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Evaluation of the recirculation process of aerobic sludge from a percolating biological filter in an upflow anaerobic sludge blanket digestion reactor, with characterization of sludge solids

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A B S T R A C T

In this work, the sustainability indicators from a sewage treatment plant in a Southern Brazilian city, with a combined system of anaerobic treatment by upflow anaerobic sludge blanket (UASB) reactor and aerobic treatment with a percolating biological filter (PBF), were assessed. The need for the process of recirculation and anaerobic digestion of excess sludge in upflow anaerobic sludge blanket digestion (UASB) reactors and the influence of this procedure on the efficiency of each treatment step were evaluated. The production and volume of sludge produced in the treatment units were also calculated for periods with and without the recirculation of the sludge. The sludge characterization results showed values of 4.7% for total solids (TS) and 65% for total volatile solids (TVS) for the UASB reactor sludge, and 2.9% TS and 69% TVS for the PBF sludge. The efficiency of the effluent treatment by the combined system UASB + PBF + desiccator remained stable for both periods analyzed and was 85% for chemical oxygen demand, 88% for biological oxygen demand and 89% for total suspended solids. Finally, it was shown that these results are similar to those obtained for the activated sludge system, but the combined system has the advantage of being more sustainable.

Keywords: Sewage treatment; Upflow anaerobic sludge blanket; Percolating biological filter; Percolator filter; Treatment plant efficiency; Hydraulic load; Sludge characterization and stability

1. Introduction

Basic sanitation in Brazil is defined by Law 11,445/2007 as the set of services, infrastructure and operational facilities necessary to promote the supply of drinking water, sanitary sewage, urban cleaning, solid waste management and drainage and rainwater management. The data obtained in 2018 by the National Sanitation Information System (SNIS) show that 74.5% of the sewage generated in Brazil is collected and only 46.3% receives some type

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of treatment. Thus, approximately 101 million Brazilians still do not have access to the sewage collection network [1].

These results suggest a significant demand for the implementation of new systems and new sewage treatment plants, as well as the expansion and modernization of existing systems, aiming to make sanitation universal, preserve water resources, and maintain the natural and urban environment, as well as public health.

In addition, nutrient recovery from wastewater can has a direct impact on reducing the use of chemical fertilizers, the discharge of nutrients into the environment and the impact of climate change [2].

Sewage treatment can use different physical, chemical and biological mechanisms and procedures, which remove pollutants with different efficiencies, depending on the type of treatment used [3]. The biological processes of domestic sewage treatment were designed to remove organic matter (carbon, nitrogen, phosphorus), stabilizing the sludge generated in the primary and secondary treatment processes, reducing undesirable contaminants, for the correct final disposal, according to the criteria defined by environmental legislation [4].

Such sewage treatment processes normally produce large amounts of sludge as a residue or by-product. The disposal process of the excess sludge and its treatment are considered one of the biggest and most complex problems, and also the costliest for the sewage treatment plants [5].

The UASB reactors produce a low volume of sludge compared with other treatment systems; however, to meet the maximum limits of the discharge standards of their effluent, they require post-treatment. Therefore, the planning of combined systems, of an anaerobic type followed by aerobic, is of great importance in complementing the removal of organic matter and nutrients [6].

Among UASB's after-treatment systems, PBF stands out. Sewage treatment stations composed of UASB reactors, followed by PBF, normally present a reduction of 20%–50% in the implantation costs and an operation reduction greater than 50% when compared with activated sludge [4,7,8]. Another advantage of PBF in relation to activated sludge refers to the generation and stabilization of the generated sludge [9]. According to these authors, a sludge stabilization treatment may be necessary before the process of dehydration and final destination.

As a common practice for sludge stabilization, anaerobic digestion converts highly resistant organic waste into bioenergy and stable organic waste. Besides that, it reduces the total mass of sludge to be discarded, reducing the operational cost of sludge disposal [10]. The use of reactors to stabilize the sludge produced in the percolating biological filters (PBFs) reduces operating costs in the treatment station plant, as it eliminates the need to build a sludge digester. On the other hand, few studies have addressed how this sludge recirculation procedure can affect the biomass characteristics of the anaerobic reactor, such as specific methanogenic activity, sludge stability, sedimentability or granule size. These characteristics can affect the treatment efficiency, in general, or more specifically, the efficiency of the UASB reactors [11].

Therefore, research aiming to assess the stability of the different types of sludge and evaluate their stabilization process, as well as verifying the efficiency of the sewage treatment of stations by combined anaerobic treatment system – UASB and aerobic – PBF, are of great relevance. Furthermore, it is important to investigate the effectiveness of traditional procedures for the stability and treatment of sludge generated after PBF, according to its characteristics.

