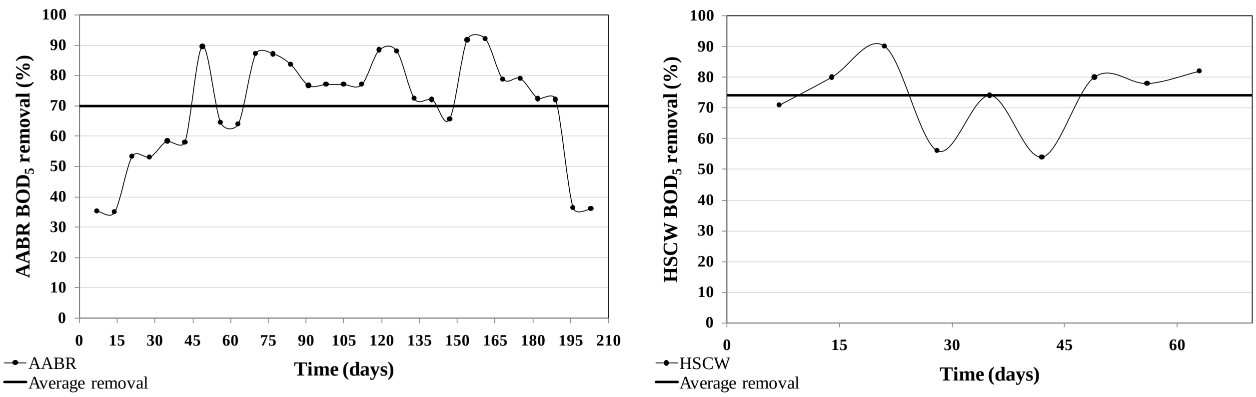

Figure 4. (A) BOD_5 removal rates of AABR; (B) BOD_5 removal rates of HSCW

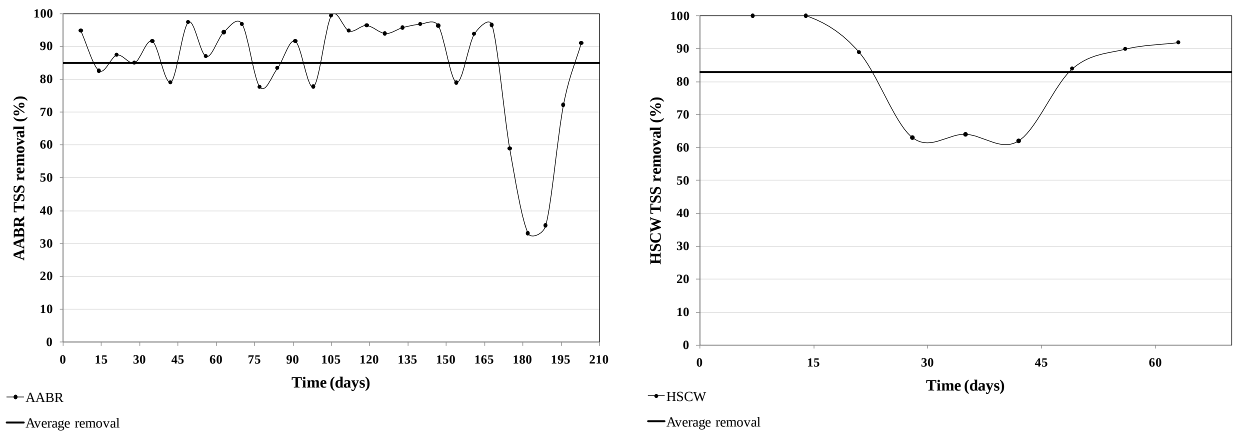

Figure 5. (A) TSS removal rates of AABR; (B) TSS removal rates of HSCW

The inlet wastewater concentrations, in COD terms, ranged from 105 to 381 $mgCOD.L^{-1}$. The outlet concentrations ranged from 12 to 147 $mgCOD.L^{-1}$ in the AABR and from 7 to 88 $mgCOD.L^{-1}$ in the HSCW. In terms of BOD_5, the inlet wastewater concentrations ranged from 36 to 162 $mgBOD_5.L^{-1}$. The outlet concentrations ranged from 4 to 39 mg $BOD_5.L^{-1}$ in the AABR and from 10 to 44 $mgCOD.L^{-1}$ in the HSCW.

