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Upflow anaerobic sludge blanket reactor and biofilter in polyethylene as an alternative of decentralized wastewater treatment in municipality of Rio Rufino – SC

Reator anaeróbio de manta de lodo e biofiltro em polietileno como alternativa de tratamento descentralizado para esgoto sanitário no município de Rio Rufino - SC

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Abstract

Basic sanitation services are essential for promoting public health and for mitigating environmental damage. Thus, the objective of this work was to evaluate a wastewater treatment system consisting of anaerobic sludge blanket reactor and biofilter, as an alternative for the decentralized wastewater treatment in the municipality of Rio Rufino - Santa Catarina. The system was evaluated for its efficiency of removal of fecal coliforms, biochemical oxygen demand, chemical oxygen demand, soluble chemical oxygen demand, phosphorus, Total Kjhedal Nitrogen, nitrite, nitrate, sedimentable solids and maintenance of the hydrogen potential in the effluent. The treated effluent had its parameters compared to the standards established by Resolution 430/2011 of the Conselho Nacional do Meio Ambiente and Law 14.675 / 2009 of the State of Santa Catarina. It was also performed the estimate of the daily biochemical oxygen demand load, originated by the population of the municipality, and its respective impact. The effluent treated by the proposed system, when properly installed, follows what was established by the legislation, which implies in reducing the impacts caused by the municipality. In this way, the system can be an interesting alternative when it comes to decentralized wastewater treatment.

Keywords: Basic sanitation; Wastewater treatment; Small size municipalities

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Resumo

Serviços de saneamento básico são essenciais para a promoção da saúde pública e para a mitigação de danos ambientais. Deste modo, o presente trabalho teve como objetivo avaliar um sistema de tratamento de efluentes domésticos constituído de reator anaeróbio de manta de lodo e biofiltro, como alternativa para o tratamento descentralizado de esgoto sanitário no município de Rio Rufino – Santa Catarina. O sistema foi avaliado pela eficiência referente a remoção de coliformes fecais, demanda bioquímica de oxigênio, demanda química de oxigênio, demanda química de oxigênio solúvel, fósforo, Nitrogênio Total Kjhedal, nitrito, nitrato, sólidos sedimentáveis e manutenção do potencial hidrogeniônico no efluente. O efluente tratado teve seus parâmetros comparados aos padrões estabelecidos pela Resolução 430/2011 do Conselho Nacional do Meio Ambiente e a Lei 14.675/2009 do Estado de Santa Catarina. Também foi realizada a estimativa da carga de demanda bioquímica de oxigênio diária, originada pela população do município, e seu respectivo impacto. O efluente tratado pelo sistema proposto, quando instalado de forma adequada, apresentou-se em acordo com o estabelecido pela legislação, o que implica na redução dos impactos causados pelo município. Desta forma, o sistema pode vir a ser uma alternativa interessante, quando se trata de tratamento descentralizado de esgoto sanitário.

Palavras-chave: Saneamento básico; Tratamento de efluentes; Municípios de pequeno porte

1 Introduction

Basic sanitation services are essential for promoting public health and for mitigating environmental damage. The treatment and distribution of potable water together with an efficient wastewater treatment system are fundamental factors for the prevention of diseases, apart from reducing the pollutant load released in water bodies and, consequently, the possibility of eutrophication of these areas. Despite this, many still do not have access to adequate sanitation services (WHO/UNICEF, 2015).

In Brazil, according to data from the Pesquisa Nacional de Saneamento Básico (PNSB, 2008), only 55.2% of municipalities are served by a wastewater collection system. Still, there being wastewater collection, in many times it does not receive any form of treatment. In the Southeast, where 95.1% of the municipalities presented a collection system, less than half of them treated the wastewater collected.

In the State of Santa Catarina, according to data from the Sistema Nacional de Informações sobre Saneamento - SNIS (2015), the wastewater collection index is only 24.77% and according to the Atlas de Saneamento published by the Instituto Brasileiro de Geografia e Estatística – IBGE (2011), most of the small municipalities of the State do not have collection systems and/or the treatment of wastewater produced, as it is the case of Rio Rufino municipality, located in the Serra Catarinense.

According to IBGE (2017), the municipality of Rio Rufino has an estimated population of 2,479 inhabitants, with a predominance of residents in rural areas. This predominance of inhabitants in these areas results in low residential density, which makes it difficult to install wastewater collection systems since dwellings tend to be located far away one another, often in places of difficult access.

