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COMPACT SEWAGE TREATMENT SYSTEMS FOR RURAL SANITATION

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Abstract: The combination of anaerobic pre-treatment and conventional aerobic technologies in a single compact unit has the potential to afford practical, sustainable and low-cost systems for the decentralized treatment of sewage. The aims of the present study were (i) to determine the efficiencies of a single-family compact (SFC) and a multi-family compact (MFC) station in removing organic matter from domestic sewage, and (ii) to investigate the behavior of aerobic intermittent sand filters (ISFs) regarding nitrification. The SFC station consisted of an upflow anaerobic sludge blanket reactor, an anaerobic upflow bed filter and an aerobic ISF, while the MFC station comprised a septic tank and two ISFs. The mean efficiencies for the removal of total chemical oxygen demand, total suspended solids and total Kjeldahl nitrogen were, respectively, 90, 93 and 75% for the SFC and 87, 91% and 74% for the MFC with ISFs operated at hydraulic loading rates of 380 $L.m^{-2}.day^{-1}$. The sand filters produced helminth-free effluents that complied with World Health Organization recommendations for water intended for agricultural reuse, although the geometric mean of *E. coli* counts (10^4 $CFU.100\ mL^{-1}$) was somewhat high, implying that the treated water was appropriate for irrigation in low-tech agriculture.

Keywords: Compact system; Intermittent flow sand filter; Nitrification; Sustainable technology; Agricultural reuse

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INTRODUCTION

The vast majority (around 75%) of Brazilian municipalities have fewer than 20,000 inhabitants (Instituto Brasileiro de Geografia e Estatística, 2011), many of whom congregate in quilombola settlements, rural communities or small villages. Much of the raw sewage generated by these populations, which account for more than 39 million people in total, is discharged into water bodies (Agência Nacional de Águas, 2017), thereby contributing to the complex problems relating to the protection of public health and the environment. However, the damage caused by the inappropriate discharge of this sewage can be prevented by employing simple, efficient, sustainable and economically viable treatment systems.

According to resolution 430 of the Brazilian National Council for the Environment (Conselho Nacional do Meio Ambiente, 2011), sewage treatment should remove a minimum of 60% of the biochemical demand of oxygen (BOD). The Brazilian National Water Agency has mapped 2,768 centralized sewage treatment stations in the country, serving around 72 million inhabitants in 1,592 municipalities, and found operating efficiencies for the removal of BOD ranging from 60 to 80% (Agência Nacional de Águas, 2017). Such variation in efficiency is a function of the treatment processes employed, all of which have to comply with legislation regarding the dilution capacity of the designated receiving water bodies.Decentralized sewage treatment systems vary from simple primary solutions to sophisticated secondary and tertiary technologies that are very effective from both sanitary and environmental viewpoints.

The choice of system depends on whether it will serve single- or multi-family homes and on the local legislation regarding effluent discharge (Parten, 2010). Low cost technologies for basic sanitation, exemplified by a septic tank followed by an anaerobic filter, work very well for individual family units and can help to mitigate the impact of sewage release. The anaerobic treatment of sewage is an ecologically balanced approach, in which the different microorganisms have specific functions and a high degree of metabolic specialization, so that even simple systems produce low amounts of sludge with the added advantage that they are inexpensive to implement, maintain and operate (Sabry, 2010; Moussavi *et al.*, 2010). Although basic sewage systems for low-income populations may not be a definitive solution, they would certainly improve sanitary conditions for millions of Brazilians.

Adoption of more sophisticated technologies allows domestic sewage to be considered a resource rather than a problem because valuable products can be recovered therefrom, including potable water, nutrients (phosphorus and nitrogen), energy (methane) and organic fertilizers (Verstraete *et al.*, 2009) as well as elemental sulfur. However, the biological and physicochemical characteristics of effluents produced by the treatment of domestic wastewater must be regulated according to whether the output is to be reused, recycled or discharged into the environment (Sousa *et al.*, 2009). In Brazil, standards for the quality of effluents and degrees of treatment are defined by directive NBR 13969 (Associação Brasileira de Normas Técnicas, 1997).