Recent studies have shown that changes in the traditional sludge recirculation processes are possible and can reduce the overload of solids generated by this process in the treatment stages [12–15]. However, it is necessary to verify the efficiency in the treated effluent in periods with and without the recirculation process, comparing the treatment efficiency with regard to the physical–chemical parameters of the treated effluent, as well as the characteristics of the different types of sludge.

Few studies have evaluated the performance of the recirculation process of the sludge produced by a PBF, considering the parameters total and volatile solids. There is also little research that assessed the need for partial stabilization in the anaerobic reactor or its direct disposal to the drainage, stabilization and partial hygiene sector (by lime addition and centrifugation).

Thus, this study aimed to evaluate the treatment efficiency in the operation of a plant, on a large scale, using a combined system with an UASB reactor followed by PBF, characterizing the aerobic sludge produced in the PBF and evaluating the need for sludge recirculation to the UASB reactor.

2. Methodology

In the municipality of Maringá, in the southern Brazilian state of Paraná, the sewage collection rate is approximately 100%, and all the collected sewage receives treatment. This corresponds to approximately 2,029,329 million m^3 $month^{-1}$, of which 468,966 thousand m^3 $month^{-1}$ or 23.11% are treated at ETE 03 Alvorada, 737,705 thousand m^3 $month^{-1}$ or 36.35% at ETE 01 Mandacaru and 822,658 thousand m^3 $month^{-1}$ or 40.54% at ETE 02 South [16].

The unit used in this research was ETE 02 Sul (coordinates 403.091E and 7.402.188N), and the company responsible is the Companhia de Saneamento do Paraná (SANEPAR). This sewage treatment unit consists of the following sectors: a preliminary treatment system, formed by a coarse screen, then a thin one and a square box type "Dorr Oliver" model degritter; the anaerobic biological system formed by eight anaerobic fluidized bed reactors (UASB), conical trunk model, better known by the company as RALF; an aerobic biological system formed by two PBFs and two secondary decanters; a contact chamber, plus a slurry centrifugation system and storage shed; and sixteen sludge drying beds (Fig. 1). Its nominal treatment capacity is 320 L s^{-1}, enabling it to serve a population of approximately 250,000 inhabitants [16].

The results of the physical–chemical analysis from June to December 2018 and from June to December 2019 were compiled to characterize the raw and treated sewage and also the sludge after PBF in the secondary settlers. In addition, the sludge discharged from the UASB reactors was characterized, in two distinct periods, with and without sludge recirculation to the UASB reactors.