These factors may imply a high cost for the municipality when it comes to the construction of a centralized effluent treatment plant, since more than 80% of the costs may be related to the collection system (BAKIR, 2001; MAURER *et al.*, 2006). Considering this, it is necessary to search economically viable alternatives for the municipalities and to allow an adequate treatment of the wastewater generated by the population, according to the legislation in force in Santa Catarina.

In this sense, the wastewater decentralized management systems tend to be more advantageous. The decentralization of effluent treatment consists of systems where the collection, treatment and final disposal stages of the effluent are performed near the point of its generation. Normally, it does not require an extensive collection system, according to NBR 13.969 (ABNT, 1997). As stated by Crites and Tchobanoglous (1998), the main objectives of these systems are related to the reduction of treatment costs due to the retention of liquid and solid residues near the origin, which makes its reuse possible, as well as providing protection to the public health, and protection of the environment.

According to Von Sperling (1996), the septic tank/filter system has satisfactory efficiency and it has often been used in communities with small populations. However, anaerobic treatment processes with the use of sludge blanket reactors (UASB) gained prominence, mainly due to economic factors.

Chong *et al.* (2012), reported that one of the main characteristics of a UASB reactor, which makes it one of the most used systems in the world, mainly in tropical countries due to greater efficiency in warmer temperatures, is the availability of granular or flocculent sludge. This allows the system to achieve high chemical oxygen demand (COD) removal efficiency without the need for a support medium.

However, in regions with a cold climate, such as Serra Catarinense, the efficiency of this type of reactor tends to decrease (MAHMOUD, 2008; LEW *et al.*, 2011). In order to overcome this difficulty, authors such as Chernicharo and Machado (1998) and Lew *et al*. (2004), evaluated the application of the reactor in conjunction with anaerobic biofilters and obtained good results, with efficiencies of up to 86% COD removal.

In this context, this work aimed to evaluate the efficiency of a wastewater treatment system, consisting of the anaerobic sludge blanket reactor and polyethylene biofilter, as a proposal for the wastewater decentralized treatment in the municipality of Rio Rufino - SC.

2 Materials and methods

2.1 Identification of the municipality

According to information provided by the Local Government of Rio Rufino, this is a municipality located in the Serra Catarinense (27º51’34” S and 49º46’33” W), 68 km away from Lages, bordering the municipalities of Bom Retiro, Bocaina do Sul, Painel, Urupema and Urubici.

In addition to this, the municipality emphasizes that has its economy based on family farming, with traditional crops such as beans and corn, and the raising of beef cattle and milk production. It stands out the wicker cultivation, which found in the municipality ideal conditions for its growth making the region responsible for a great part of national production of wicker.

2.2 Description of the wastewater treatment system

The equipment that constitutes the system under study was developed by FIBRATEC Engenharia®, with headquarters in the municipality of Chapecó / SC. The system consists of grease trap, anaerobic sludge blanket reactor (bioreactor) and an anaerobic biofilter with high-density polyethylene (HDPE) corrugated tubes. According to information provided by the manufacturer, this system is designed for family dwellings, of medium standard, with six permanent occupants, which results in a flow rate of about 780 $L.d^{-1}$.

The grease trap is a very important component of system operation. It was developed according to NBR 8160 (ABNT, 1999) and acts on the retention of fat and solids, mainly from kitchens. Besides that, to facilitate its maintenance, the grease trap has a collecting basket, easy to remove, coupled inside. Its main objective, as an integral part of the system, is to prevent clogging of pipes and prevent large fat load reaching the reactor, which can reduce its efficiency.

In relation to the bioreactor, anaerobic sludge blanket reactors are reactors whose biomass concentration is quite high. In these reactors, the biomass grows dispersed in the medium and with its growth can be formed agglomerates of bacteria called granules. The formation of these granules tends to assist it in increasing the system's efficiency. In addition, the production of sludge is low, and it is already stabilized. In this way, it can be directly dehydrated in sludge drying beds (VON SPERLING, 1996).