A current trend in the development of more efficient decentralized wastewater treatments is to employ compact systems that unite different processes, rather than running each in a separate unit, such that the advantages of one process compensate for the disadvantages of others (Foresti *et al.*, 2006). In this context, sequential anaerobic–aerobic systems are of particular interest because they combine anaerobic pre-treatment and conventional aerobic technologies based on activated sludge processes, and may be employed in accessible, feasible and low-cost compact systems (Kassab *et al.*, 2010). Anaerobic digestion is an appropriate technology for treating domestic sewage because it is cheap, removes around 70% of the organic load and generates small amounts of sludge. The anaerobic pre-treatment unit can be connected to an aerobic intermittent sand filter (ISF) to generate a nutrient-rich effluent that complies with regulatory standards and can be reused in crop irrigation (Luna *et al.*, 2013). According to Tonetti et al (2005), this technology is feasible for small rural communities, isolated urban districts, housing estates and commercial premises located near to main roads.

In light of the above, the aims of the present study were (i) to determine the efficiencies of a single-family compact (SFC) and a multi-family compact (MFC) station in removing organic matter from domestic sewage, and (ii) to investigate the behavior of aerobic intermittent sand filters (ISFs) with respect to nitrification.

MATERIALS AND METHODS

Origin of raw sanitary sewage

Raw sewage (RS) originated from the eastern interceptor of Companhia de Água e Esgoto da Paraíba (CAGEPA) that transports 48% of the sewage of Campina Grande, Paraiba, Brazil (Queiroz *et al.*, 2019). The sewage was pumped from the *sewage lift station at* the Estação Experimental de Tratamentos Biológicos de Esgotos Sanitários (EXTRABES) located in the Tambor *district of* Campina Grande (7º13'11" S, 35º52'31" W; altitude 550 m) *to a* 1 m^3 storage tank and maintained under slow stirring to prevent sedimentation.

Description of the SFC station and mode of operation

The SFC station (**Figs 1–2**) consisted of an upflow anaerobic sludge blanket (UASB) reactor with

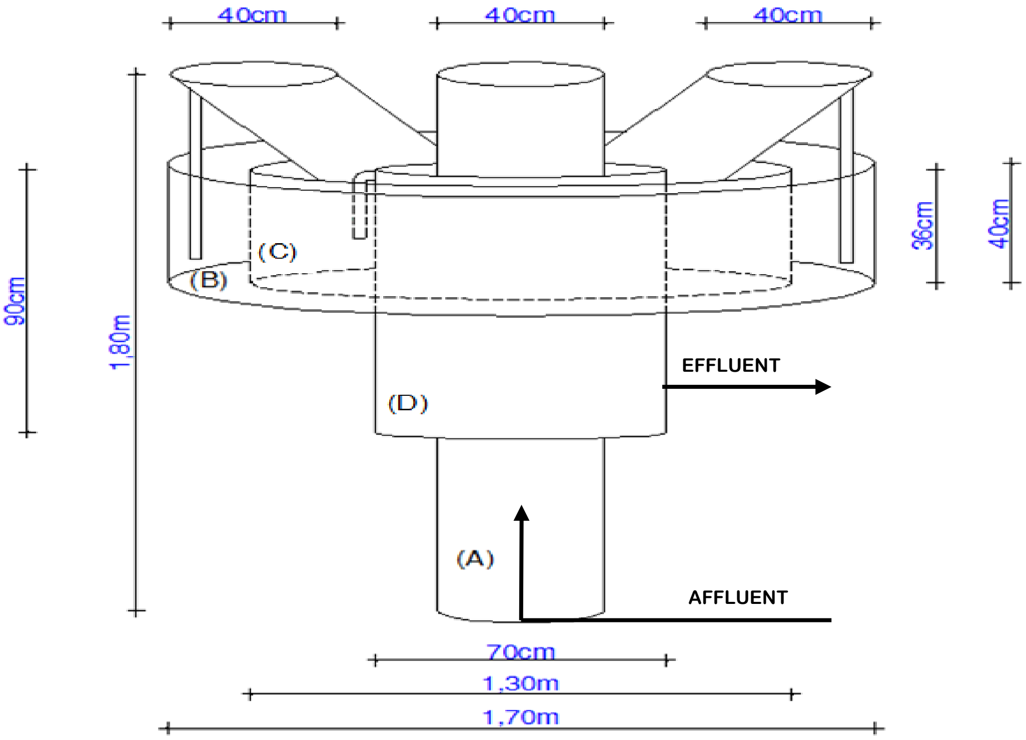

Fig. 1 Schematic representation of the single-family compact station showing: A – upflow anaerobic sludge blanket reactor; B - anaerobic upflow bed filter; C – siphoning tank; and D - aerobic intermittent sand filter.