The AABR had a COD average outlet concentration of 48±25 mgCOD.L^{-1} compared to 47± 21 mgCOD.L^{-1} for the HSCW and a BOD_5 average outlet concentration of 23±11 mgBOD_5.L^{-1} compared to 38±11 mg BOD_5.L^{-1}, respectively (Table 1). The organic matter concentration decrease between the inlet and outlet in both systems and the standard deviation of COD and BOD_5 averages shows that the inlet concentrations varied widely along the monitoring period. This variation may be related to the source of the wastewater, that was most from public toilets, public lavatories, pool overflow and washing floors.

Regarding the organic matter and suspended solids removal rates, the AABR achieved 78±9% of COD average removal, with a maximal removal of 92%; 70±18% of BOD_5 average removal, with a maximum removal of 92% and 85±17 of TSS average removal, with a maximum removal of 99 %. The AABR removal rates of COD in the present study were similar than previously researcher using synthetic low strength wastewater. Sarathai, Kootattep & Morel (2010) and Bae *et al.* (2014) found similar COD removal rates with Anaerobic Baffled Reactors, operated with low-strength synthetic wastewater. Lee *et al*. (2014) found a COD average removal rate of 84%, but the authors related the high value to the secondary polishing system, consisted by an Anaerobic fluidized membrane bioreactor.

Hahn and Figueroa (2015), used an Anaerobic Baffled Reactor, in pilot scale, consisted of four sequential chambers, constructed with PVC pipes, with a total hydraulic volume of 869 L, to treat 1.728 L. per day of domestic wastewater with an influent COD averaged of 760 ± 190 mg.L^{-1}. Their COD average removals were 43±15%, much less than the AABR, even treating a more concentrated wastewater. The BOD_5 average removal rates were also lower than the AABR, 47 ± 15% compared to 70± 18%. In this case, the higher COD removal rates reached by the AABR could be explained due the ambient temperature (27°C to 30°C) operated during the monitoring period, since the other system was operated in temperatures between 12 to 23°C.

About the HSCW, in this study, the system achieved an average COD removal rate of 70±18%, with a maximum removal of 98%; 74±12% of BOD_5, with a maximum removal of 90%, and 83±16% of TSS, with a maximum removal of 100%. According to Sundaravadivel & Vigneswaran (2010), generally, constructed wetlands are known to perform very well with respect to BOD_5 and COD removals.

Calijuri *et al*. (2009) register average removals of 80% and 60% for BOD_5 and COD, respectively, in a HSCW, filled with crushed rock and *Typha sp*. and *Brachiaria sp*. as the species plants. The domestic wastewater treated in this system was a UASB effluent, with low BOD_5 concentrations (70 mg.L^{-1}). The authors concluded that the system promoted high complement removal, regardless of the operation or phase considered, rarely producing effluent with concentrations higher than 15 mgBOD_5.L^{-1} and 20 mgTSS.L^{-1}. In the present study, the average removal rates were similar to Calijuri *et al*. (2009), although the HSCW affluent was not pre-treated as in Calijuri *et al*. (2009), showing a better performance in the present study, which obtained a COD average removal rates of 82±9%.

Comparing the both systems used in this study, the AABR showed to be as efficient as the HSCW in organic matter removal and suspended solids, with no significant statistical difference between each other, in terms of COD, BOD_5 and TSS It demonstrates that the organic matter removal occurred in each type of treatment, proving the effective capacity to remove organic matter both systems, even being fed with low-strength wastewater.

The organic matter removal and the outlet concentrations, in terms of BOD_5, from both systems, reached the Sao Paulo State legislation standards (Sao Paulo State Decree, n° 8.468/1976) on control of effluent discharge, that standardizes a maximum limit of 60 mgDBO_5.L^{-1}, with 80% of removal rate.

Total Coliforms and *E.coli* removal

The Total Coliforms (TC) and *E.coli* average concentrations in the treatments used in this research is presented in Table 1. The TC and *E.coli* removal rates, in the AABR, were 2.0 log units. The TC removal rate, in the HSCW was 3.0 log units and *E.coli* was 2.5 log units. Comparing the AABR and the HSCW for Total Coliforms and *E.coli* results, it is possible to infer that the outlet concentration, in both systems, have a low removal rate, reducing only two or three log units, not having advantages over each other in this topic.
The Brazilian National Council of Environment Resolution CONAMA n°430/2011, states that the maximum concentration of *E.coli* in the treated effluent must be between $2,0x10^2$ to $2,5x10^3$ $MPN.100^{-1}$, depending of the type of waterbody receptor, therefore, in this case, both AABR and HSCW need a disinfection step to improve the coliforms inactivation.