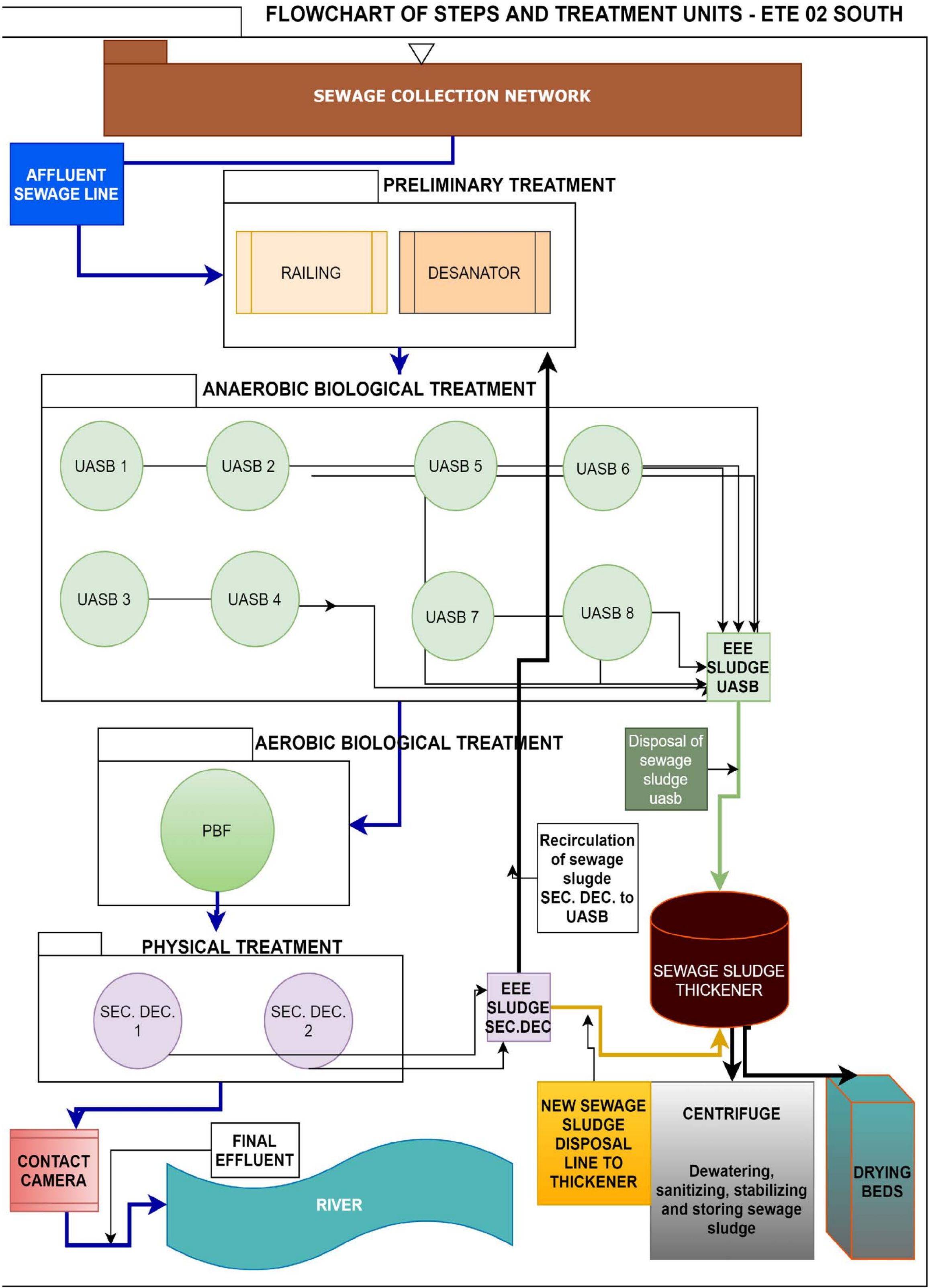

Fig. 1. Flow diagram of treatment process of sewage treatment plant, Maringá, Brazil, in periods without (2018) and with (2019) the sludge recirculation process. The yellow arrow represents the new disposal line to the period without recirculation.

Monitoring was carried out individually for each stage and treatment unit, evaluating treatment efficiencies in each sector and treatment unit. The pH was determined using a pH meter DM-22 (Digimed, São Paulo – Brazil); the temperature was verified by a digital skewer thermometer with a range of 45°C–230°C (Incoterm); to measure the flow, a Parshall channel and an ultrasonic meter Log Box (Magelis) were used; the COD value was obtained using a DRB 20 cast aluminum block COD digestion reactor (HACH, Colorado – USA) and DR 2800 spectrophotometer (HACH, Colorado – USA), and the BOD_5 value using the 411D BOD incubator (Ethik Technology, São Paulo – Brazil) and bottles for OxiTop BOD analysis (WTW). The analysis of sedimentable solids (SED) was performed in a 1-L Imhoff Cone with a graduation of 0.1 mL.

The analysis of total suspended solids (TSS), total fixed suspended solids (TFSS), total volatile suspended solids (TVSS), total solids (TS), total fixed solids (TFS) and total volatile solids (TVS); total dissolved solids, total fixed dissolved solids and total volatile dissolved solids were made using a water bath, six-mouth model (Labstore, Paraná – Brazil). Subsequently, a desiccator (internal diameter 250 mm), an AUW analytical balance (Mars), COEL HM drying oven (Biomatic) and muffle furnace (Fornitec) were used. Alkalinity was determined by the titration method using 0.02 N sulfuric acid and mixed indicator.

All analyses were performed in the laboratory of the Sewage Treatment Plant ETE02 – Sul laboratory, following the international analysis methodology [17]. Sampling was done monthly from the affluent to the final effluent, and also the effluents of each sector of the treatment unit, totaling 13 sampling points. Specific samples of approximately 3 L were carried out at each point of the liquid sewage, in bottles with the proper preservatives, according to the analytical standards of each parameter. The time chosen to perform the collections was the one with the highest sewage flow at the station, approximately 2 P.M., considered the worst case in relation to the ETE efficiency results, in relation to the physical–chemical parameters. Altogether, there were 10 individual monitoring points for the discarded sludge, eight in the reactors and two in the secondary settlers.