Fig. 2 Views of the single-family compact (SFC) station: A – upflow anaerobic sludge blanket reactor; B - anaerobic upflow bed filter; C – siphoning tank; D - aerobic intermittent sand filter.

W-type lateral separators inclined at 45º, an anaerobic upflow bed filter (UBF) with polyurethane hub filter bed, a flow transfer chamber and an aerobic ISF. The UBF was fitted with a 5 cm high false base made of a nylon screen for sludge accumulation, and a 20 cm high filter bed comprising 2 cm polyurethane cubes with 97% void volume (Sousa *et al.*, 2017).

The top of the UBF was covered with a nylon screen and a 3 cm high layer of 19 mm gravel was placed over the screen to accommodate the support material. The flow transfer chamber comprised a 42 L tank fitted with a 40 mm diameter polyvinyl chloride (PVC) siphon tube connected to 25 mm diameter PVC tubing to deliver the UBF effluent to the ISF. The intermittent filter consisted of a 5 cm high layer of gravel and a 40 cm high layer of washed sand topped off with a 5 cm layer of gravel. The diameter of the sand particles was 0.70 mm with a uniformity coefficient of 3.18, while the gravel layer presented a void volume of 45%. Details of the components of the SFC station are shown in Table 1 and specifications of the materials recommended for the construction of the ISF are presented in **Fig. 2** and **Table 2**.

Table 1. Components of the single-family compact station and their capacities

Component	Area (m^2)	Depth (m)	Volume (L)	HRT (h)
UASB	0.1256	1.50	300	19
Anaerobic UBF	0.228	0.35	80	6,6
Siphoning tank	0.212	0.20	42	3,36
Aerobic ISF	1.200	0.70	791	< 1

HRT: hydraulic retention time; UASB: *upflow* anaerobic sludge blanket; UBF: upflow bed filter; ISF: intermittent sand filter.

Table 2. Materials used in the construction of intermittent sand filters as recommended by the directive no. 6502 issued by Associação Brasileira de Normas Técnicas (1995)

Composition	Particle diameter (mm)	Proportion (%)
Gravel	2.0 – 60	3.689
Coarse sand	0.6 – 2.0	55.65
Fine-grained sand	0.06 – 0.2	39.45
Silt	0.002 – 0.06	0.99
Clay	< 0.002	0.23
Total	-	100

Source: NBR 6502: Rocks and soils. ABNT/ NBR 6502 (1995)

The SFC station operated over a period of 270 days with a flow rate of approximately 300 $L.day^{-1}$ on the assumption that the per capita contribution to RS of a typical family of three individuals would be 100 $L.day^{-1}$. The RS was initially digested in the UASB reactor and the effluent distributed via the W-type lateral separator to the anaerobic UBF, the output of which overflowed into the siphoning tank. The siphon was configured to feed the aerobic ISF with 42 L of UBF effluent per batch.

Description of the MFC station and mode of operation

The MFC station consisted of a septic tank (ST) with an effective volume of 2.9 m^3 and two parallel rectangular aerobic ISFs (**Fig. 3**). The brick-built ST comprised three interconnected compartments, the first of which contained baffles to prevent thermal shock when the raw sewage entered the system, and the third was fitted with a siphon system set to deliver a hydraulic loading rate (HLR) of 380 $L.m^{-2}.day^{-1}$ to the two ISFs through a network of perforated tubes located above the filter beds. Each of the naturally aerated ISFs was constructed with a 10 cm high gravel (19 mm) base layer and a 100 cm (ISF1) or 50 cm (ISF2) high sand layer topped off with a 5 cm high gravel (19 mm) layer. Networks of perforated tubes (30 mm diameter) were placed within the gravel layers close to the base of each filter to allow drainage of the effluent. Specifications of the materials recommended for the construction of the ISF are presented in Table 2. The MFC station was operated with a flow rate of 1500 $L.day^{-1}$, a volumetric loading rate of 510 L. $m^{-3}.day^{-1}$ and a HRT of 24 h.