On the other hand, the upflow anaerobic biofilter has, as a filter medium, pieces of high-density polyethylene corrugated tubes, which are commonly used in drainage systems or protection of electricity-conducting cables, replacing the conventional filter mediums. The use of this material provides a greater surface area in addition to its advantages in the maintenance of the system, since microorganisms, at the end of their metabolic activity, are not able to maintain fixation in the tubes and end up being carried by the effluent flow, not generating accumulations in the filter medium. Moreover, it is also notable for its smaller weight, which facilitates the transportation of the equipment. Figure 1 shows the equipment used.

Figure 1 – a) Bioreactor / Biofilter. b) Grease trap. FIBRATEC Engenharia®

2.3 Location, installation and startup of the treatment systems

The definition of the points of installation was taken based on the selection of residences with approximately eight low-income inhabitants, considering a low standard of living, it is necessary a larger number of inhabitants to reach the project flow established for the system. The income criterion was defined to provide an immediate improvement and better quality of life for low-income residents.

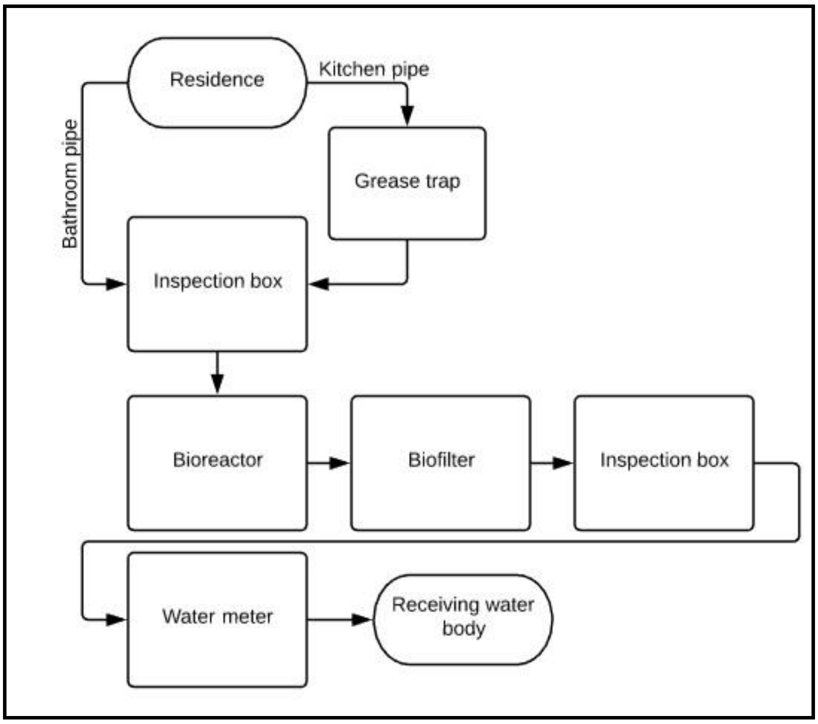
In this way, four residences, each with four permanent residents, were selected to receive the treatment systems. Two of the residences, closer to the urban center of the municipality (27º52'21" S and 49º47'29" W), were linked to the first system. The other two residences, far from the urban area and close to the river that receives the municipal wastewater flows, were connected to the second system (27º52'30" S e 49º48'08" W), hereinafter referred to as System 1 and System 2 only.

The installation of the systems was executed by the Secretaria de Obras de Rio Rufino and the Serviço Autônomo de Saneamento Básico (SASB), which provided specialized manpower, machinery and equipment to its correct operation.

It was installed the bioreactors, biofilters, grease traps, in addition to 50-liter inspection boxes (inlet and outlet) to facilitate the collection of samples. Also, it was installed water meters to monitor the flow of the systems. Figure 2 shows the schematic used.

The startup of the systems occurred after the addition of 100 liters of fresh bovine manure to the reactor (10% of the volume), collected from local producers, as recommended by EMBRAPA (2010).

Figure 2 - Equipment installation diagram



2.4 Monitoring and sampling

Four sample collections with pre-defined intervals (approximately 15 days) were performed. The collections were performed between 06/09/2017 and 10/19/2017, following the Guia Nacional de Coletas e Preservação das Amostras (Agência Nacional de Águas - ANA, 2011), by means of simple sampling. Samples were collected from the raw wastewater (systems inlet) and from the treated effluent (systems outlet). Also, it was executed readings of the flow rate that passed through the systems by reading the volume indicated in the water meter in relation to the time between collections.