3. Results and discussion

The data related to the monitoring of the parameters flow rate or surface application and volumetric hydraulic load, in the two study periods, with and without recirculation, are shown in Table 1. An increase of approximately 7% is observed in the study period, due to the implementation of the recirculation process. In relation to the hydraulic retention time (HRT), there was a decrease of 7% in the period with recirculation, because the time is inversely proportional to the volumetric hydraulic load. The HRT determines the contact time between wastewater and microorganisms, and is an important index of efficiency of the bioreactor [18]. Regarding these variations of less than 10%, some authors [4,6,9] report that the reactors can operate for a limited period of 3 to 6 h with maximum flow rates, as this does not affect the treatment, as long as it does not exceed the volumetric hydraulic load value of 5.0 $m^3 m^{-2} d^{-1}$, which is equivalent to a hydraulic holding time of 4.8 h.

The results evidenced that, during the study, the maximum project values were never exceeded, except for the surface application load of the PBF, which, on average, was 33.5 and 35.9 $m^3 m^{-2} d^{-1}$ for 2018 and 2019, respectively. The project load is 20 to 30 $m^3 m^{-2} d^{-1}$, for two units, but considering that in the two periods analyzed, the station operated with only one PBF unit, this explains the overload. Thus, the recirculation process did not influence the unitary hydraulic processes of the treatment modules.

Regarding the comparison between the study periods, with and without recirculation, for the parameter volumetric organic load, there was an increase of 30.6%, 31.2%, 34.1%, 10.1%, –6.3% and 18.7% for the parameters COD, BOD_5, SED and TS, and TFS and TVS, respectively, in the units of treatment with UASB, in the period with recirculation. This increase in the period of 2019 corresponds to the organic sludge load that was recirculated to the UASBs, while the negative value –6.3% (TFS) indicates that the non-organic (fixed) part of the sludge is retained in the reactors, but the lighter organic (volatile) part is later dragged along with the effluent to the other treatment units.

The volumetric organic load has a substantial influence on the reactor performance and on the variations of the UASB microbial community, for the treatment of wastewater [19]. The increase in the volumetric organic load critically affects methanogenic activity, extracellular polymer content, sedimentation speed and the granulation of the sludge [20,21].

Regarding the UASB system and the parameter applied COD, there was an increase of 24.39%, in the period with sludge recirculation, while in the system formed by the PBF + DEC. SEC, the increase was 7.86% (Table 2). This increase in the two treatment stages is related to the sludge load that was recirculated together with the affluent input of the UASB reactors, with the escape of solids in the reactor effluent to the PBF and, later, to the decanters. This increase also occurred for the removed total suspended solid parameter (TRSS), for the same reason.

The UASB system and the sludge production coefficient parameter (Y) showed a higher value for the period without recirculation, 0.32 kg TRSS kg $CODapl.^{-1}$, while in the period with circulation the value was 0.26 kg TRSS kg $CODapl.^{-1}$.

As for the treatment system formed by PBF + DEC. SEC, this presented equal values for the two periods, without and with recirculation, of 0.14 kg TRSS kg $CODapl.^{-1}$. Low rate filters can present values between 0.07 to 0.25 kg COD $m^{-3} d^{-1}$ [4].

For the UASB reactor system, the sludge volumes produced were 138.77 and 129.63 $m^3 d^{-1}$, with and without recirculation, respectively, with a difference of 9.14 $m^3 d^{-1}$ for the period with recirculation, considering that the values of sludge produced in the PBF were not added, as these were recirculated to the UASB reactors. Regarding the system formed by PBF + DEC-SEC results were 33.49 $m^3 d^{-1}$ without recirculation, and 36.20 $m^3 d^{-1}$ with recirculation. The results obtained by the sum of the sludge volumes in the two systems, UASB + PBF + DEC-SEC, were 163.11 $m^3 d^{-1}$ without recirculation, and 174.97 $m^3 d^{-1}$ with recirculation.

In relation to the process of disposing of the volume of sludge produced theoretically, and the one produced

Table 1
Mean values of the hydraulic calculations of a sewage treatment plant – Maringá, Brazil, in periods without (June to December 2018) and with (June to December 2019) sludge recirculation process