Physicochemical and microbiological analyses of effluents

Physicochemical parameters of the two processes, including pH, alkalinity, total and filtered chemical oxygen demand (COD_T and COD_F, respectively), total suspended solids (TSS), volatile suspended solids (VSS), turbidity, *total Kjeldahl nitrogen (*TKN), ammonium ($N\text{-}NH_4^+$), nitrate ($N\text{-}NO_3^-$), nitrite ($N\text{-}NO_2^-$), total phosphorus (P_T) and phosphate ($P\text{-}PO_4^{-3}$*)*, were determined following procedures recommended by American Public Health Association (2012). The numbers of *Escherichia coli* colony-forming units (CFU) and helminth eggs were established according to the modified method of Bailenger (1979).

RESULTS AND DISCUSSION

Variation in pH and total alkalinity

The pH values of the RS affluents, and the effluents from the UASB and UBF (SFC station) or ST (MFC station) exhibited only small variations (**Table 3**) and

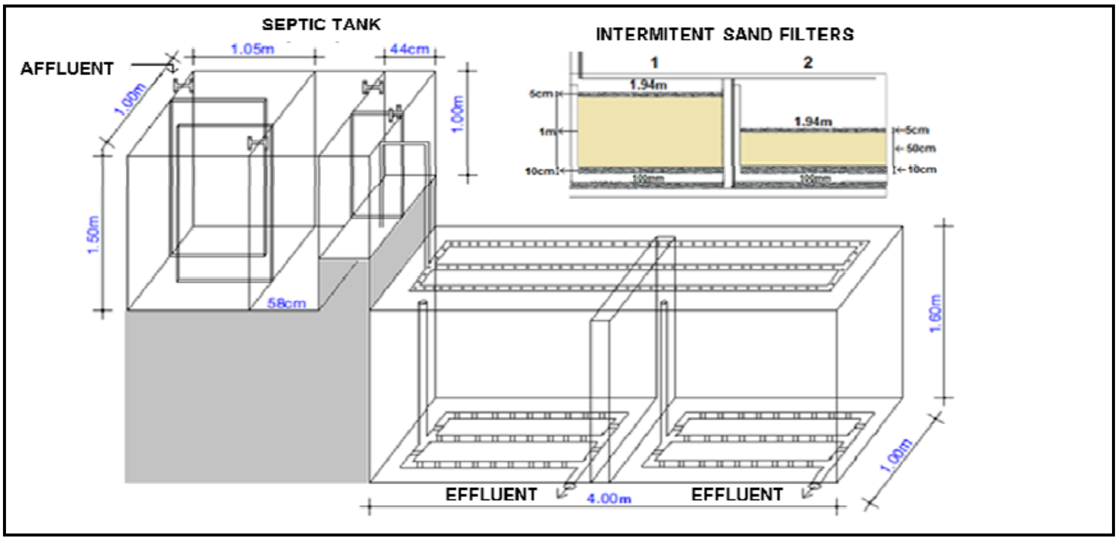

Fig. 3 Schematic representation of the multi-family compact station.

Table 3. pH and total alkalinity of raw sewage (RS) and effluents from the single-family compact (SFC) and multi-family (MFC) stations

Parameter		SFC station				MFC station			
		RS	UASB	UBF	ISF	RS	ST	ISF_1	ISF_2
pH	Mean	7.3	7.3	7.4	6.1	7.3	7.3	6.0	6.0
	Maximum	7.6	7.8	7.7	6.9	7.6	7.8	7.7	6.9
	Minimum	7.0	7.0	7.0	5.8	7.0	7.0	5.5	5.4
Alkalinity ($mg\ CaCO_3.L^{-1}$)	Mean	350	370	378	166	355	367	159	128
	Maximum	386	420	409	242	385	419	185	240
	Minimum	282	290	298	104	280	293	90	109
	SD	35	43	44	54	35	43	36	54
	CV (%)	10	8.6	8.4	5.2	10	8.5	3.6	3.0