2.5 Laboratory evaluation

For the samples collected, pH, sedimentable solids, BOD_5, COD, soluble COD, nitrite, nitrate, phosphorus, Total Kjeldahl Nitrogen (TKN) and fecal coliforms were analyzed, to verify the efficiency of the system and the attendance to legal requirements established by State Law 14.675 / 2009 and CONAMA Resolution 430/2011.

The analytical procedure was conducted at the Laboratório de Tratamento de Água e Resíduos (LABTRAT) of the Centro de Ciências Agroveterinárias (CAV), in Lages/SC. The analyzes were performed in duplicate, except for BOD_5, pH and sedimentable solids, which were performed once for each sample.

The analytical determinations of physical-chemical and microbiological quantities were conducted according to the procedures described in the "Standard Methods for the Examination of Water and Wastewater" 21st edition (APHA, 2005), except for nitrate and TKN. For the determination of nitrate, it was used the methodology indicated by the German Institute of Standardization (Deutsches Institut für Normung - DIN) and the determination of Total Kjeldahl Nitrogen was conducted according to the methodology established by the United States Environmental Protection Agency (USEPA).

2.6 BOD load estimation and evaluation of its impact on the receiving water body

Initially, it was estimated the flow rate of the water body, which receives the largest municipality wastewater portion, in an area slightly impacted by anthropic activities (27º53'05" S and 49º48'44" W), to obtain an estimate of its natural flow rate. To determine the flow rate, the half section method was used as described by the Agência Nacional de Águas (2014). This method consists in the calculation of the partial flows, obtained along the section of interest. The speeds in each subsection were determined with the use of a hydrometric reel, model C2 10.150 OTT®.

From the flow data observed in the treatment systems, mean concentration of BOD_5 in raw wastewater and in treated effluent, river flow rate and municipality total population, estimates were made. These estimates had the objective of calculating the total daily BOD_5 load, which consists of the product of the wastewater flow by the concentration of BOD_5, released in the receiving water body. Were considered the untreated wastewater and effluent treated by the equipment under study, if the system implemented for the entire population.

3 Results and discussion

3.1 Startup and operation of the treatment systems

It should be noted that System 1 had its performance impaired due to problems in its installation. The pipes referring to the laundry were directly connected to the system, which resulted in high flow rates, approximately 3,600 $L.d^{-1}$. This fact was only verified in the second collection, which may have impaired the formation of the sludge in the reactor. System 2, on the other hand, was installed properly. The average flows recorded were approximately 725 $L.d^{-1}$, very close to the system design flow, of 780 $L.d^{-1}$.

According to Ozgun *et al.* (2013), the upward flow velocity, which depends directly on the flow rate, is of great importance in anaerobic reactors, especially with respect to the physical characteristics of the effluent. Since it can promote the release and washing of colloidal or particulate organic matter that would reside in the sludge bed, at the bottom, reducing the efficiency of the treatment. Therefore, controlling this parameter becomes essential for the operation of the reactor.

3.2 Characterization of the treated effluent and evaluation of the efficiency of the systems

Since the treatment systems were installed in households of different families, it was possible to notice different characteristics in the raw wastewater generated by them, besides differences in treated effluent, mainly due to the factors reported in the previous topic.

Regarding the effluent treated, both in System 1 (E1) and System 2 (E2), pH and sedimentable solids content did not exceed the limit determined by State Law 14.675/2009 and CONAMA Resolution 430/2011 in all collections (Table 1). For fecal coliforms, since the treatment system studied is not aimed at the elimination of these organisms, the two systems reached, in average, values close to a logarithmic unit of inactivation. In System 2 influent (I2), high numbers of coliforms were observed when compared to the system 1 influent (I1). This fact can be justified, due to the higher flows recorded in System 1, which may have diluted the sample.

For BOD_5, the effluent treated by System 2 was also in agreement with the legislation in force in the State of Santa Catarina. The treatment system showed a removal efficiency of more than 80% in all collections, unlike System 1, which did not reach the minimum efficiency established by any of the legislation cited in this study. This fact reinforces that, despite being a system of easy operation, its correct installation and maintenance is fundamental so that the effluent reaches suitable characteristics for the launching in water bodies.

It should be noted that, for the concentrations of BOD_5 and COD, a high variability was observed in the raw wastewater of the two systems, as can be observed in Table 1. This large difference between the values is mainly due to the variable amount of feces found at sampling points on collection days since they promote a great increase in the concentration of solids and consequently in the final concentrations of BOD_5 and COD. This can be verified by observing soluble COD values, which indicate a much lower variability since only the portion of the solubilized constituents in the sample are related.