YEAR	Months	Treatment Sectors	Flow rate ($m^3 d^{-1}$)	Unit volume (m^3)	Area (m^2)	Constant	SF ($m^3 m^{-2} d^{-1}$)	VHL ($m^3 m^{-3} d^{-1}$)	HRT (h)	VOL COD (kg $m^{-3} d^{-1}$)	RVOL COD5 (kg $m^{-3} d^{-1}$)	RVOL SS (g $m^{-3} d^{-1}$)	RVOL TSS (kg $m^{-3} d^{-1}$)	RVOL TFSS (kg $m^{-3} d^{-1}$)	RVOL TVSS (kg $m^{-3} d^{-1}$)
2018	JUN-DEC	Grit removal (1 UNIT)	26,956.8	291.6	81.0	86.4	332.8	92.4	0.3	–	–	–	–	–	–
2018	JUN-DEC	UASB (8 UNIT)	3,369.6	1,152.0	157.8	86.4	21.4	2.9	8.3	2.1	1.1	0.02	1.1	0.4	0.7
2018	JUN-DEC	PBF (1 UNIT)	26,956.8	1,206.0	804.0	86.4	33.5	22.4	1.1	5.7	2.4	0.02	3.2	1.6	1.6
2018	JUN-DEC	DEC. (2 UNIT)	13,478.4	1,565.5	530.0	86.4	25.4	8.6	2.8	2.0	0.8	0.01	1.1	0.6	0.5
2019	JUN-DEC	Grit removal (1 UNIT)	28,828.8	291.6	81.0	86.4	355.9	98.9	0.2	–	–	–	–	–	–
2019	JUN-DEC	MEAN UASB (8 UNIT)	3,603.9	1,152.0	157.8	86.4	22.8	3.1	7.8	2.8	1.5	0.03	1.2	0.4	0.9
2019	JUN-DEC	PBF (1 UNIT)	28,828.8	1,206.0	804.0	86.4	35.9	23.9	1.0	6.6	2.7	0.04	2.1	0.5	1.6
2019	JUN-DEC	MEAN DEC. (2 UNIT)	14,414.4	1,565.5	530.0	86.4	27.2	9.2	2.6	1.9	0.7	0.01	0.8	0.2	0.6
PROJECT MAX. VALUES		Grit removal (1 UNIT)	41,472.0	291.6	81.0	86.4	512	142	0.2	–	–	–	–	–	–
PROJECT MAX. VALUES		UASB (8 UNIT)	5,184.0	1,152.0	157.8	86.4	33	4.5	4.5	2.5 and 3.5	1.2 and 1.7	–	1.0 and 1.5	–	–
PROJECT MAX. VALUES		PBF (1 UNIT)	20,736.0	1,206.0	804.0	86.4	20 and 30	17.2	1.4	1.0 and 2.0	0.5 and 1.0	–	0.5 and 1.0	–	–
PROJECT MAX. VALUES		DEC-SEC (2 UNIT)	20,736.0	1,565.5	530.0	86.4	22.1 and 36.3	13	1.8	–	–	–	–	–	–
COMPARISON 2018 AND 2019 (%)		Grit removal	6.9	–	–	–	6.9	6.9	–6.9	–	–	–	–	–	–
COMPARISON 2018 AND 2019 (%)		MEAN UASB (8 UNIT)	7.0	–	–	–	7.0	7.0	–6.9	30.6	31.2	34.1	10.1	-6.3	18.7
COMPARISON 2018 AND 2019 (%)		PBF	6.9	–	–	–	6.9	6.9	–6.9	15.5	11.2	101.7	–33.5	–65.6	–2.1
COMPARISON 2018 AND 2019 (%)		MEAN DEC. (2 UNIT)	6.9	–	–	–	6.9	6.9	–6.9	–4.8	–14.7	32.2	–31.0	–64.7	11.1

Table 2
Mean results of coefficient of sludge production, production and volume, in the systems (UASB) and (FBP + DEC.SEC) and sludge decart volumes in a sewage treatment plant – Maringá, Brazil, in periods without (2018) and with (2019) the sludge recirculation process