UASB: *upflow* anaerobic sludge blanket; UBF: upflow bed filter; ISF: intermittent sand filter; ST: septic tank; SD: standard deviation; CV: coefficient of variation.

were close to the optimal range (7.0 to 7.2) for the development of methanogenic archaea (Bitton, 2005). However, alkalinity increased in comparison with that of RS during the anaerobic processes as a result of ammonification (van Haandel and van der Lubbe, 2012). In the aerobic phase, pH values were reduced with the consumption of alkalinity, thereby confirming the occurrence of nitrification (Tchobanoglous *et al.*, 2003). Theoretically, the process of consumes 7.14 mg $CaCO_3$ per mg of $N\text{-}NH_4^+$ to produce NO_3^- (van Haandel and van der Lubbe, 2012), hence the observed reduction of between 184 and 222 mg $CaCO_3.L^{-1}$ would be equivalent to a nitrification of around 30 mg $N.L^{-1}$. The low values of alkalinity in the aerobic filters of the SFC and MFC stations were confirmed by the high concentrations of NO_3^- detected in the effluents from the corresponding ISFs (**Tables 4–5**).

Removal of COD, suspended solids and turbidity

In the SFC station (Table 4), the concentrations of COD_T and COD_F diminished progressively with respective removals of 41 and 52% in the aerobic ISF alone and overall process efficiencies of 90 and 79%. *In the MFC station (Table 5), 48% of COD_T was removed in the ST unit, while the aerobic filters contributed substantially to the overall COD_T removal efficiencies of 87% with ISF1 and 88% with ISF2.*

*In the MFC station (Table 5), 48% of COD_T was removed in the ST unit while the ISF_1 and ISF_2 units contributed to the overall COD_T removal efficiencies of 87 and 88%, respectively. These values are similar to the that reported by (*Luna *et al.*, 2013) for the post-treatment of ST effluents using a single pass ISF, but higher than the performance obtained by Tonon *et al.* (2015) in the treatment of wastewater using an anaerobic filter and sand filter. Tonetti *et al.* (2010) employed an anaerobic filter with aerobic sand filter to treat domestic sewage and reported an 80.8% removal of COD_T when the thickness of the sand layer was 100 cm and the HLR was 300 $L.m^{-2}.day^{-1}$. Assayed *et al.* (2010) employed an ST in combination with an ISF with a 100 cm sand layer to treat wastewater at a mean flow rate of 150 $L.m^{-2}.day^{-1}$ and established a COD_T removal of 93%. The high removal efficiency attained by these authors may be related to the applied HLR of

Table 4. Chemical characteristics (mean values ± standard deviation) of the raw sewage (RS) and effluents from the single-family compact station

Parameter	RS	Effluent			Overall efficiency (%)
		UASB	UBF	ISF	
COD_T ($mg.L^{-1}$)	470 ± 98	189 ± 36	112 ± 14	47 ± 20	90
COD_F ($mg.L^{-1}$)	168 ± 62	111 ± 25	80 ± 18	36 ± 21	79
TSS ($mg.L^{-1}$)	150 ± 40	52 ± 31	40 ± 30	10 ± 6.0	93
VSS ($mg.L^{-1}$)	124 ± 39	35 ± 19	32 ± 24	8.0 ± 5.0	94
Turbidity (NTU)	219 ± 98	89 ± 72	58 ± 32	5.0 ± 4.8	98
TKN ($mg.L^{-1}$)	60 ± 16	54 ± 12	44 ± 9	15 ± 4.0	75
$N\text{-}NH_4^+$ ($mg.L^{-1}$)	50 ± 11	54 ± 9.0	52 ± 6	12 ± 3.0	76
$N\text{-}NO_2^-$ ($mg.L^{-1}$)	0.2 ± 0.03	0.2 ± 0.03	0.1 ± 0.01	0.7 ± 0.02	-
$N\text{-}NO_3^-$ ($mg.L^{-1}$)	0.8 ± 0.04	0.5 ± 0.03	0.6 ± 0.05	29 ± 8.0	-
P_T ($mg.L^{-1}$)	7.9 ± 0.6	6.4 ± 1.0	5.8 ± 1.5	5.4 ± 0.9	32
$P\text{-}PO_4^{-3}$ ($mg.L^{-1}$)	5.8 ± 0.3	5 3 ± 1.0	4.7 ± 1.2	4.6 ± 0.9	21