The high COD values found in this work also diverge from the typical values for municipal wastewater, which can vary between 250 $mg.L^{-1}$ and 800 $mg.L^{-1}$, according to Tchobanoglous *et al.* (2016). However, when it comes to wastewater from rural areas, concentrations tend to be higher, since raw wastewater may have characteristics similar to that of concentrated black waters, which are mainly composed of feces and urine. Lutterbeck *et al.* (2018), for instance, found COD values of 1074.5 $mg.L^{-1}$ when evaluating the raw sewage produced in a rural property located in the municipality of Vera Cruz do Sul - RS.

With regard to concentrated black waters, Wang *et a*l. (2017), cited COD values close to 13,960 $mg.L^{-1}$ and de Graaff *et al.* (2010), found values of up to 9,800 $mg.L^{-1}$, both studying anaerobic reactors. These results reinforce the tendency of the raw wastewater evaluated in this study to consist predominantly of feces and urine.

It is worth mentioning that the average COD / BOD_5 ratio was 1.5 for the raw wastewater in the System 1 and 2.0 for raw wastewater in the System 2, which indicates a wastewater with characteristics that favor biological treatment processes and consequently is adequate to the system evaluated in this study.

Table 1 - Results obtained, the efficiency of treatment systems and limits imposed by the laws in force in Santa Catarina

Parameter	**I1 ($\bar{X}$± s)**	**I2 ($\bar{X}$± s)**	**E1 ($\bar{X}$± s)**	**E2 ($\bar{X}$± s)**	**Effic. Sist. 1 (%)**	**Effic. Sist. 2 (%)**	**Law 14.675/2009**	**Resolution CONAMA 430/2011**
pH	7.9 ±1.2	7.4 ±1.2	7.5 ±0.6	6.8 ±0.2	-	-	6 a 9	5 a 9
Sediment. solids (mL/L)	29.4 ±34.8	53.9 ±58.9	0.0 ±0.0	0.3 ±0.5	100	99.4	-	1
BOD5 (mg/L)	2,600 ± 1,539	2,200 ±1,769	866.7 ±11.5	145 ±67.6	66.66	93.41	60 or 80% removal	120
COD (mg/L)	4,139 ±2204	4,401 ±3258	1,066 ±107.4	174.8 ±72.7	74.24	96.03	-	-
Soluble COD (mg/L)	1,978 ±734	941 ±178.8	962.8 ±76.1	109.5 ±39,6	51.32	88.36	-	-

Nitrite (mgN/L)	<0.5	<0.5	<0.5	<0.5	-	-	-	-
Nitrate (mgN/L)	5.2±3.9	2.3 ±0.3	1.7±0.9	0.5±0.1	67.31	78.26	-	-
Phosphorus (mgP/L)	28.8±8.3	17.5 ±5.2	18.9 ±3.5	2.1±0.8	34.37	88.00	4 or 75% removal	-
TKN (mgN/L)	617.4 ±313.1	450.1 ±177	317.8 ±92.7	61.6 ±58.5	48.53	86.31	-	-
Fecal coliforms (UFC/100mL)	$1.0x10^7$ ± $1.1x10^7$	$3.8x10^7$ ± $2.0x10^7$	$6.2x10^5$ ± $9.3x10^5$	$3.3x10^6$ ± $2.5x10^6$	-	-	-	-

The observed TKN concentrations in the raw wastewater of both systems also were higher than the typical values for municipal wastewater (Table 1). Tchobanoglous *et al.* (2016), presented values for municipal wastewater, between 20 $mg.L^{-1}$ and 70 $mg.L^{-1}$. However, in rural areas, TKN concentrations also tend to be higher, following the same behavior observed for COD. Lutterbeck *et al.* (2018), found average values of 232.9 $mg.L^{-1}$ and in the case of concentrated black waters, the concentrations of NKT can reach values between 597.2 $mg.L^{-1}$ and 1,900 $mg.L^{-1}$ (de GRAAFF *et al.*, 2010; WANG *et al.*, 2017).