Unit	Parameters and equations	Results		Discharge and/or recirculation of PBF sludge in DEC-SEC		Sludge difference (produced × discharge)	
		Without	With	Without	With	Without	With
UASB	Applied COD (kg COD d^{-1})	19.462.81	25.740.98	–	–	–	–
	TRSS (kg TSS d^{-1})	6.253.98	6.694.96	–	–	–	–
	Y Coefficient = (kg TRSS kg^{-1} $COD_{apl}{}^{-1}$)	0.32	0.26	–	–	–	–
	C = Excess sludge concentration – discarded or recirculated (% TS)	4.73	4.62	–	–	–	–
	C = Excess sludge concentration – discarded or recirculated (% SVT)	64.70	64.52	–	–	–	–
	y = Excess sludge density (kg m^{-3})	1,020	1,020	–	–	–	–
	$P_{Sludge} = Y{\cdot}CO_{CODaPpl}$ (kg TSS d^{-1})	6,253.98	6,694.96	–	–	–	–
	$V_{Sludge} = P_{Sludge}/y{\cdot}C_{Sludge}$ (m^3 d^{-1}) p/8 unit UASB	129.63	138.77	52.88	52.88	59.21%	61.89%
	$V_{Sludge} = P_{Sludge}/y{\cdot}C_{Sludge}$ (m^3 d^{-1}) p/1 unit UASB	16.20	17.35	6.71	6.71	59.21%	61.89%
PBF + (DEC-SEC)	Applied COD (kg COD d^{-1})	6,954.85	7,547.90	–	–	–	–
	Total suspended $solids_{removed}$ (kg TSS d^{-1})	997.40	1,078.27	–	–	–	–
	Y Coefficient = (kg TSS_{rem}/kg COD_{apl})	0.14	0.14	–	–	–	–
	C = Excess sludge concentration – discarded or recirculated (% TS)	2.92	2.39	–	–	–	–
	C = Excess sludge concentration – discarded or recirculated (% SVT)	68.93	67.95	–	–	–	–
	y = Excess sludge density (kg m^{-3})	1,020	1,020	–	–	–	–
	$P_{Sludge} = Y{\cdot}CO_{CODapl}$	997.40	1,078.27	–	–	–	–
	$V_{Sludge} = P_{Sludge}/y{\cdot}C_{Sludge}$	33.49	36.20	15	0	55.21%	100%
UASB + PBF	C = Concentration of MIXED excess sludge –discharged (% TS)	3.89	3.58	–	–	–	–
	C = Concentration of MIXED excess sludge – discharged (% TVS)	66.66	66.12	–	–	–	–
	$P_{Sludge} = Y{\cdot}CO_{CODapl}$ (kg TRSS d^{-1})	7,251.38	7,773.23	–	–	–	–
	$V_{Sludge} = P_{Sludge}/y{\cdot}C_{Sludge}$ (m^3 d^{-1})	163.11	174.97	67.88	52.88	58.38%	69.78%

during the operation of the station, the results show that there was a deficit in the removal of sludge in the UASB reactors in both periods, of –59.21% and –61.89% in 2018 and 2019, respectively. When the production of sludge from the secondary settlers is added, this deficit decreases for the period without recirculation to –58.38% and increases for the period with recirculation to –69.78%. This shows that the number of discharges and the volume of excess sludge disposed are much lower than recommended by the literature [6,9] and by the project data [16].

Regarding the sludge TS of the UASB reactors, these showed very similar results, with 4.73 mg L^{-1} in the period without recirculation and 4.62 mg L^{-1} in the period with recirculation. The lower concentration for the recirculation period can be explained by the volume of sludge with the lowest solids concentration in the PBF + DEC-SEC., 2.39 mg L^{-1}, which is recirculated to the reactors and later discarded along with the UASB reactor sludge (Table 3).

The TVS (%) showed very close values in the two periods, 64.70% and 64.54% without and with recirculation, respectively, as shown in Supplementary Material (SM). According to the literature, these values indicate an already stabilized sludge that can proceed to the next treatment stage [4,6,9].

For the system formed by PBF + DEC-SEC, the TS content was 2.92 mg L^{-1} without recirculation and 2.39 mg L^{-1} with recirculation, and comparing the years, there was an increase of 18.15% in the concentration of ST in the period without recirculation. This increase can be explained by the smaller disposal volumes when compared with the larger volume that was recirculated. Still, the percentage of TVS had a difference of approximately 1% between years, with 68.93% in 2018, without recirculation, and 67.95% in 2019, with recirculation.

In addition, a comparison was made in the characterization of the different types of sludge (anaerobic and

Table 3
Characterization of the different types of sludge (anaerobic UASB), (aerobic FBP + DEC.SEC.), and mixed (UASB + FBP + DEC.SEC), in relation to the content of solids, in a sewage treatment plant – Maringá, Brazil, in periods without (2018) and with (2019) the sludge recirculation process