UASB: *upflow* anaerobic sludge blanket; UBF: upflow bed filter; ISF: intermittent sand filter; COD_T: total chemical oxygen demand; COD_F: filtered chemical oxygen demand; TSS: total suspended solids; VSS: volatile suspended solids; NTU: nephelometric turbidity units; TKN: *total Kjeldahl nitrogen.*

Table 5. Chemical characteristics (mean values ± standard deviation) of the raw sewage (RS) and effluents from the multi-family compact station

Parameter	RS	Effluent			Overall efficiency (%)	
		ST	ISF_1 (100 cm)	ISF_2 (50 cm)	ISF_1	ISF_2
COD_T ($mg.L^{-1}$)	461 ± 103	222 ± 23	60 ± 23	54 ± 21	87	88
COD_F ($mg.L^{-1}$)	133 ± 72	38 ± 24	34 ± 18	36 ± 24	74	73
TSS ($mg.L^{-1}$)	137 ± 39	44 ± 12	12 ± 8.0	11 ±7.0	91	92
VSS ($mg.L^{-1}$)	98 ± 36	41 ± 12	9.0 ± 6.0	9.0 ± 6.0	91	91
Turbidity (NTU)	220 ± 88	121 ± 92	8.0 ± 6.4	7.0 ± 5.8	96	97
TKN ($mg.L^{-1}$)	53 ± 18	49 ± 13	14 ± 9.0	13 ± 6.8	74	75
$N\text{-}NH_4^+$ ($mg.L^{-1}$)	43 ± 12	42 ± 4	10 ± 6.0	9.0 ± 6	77	79
$N\text{-}NO_2^-$ ($mg.L^{-1}$)	0.2 ± 0.05	-	0.4 ± 0.03	0.4 ± 0.03	-	-
$N\text{-}NO_3^-$ ($mg.L^{-1}$)	0.8 ± 0.04	0.5 ± 1	29 ± 10	35 ± 13	-	-
P_T ($mg.L^{-1}$)	7.8 ± 1.6	6.9 ± 1	5.0 ± 1.0	5.0 ± 0.9	36	36
$P\text{-}PO_4^{-3}$ ($mg.L^{-1}$)	5.5 ± 0.6	5.0 ± 1	4.0 ± 1.0	4.0 ± 0.9	27	27

ST: septic tank; ISF: intermittent sand filter; COD_T: total chemical oxygen demand; COD_F: filtered chemical oxygen demand; TSS: total suspended solids; VSS: volatile suspended solids; NTU: nephelometric; turbidity units; TKN: *total Kjeldahl nitrogen.*

150 $L.m^{-2}.day^{-1}$, which was substantially lower than the rate of 380 $L.m^{-2}.day^{-1}$ employed in the present study.

In the SFC station, removal of the largest proportion *of* TSS (65%) and VSS (72%) occurred in the UASB reactor while the overall efficiencies for the removal of TSS and VSS were 93 and 94%, respectively (**Table 4**). These values are higher than those reported previously for analogous treatment systems, which ranged from ≤ 65.7% (Tonon *et al.*, 2015) up to 89.1% (Tyagi *et al.*, *2009)* and 91% (Andrade *et al.*, 2014). In the MFC station, removal of most of the TSS (68%) and VSS (58%) occurred in the ST unit while the overall efficiencies for the removal of suspended solids were ≥ 91% for both ISFs (Table 5). According to *Tao et al. (2009), an* analogous system operating with a HLR *of* 200 $L.m^{-2}.day^{-1}$ *gave a TSS* removal > 90%, while a similar system operating with a *HLR of* 150 $L.m^{-2}.day^{-1}$ resulted in 95% removal of TSS (Assayed *et al.*, 2010). The issue of TSS removal is important because the performance of drip irrigation, a technique that is recommended for use with recycled wastewater because it minimizes the health risks to farmers, is limited by clogging. According to Capra and Scicolone (2004), TSS values in treated wastewater should be less than 50 $mg.L^{-1}$ in order to prevent this problem, while the World Health Organization (2006) advises that the maximum concentration of TSS in wastewater for reuse in irrigation or discharge into aquifers should be 30 $mg.L^{-1}$.