Energy cost and Treatment capacity per area

In order to compare the average daily energy power consumption per habitant from the treatment systems, the energy power consumption by the pumps used in both treatments and the air compressor which provided air to the aerobic chamber in the AABR were calculated.

The air compressor used in this research was Schulz (*Twister Bravo*, model CSL 10/100), with a motor power of 1.5 kW. The air compressor started every 60 min., working for approximately 10 min., with a total operation of 4 hours per day. Thus, the daily power consumption was 6.0 $kWh.d^{-1}$(Consumption = motor power x time). So, per month, it has a consumption of 180 kWh/month (6.0 x 30 days). Following this calculations, the used pump has a motor power of 0.7 kW, works for 2 hours per day, with a consumption of 1.4 kWh/day and 42 kWh/month.

According to Sao Paulo State Company of Energy Power and Light (CPFL, 2016) the power price, for Bauru city, in a residential class and with taxes included, is U$0.0781 per kWh. Using a flow of 1.6 $L.min^{-1}$, the AABR has capacity to treat wastewater for 20 habitants, so the cost per capita is U$ 0.86 per month. As the two pumps used for each system are the equal, the HSCW has an operating cost of U$ 3.26 per month and treating wastewater for 20 habitants, HSCW have a operation cost of US $ 0.16 per capita/month.

In the case of the AABR configuration used in this study, the aerobic chamber was important as a polishing step of the effluent, removing an average of 55% of COD. Removes it from the system would reduce the operating costs, but would also reduce the efficiency. Thus, the HSCW proved to be higher cost effective since it had high removal rates at a lower cost without the need for tertiary treatment. To match the two systems, it is possible to add another type of tertiary treatment to the AABR or to connect the two systems, using the HSCW as a tertiary system, increasing the efficiency of treatment, since HSCWs are commonly used to treat municipal and domestic wastewaters as tertiary treatment stages (Vymazal, 2009).

The average daily consumption of power energy, per habitant, of both treatment systems was compared with the energy power consumption of an electric shower, with a motor power of 3.5kW, used by a family of 4 people, each using for 10 min.per day (Table 2).

Table 2. Approximate consumption values (per $capita.day^{-1}$) of the treatment systems, and of an electric shower.

Equipment	Power (kW)	WT (h.day-1)	Habitants	Consumption ($kWh/capita.day^{-1}$)
AABR (air compressor + pump)	2.2	6	20	0.03
HSCW (pump)	0.7	2	20	0.07
Electric shower	3.5	0.67	4	0.59

* WT - Working time

The results in Table 2 indicate lower power consumption of the AABR and HSCW compared to an electric shower commonly used in a residence. This fact evidence the feasibility of using an aeration system comprising an air compressor and a pumping system, easily found on the market, and with a low maintenance.

About the treatment capacity, the AABR used a area of 6.0 m^2, with estimated treatment, in an admitted flow of 1.6 $L.min^{-1}$, for 20 habitants, so the total area per capita is 0.25 m^2. The HSCW, treats 58 $L.m^2.d^{-1}$ in a area of 40 m^2, for 20 habitants, thus the total area per capita is 2.02 m^2. In this regard, the AABR is more advantageous than the HSCW, for treat wastewater for the same number of habitants in a smaller area, being more applicable in small areas, such as a residential condominium, commercial areas and small rural areas

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CONCLUSIONS

The results obtained in this study showed that the AABR and HSCW, are promising alternatives in the treatment of low strength domestic wastewater, with satisfactory results, especially in COD and BOD reducing, obtaining 78 and 81% average removal of COD, 70 and 72% of BOD, and 85 and 82% of TSS, respectively. The Total Coliforms and *E.coli* removal rates, in the AABR, were 2.0 log units and in the HSCW were 3.0 log and 2.5 log units, respectively, both requiring a tertiary treatment for pathogens microorganisms inactivation. According to the results, both systems showed excellent performance in organic matter removal and suspended solids, with no significant difference between each other.

About the energy power consumption per month by each system, the AABR consumes 180 kWh/month, with a total cost per capita of US$ 0.86 a month and the HSCW 42 kWh/month, with a total cost per capita of US$ 0.16 a month, so the HSCW showed to be cheaper, in energy cost. However, it is possible to concluded that the more expensive operation of the AABR was due to the air compressor, that can be solved using another type of tertiary system, even the HSCW studied. Comparing the two systems with a common electric shower, it was concluded that both systems spend less energy per month than the electric shower.

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