Characterization of the sludge of the reactors (UASB)												
	Without recirculation						With recirculation					
	N° DESC.	VOL. (m^3)	(%) TS	(%) TFS	(%) TVS	(VS/TS)	N° DESC.	VOL. (m3)	(%) TS	(%) TFS	(%) TVS	(VS/TS)
RALF 01	9	564	4.42	34.79	65.21	0.65	11	658	4.37	35.63	64.37	0.64
RALF 02	8	550	4.31	36.59	63.41	0.63	9	564	4.27	36.60	63.40	0.63
RALF 03	6	470	5.15	36.10	63.90	0.64	11	611	4.72	34.70	65.30	0.65
RALF 04	6	423	4.72	34.15	65.85	0.66	14	752	4.78	36.31	63.69	0.63
RALF 05	7	470	4.45	35.16	64.84	0.65	16	987	4.29	35.32	64,68	0.65
RALF 06	6	282	4.84	32.76	67.24	0.67	12	799	4.7	35.24	64.76	0.65
RALF 07	4	188	5.01	37.01	62.99	0.63	5	329	4.99	34.20	65.80	0.66
RALF 08	9	564	4.91	35.84	64.16	0.64	12	752	4.82	35.64	64.16	0.64
TOTAL	55	3,511					90	5,452				
Characterization of the sludge of decanters												
Without recirculation							With recirculation					
	N° DESC.	VOL. (m^3)	(%) TS	(%) T.F.S.	(%) T.V.S.	(VS/TS)	N° DESC.	VOL. (m^3)	(%) T.S.	(%) T.F.S.	(%) T.V.S.	(VS/TS)
DEC 01	35	1,260	2.91	30.55	69.45	0.69	55	2,130	2.41	31.55	68.45	0.68
DEC 02	47	1,770	2.93	31.59	68.41	0.68	65	2,580	2.36	32.54	67.46	0.67
TOTAL	82	3,030					120	4,710				
Characterization of mixed sludge (UASB + DEC)												
	Without recirculation						With recirculation					
	N° DESC.	VOL. (m^3)	(%) T.S.	(%) T.F.S.	(%) T.V.S.	(VS/TS)	N° DESC.	VOL. (m^3)	(%) T.S.	(%) T.F.S.	(%) T.V.S.	(VS/TS)
MEAN RALF´S	7	439	4.73	35.3	64.7	0.65	11	682	4.62	35.46	64.54	0.65
MEAN DEC´S	41	1,515	2.92	31.07	68.93	0.69	60	2,335	2.39	32.05	67.46	0.67
MIXED	48	1,954	3.84	33.34	66.66	0.67	71	3,017	3.59	33.34	66.66	0.66
TOTAL	137	6,541					180	10,162				

aerobic), and it was found that the sludge produced by the treatment system formed by PBF + DEC-SEC, using polypropylene plastic support medium, generates sludge with characteristics similar to anaerobic sludge than to aerobic sludge (Table 3). Thus, the disposal of the sludge from the secondary decanters was carried out, directly to the centrifuge sludge condenser, which also receives the sludge from the UASB, forming a sludge mixture with TS content of 3.59 to 3.84 mg L^{-1} and TVS percentage of 66.66% to 67.95%, which does not present problems in drainage and sanitation, storage and final destination.

The results of the physical–chemical parameters and efficiency of treatment are presented in Fig. 2 and supplementary material SM1. An increase in organic load was seen in the period of 2019, due to the recirculation of sludge and due to suspended solids reaching other treatment sectors (SM1). Based on the concentration of suspended solids, above 50%, and on the total and dissolved solid parameters, it can be seen that there was no significant increase in the Affluent, UASB and FBP sectors. On the other hand, the decrease in organic load occurred only in the sedimentation sector, in the secondary decanters (SM1). These results suggested that a suspended solids replenishment cycle occurs when the DEC-SEC recirculation is performed for the beginning of the process and, later, for the other treatment sectors.

Regarding the BOD_5 parameter, there was also an increase between 15.7% and 19.6% in the recirculation period, in practically all sectors, due to the increase in more biodegradable suspended solids (SM1). An exception was observed only in the decanting sector, in which the solids are recirculated. As for the COD parameter, there was an increase of 23.5% in the tributary, 8.5% in the UASB and 1.9% in the PBF, while in the settling sectors, there was a decrease of 22% in the concentration, and after the counting chamber, of 14.8%.

The temperature remained practically the same in the months in relation to the two periods analyzed, with values of approximately 24°C–26°C, values that favor anaerobic and aerobic biological treatment [4,6,9]. The pH value remained above 6.0 for UASB, a limiting value for hydrolysis, acidogenesis, acetogenesis and metagenesis to occur [4,6,7,9,22].

In the period with recirculation, there was an increase of 25.8% in alkalinity in the affluent, while in the other sectors this increase was not representative. In this sense, the buffer system worked and the bacterial reactions did not change with recirculation.

4. Conclusion

The domestic sewage treatment station formed by a combined system (UASB + PBF + SEC-DEC) presented a good performance with efficiency similar to the activated sludge system, in the two analyzed periods, that is, with and without sludge recirculation.

Regarding the recirculation process, it is concluded that the period without recirculation presented lower concentrations in the parameters of discharge of the final effluent, compared with the period with recirculation. Therefore, it can be suggested that the process of recirculation increases the organic load in all stages of treatment, decreasing the quality of the treatment and increasing the concentrations of the parameters of the final effluent.