The efficient removal of TSS and VSS from the IFS effluents had a positive effect on turbidity since the effluent from the ISF of the SFC station and those from $IFS_1$and ISF_2 of the MFC station presented mean values of 5, 8 and 7 NTU, respectively, values that were much lower than those (9 and 11 NTU) reported by Oliveira Cruz *et al.* (2018, 2019).

Removal of nitrogen and phosphorus

In the SFC station, concentrations of $N\text{-}NH_4^+$ rose slightly in the UASB and UBF units (by 8 and 4%, respectively) of the SFC station (Table 4) as a result of ammonification reactions. Nevertheless, overall efficiencies for the removal of $N\text{-}NH_4^+$ and TKN were 76 and 75%, respectively, producing a final effluent with an $N\text{-}NH_4^+$ concentration that complied with the standard (maximum 20 $mg.L^{-1}$) established by the Brazilian regulatory agency (Conselho Nacional do Meio Ambiente, 2011). Moreover, the concentrations of $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ in the ISF effluent increased by 3.5 and 36 fold in comparison with those of the RS, thereby confirming the effectiveness of the nitrification process even with the system operating at a HLR of 380 $L.m^{-2}.day^{-1}$, a rate that was higher than the maximum value (200 $L.m^{-2}.day^{-1}$) recommended by Associação Brasileira de Normas Técnicas (1997) and Tonetti *et al.* (2005). This result is noteworthy because nitrifying bacteria grow much slower than heterotrophic organisms and require longer cell retention times (Gray, 2004). The overall removal efficiencies of P_T and $P\text{-}PO_4^{3-}$ were 32 and 21%, respectively, indicating that the final effluent contained significant amounts of these products (Table 4). However, such levels would not be harmful if the effluent is reused in irrigation and not discharged directly into streams, rivers or lakes where it could contribute to eutrophication.

In the MFC station, negligible reductions in the concentrations of TKN and $N\text{-}NH_4^+$ were observed in the ST, while removals in the range 74 to 79% occurred in ISF_1 and IFS_2, (**Table 5**). These reductions resulted from the transformation of $N\text{-}NH_4^+$ into NO_2^- and NO_3^-, the concentrations of which showed respective increases of 2-fold and up to 44-fold in the ISFs. The levels of $N\text{-}NH_4^+$ present in the effluents from ISF_1 and ISF_2 complied with the standards required by Conselho Nacional do Meio Ambiente (2011). The high concentrations of NO_2^- and NO_3^- in ISF_1 and IFS_2 effluents verify the effectiveness of the oxidation reactions carried out by nitrifying bacteria and the value of biological filtration. The overall removal efficiencies

Table 6. Levels of *Escherichia coli* colonies and helminth eggs in the raw sewage (RS) and effluents from the single-family compact (SFC) and multi-family (MFC) stations

Parameter		*E. coli* (CFU.100 mL^{-1})			Helminths (eggs.L^{-1})		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum
SFC station (n = 20)	RS	4.62 x10^6	1.60 x 10^6	7.60 x10^6	168	70	312
	UASB	9.07 x10^5	1.00 x 10^5	4.00 x10^6	28	14	61
	UBF	2.74 x 10^5	3.20 x 10^4	1.35 x10^6	3.15	0.8	9
	ISF	9.40 x 10^4	2.20 x 10^4	5.30 x10^5	ND	ND	ND
MFC station (n = 20)	RS	1.14 x 10^7	1.50 x 10^6	2.25 x10^7	241	170	344
	ST	1.98 x 10^6	4.45 x 10^4	5.10 x10^6	117	75	169
	ISF$_1$	3.24 x 10^4	1.00 x 10^3	1.25 x10^5	ND	ND	ND
	ISF$_2$	5.92 x 10^4	2.00 x 10^4	2.45 x10^5	ND	ND	ND

CFU: colony-forming units; UASB: *upflow* anaerobic sludge blanket; UBF: upflow bed filter; ISF: intermittent sand filter; ST: septic tank; ND: none detected

of P_T and $P\text{-}PO_4^{3-}$ were 36 and 27%, respectively for both filters.

Removal of pathogens

The effectiveness of a wastewater treatment in removing pathogenic microorganisms is determined from the log of the ratio of pathogen concentration in the raw sewage and the effluent (Water Research Australia, 2014). In the SFC, the efficiencies of the UASB, UBF and ISF units for the removal of *E. coli* were 80, 70 and 65%, respectively, while the overall efficiency of the station was 98% (Table 6). The performance of the MFC was slightly higher with overall efficiencies for the removal of *E. coli* of 99.7 with ISF$_1$ and 99.4 with ISF$_2$. Despite the high levels of removal attained, which were equivalent to more than 2 $\log_{10}$ units, the geometric mean of coliform counts was 10^4 CFU.100 mL^{-1}, a value greater than the maximum (10^3 CFU.100 mL^{-1}) recommended by the World Health Organization (2006) for effluents intended for unrestricted irrigation. Latrach *et al.* (2016) reported that a multi-soil-layering system with a sand filter operating at a low HLR (i.e. 100 L.m^{-2}.day^{-1}) was able to remove total coliforms, fecal coliforms and fecal streptococci with an efficiency of over 3 $\log_{10}$ units. It is likely that removal efficiency is influenced by the HLR and, consequently, dependent on the aerobic filter resting time and other factors including temperature.

As shown in **Table 6**[, the levels of helminth eggs in the RS varied considerably. In the SFC station, 83% of the eggs were removed in the UASB unit in agreement with the removal efficiency reported by van Haandel *et al.* (2006). In the sludge blanket reactor, worm eggs were trapped in the sludge bed because of the upward flow in the reactor, and egg removal was related directly with the reduction in TSS, which was determined to be 65%. The anaerobic UBF showed a higher efficiency (87%) in removing the remaining helminth eggs, which were likely trapped in the sludge contained in the false bottom of the filter, and no eggs were detected in the final effluent from the SFC. The MFC station was also 100% efficient in removing helminth eggs, a finding similar to that reported by Leonel et al (2016) for a system composed of an anaerobic filter and ISF, which removed 100% of helminth eggs and 99.8% of *Giardia* cysts. According to the World Health Organization (2006), treated wastewater effluents should contain ≤ 1 egg.L^{-1}.

Maintenance of SFC and MFC stations

The major problem encountered during the use of SFC and MFC stations was clogging of the ISFs. Although literature on this subject is scarce, Leverenz *et al.* (2009) managed to identify a number of variables that were important in the clogging phenomena, for example the concentration of COD in the affluent, HLR, dosing frequency of the filter and time of operation. In the present study, it was observed that clogging of the two ISFs of the MFC station, operating at an HLR of 380 L.m^{-2}.day^{-1} and 3 h resting time, occurred between 12 and 14 weeks. However, restoration of the filters was achieved simply by replacing the top 5 cm of the sand bed as described by Oliveira Cruz *et al.* (2018). In the SFC station, the ISF was protected to some extent by the UBF, such that the time between filter maintenance operations was prolonged by some 50%.

CONCLUSIONS

Combinations of anaerobic and aerobic processes, as exemplified by the SFC and MFC systems described herein, were efficient in removing organic matter from domestic wastewater. The removal efficiencies of the SFC system were 90, 93, 98 and 76% for COD_T, TSS, turbidity and $N\text{-}NH_4^+$, respectively, while those of the MFC system were 88, 92, 97 and 79%. The two systems were efficient in eliminating helminth eggs since none were detected in the final effluents, in compliance with the World Health Organization standard (≤ 1 egg.L^{-1}). However, both systems produced effluents containing counts of *E. coli* that were higher than the World Health Organization limit (10^3 CFU.100 mL^{-1}) for treated water intended for unrestricted irrigation. However, such effluents would carry a minimal risk of enteric infections for farmers and could be employed in low-tech agricultural irrigation. Both systems offered the advantage of being cheap and easy to maintain and would certainly improve the sanitary conditions and health of rural populations, particularly in north and northeastern Brazil.

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