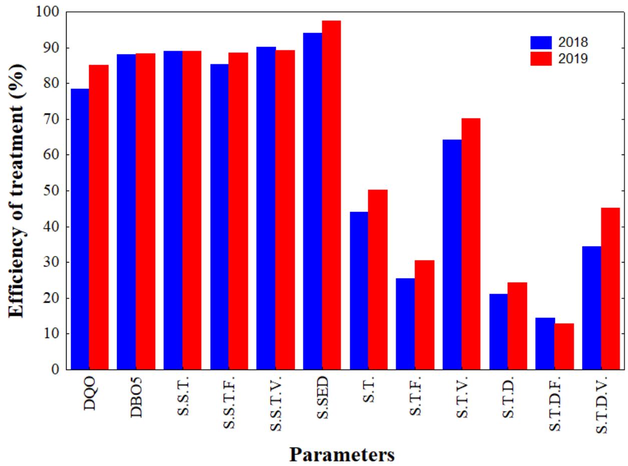

Fig. 2. Efficiency of treatment of the final effluent in a sewage treatment plant, Maringá, Brazil, based on physical and chemical parameters (mean values), in periods without (2018) and with (2019) the sludge recirculation process.

Concerning the characterization of the sludge from the UASB reactors, with and without the recirculation process, it was concluded that there was no significant difference in relation to the parameters of total and volatile solids.

The characterization of the PBF sludge from the secondary settlers showed that this sludge, even though it is from an aerobic treatment process, presents characteristics of a partially stabilized sludge in relation to the parameters of total and volatile solids, similar to the sludge from anaerobic reactors and different from the activated sludge systems. In this way, there were no operational problems in stopping the sludge recirculation for the UASB reactors and directing it to the dewatering and alkaline treatment with lime, via centrifugation. Furthermore, it was observed that there is no need to stabilize the sludge from the secondary settlers after PBF in the UASB reactors with the recirculation process, as this worsened the quality of the final effluent release.

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Supplementary information

SM1 - Physical and chemical parameters (mean values) for the different sectors of the treatment process, in periods without (2018) and with (2019) the sludge recirculation process

Parameter and unit	Mean. Afflu			Mean. 8 Ralf´s			Mean. 1 PBF			Mean. 2 Dec´s			MEAN. EFL F		
	Without	With	(%)	Without	With	(%)	Without	With	(%)	Without	With	(%)	Without	With	(%)
Flow (L s^{-1})	312	334	7.0	39	42	7.0	312	334	7.0	156	167	7.0	312	334	7.0
Temp. (°C)	24.5	26.2	6.9	25.3	26.1	3.1	25.4	26	2.4	25.2	25.8	2.4	25.5	25.9	1.6
pH	7.2	7.4	2.8	6.7	6.9	3.0	7.4	7.7	4.0	7.4	7.6	2.7	7.4	7.6	2.7
ALC (mg L^{-1})	310	390	25.8	440	460	4.5	374	420	2.3	366	408	11.5	370	401	8.4
COD (mg L^{-1})	722	892	23.5	258	280	8.5	184	206	1.9	173	135	–22	130	133	2.3
BOD_5 (mg L^{-1})	386	472	22.3	108	125	15.7	71	83	16.9	54	56	3.7	46	55	19.6
TSS (mg L^{-1})	290	380	31	58	88	51.7	41	74	80.5	37	40	8.1	32	42	31.2
TFSS (mg L^{-1})	68	113	66.2	14	23	64.3	10	19	190	13	12	–7.7	10	13	30
TVSS (mg L^{-1})	222	267	20.2	45	65	44.4	31	56	80.6	24	29	20.8	22	29	31.8
SEDS (mL L^{-1})	6.7	8.3	23.9	0.9	1.7	88.9	0.7	1.0	42.9	0.4	0.2	–50	0.4	0.2	–50
TS (mg L^{-1})	857	949	10.8	545	553	1.4	522	524	0.4	485	478	–1.5	479	473	–1.3
TFS (mg L^{-1})	446	481	7.9	340	345	1.4	333	357	7.2	336	342	1.8	332	334	0.6
TVS (mg L^{-1})	411	468	13.9	205	208	1.4	189	167	–11.7	148	136	–8.1	147	139	–5.45
TDS (mg L^{-1})	567	569	0.3	487	462	–5.2	481	450	–6.45	458	437	–4.6	447	431	–3.6
TDFS (mg L^{-1})	378	368	–3.7	326	322	–1.3	323	338	4.6	323	331	2.4	323	321	–0.7
TDVS (mg L^{-1})	189	201	6.3	161	140	–3.1	158	112	–29.1	135	107	–20.8	124	110	–11.3