The low concentrations of nitrite and nitrate observed in this work corroborate with the reports of Von Sperling (1996), who reported that, in domestic wastewater, the predominant forms of nitrogen are organic nitrogen and ammonia. It is also noted since the pH presented by the treated effluent is close to neutrality, in this way most of the ammoniacal nitrogen tends to present in its ionized form and not in the form of free ammonia, which is toxic to fish even at low concentrations.

The high nutrients removal rates presented by the systems also are relevant, since this is an atypical behavior for anaerobic reactors (FORESTI *et al.*, 2006; MOAWAD *et al.*, 2009). According to Lutterbeck *et al.* (2018), this unexpected efficiency may be related to characteristics of the raw wastewater (high concentrations of COD, TKN and total phosphorus), which could have provided better conditions for nitrification and denitrification.

Regarding the total phosphorus, similar results of removal efficiency in anaerobic reactors were presented by de Graaf *et al.* (2010). The authors report that the removal of phosphorus may be related mainly to the removal of suspended solids. According to Ohlinger, Young and Schroeder (1998), probably part of the phosphate released during the degradation of solids can precipitate directly in the reactor.

The results presented in this work indicate that the treatment system under study can be an interesting alternative for the decentralized treatment of effluents in small municipalities and rural areas. However, in order to obtain better results, especially with regard to the removal of nutrients and pathogens, the use of UASB reactors together with other treatment systems, such as constructed wetlands, is relevant (SOUSA *et al.*, 2001; EL KHATEEB and EL-GOHARY, 2003; DORNELAS *et al.*, 2009).

3.3 Biochemical oxygen demand load

The estimated flow rate to the river was approximately 180 $L.s^{-1}$. Based on System 2, which did not present installation problems, an average flow rate of 725 $L.d^{-1}$ was observed. Dividing the System 2 flow rate by the 8 residents who contribute to the system, the daily flow rate per capita is approximately 90.6 L.inhab-1.d^{-1}. The mean BOD_5 recorded in the System 2 inlet was 2,200 $mg.L^{-1}$, indicating a contribution of 199.32 g.inhab-1.d^{-1}, larger than the typical values of 55 to 68 $g.inhab^{-1}.d^{-1}$ for Brazil (TCHOBANOGLOUS *et al.*, 2016).

Based on the total population of the municipality (2,479 inhabitants), it is estimated that the daily BOD_5 load added on the river would be 494.11 kg $BOD_5.d^{-1}$. Taking into account the river flow rate, the BOD_5 would be 31.32 $mg.L^{-1}$, which would exceed the limits of 3 $mg.L^{-1}$ and 5 $mg.L^{-1}$, established by CONAMA Resolution 357/2005, for rivers of class 1 and 2 respectively. If the treatment system was available to the 100% of the inhabitants, with an average BOD_5 of 145 $mg.L^{-1}$ in the treated effluent, the BOD_5 load added to the river would be only 32.56 kg $BOD_5.d^{-1}$, reflecting at a concentration of 2.06 $mg.L^{-1}$ in the river, which would not exceed the limits above cited.

In this study, the concept of pollutant load was only used in relation to BOD_5, in order to obtain a notion of the impact that it could bring on a water body receiving the wastewater outflows of a small municipality. However, several uses for the pollutant load have been proposed. Wang *et al*. (2013), for instance, used the concept of pollutant load to evaluate which land use and occupation activities had the greatest impact on water quality in Chongqing, China.

Pinto (2016), in a study carried out in the Rio Verde basin located in the State of Minas Gerais, showed that the assessment of pollutant load may provide a more reliable result regarding water quality than the evaluation only concentration of the pollutants in the effluent. Knowing that the impact caused by the high effluents discharge into water bodies is increasing and Brazilian legislation still only recommends the evaluation of the concentration of pollutants in the effluent, the study and application of the concept of pollutant load becomes essential for the maintenance of the water quality.

4 Conclusions

The effluent treated by System 2, which was installed in an adequate manner, reached, in all the collections conducted until this study date, the requirements imposed by the laws in force in the State of Santa Catarina, which indicates that the system may become an alternative feasible when it comes to decentralized wastewater treatment. In addition, it is also evident the importance of correct installation and maintenance of the systems, since even simple, they are fundamental to obtain satisfactory results.

With the evaluation of the impact caused by the wastewater launching in water bodies, using the concept of pollutant load, it becomes evident the importance of wastewater treatment in rural areas and small municipalities. In addition, the pollutant load concept can provide more representative data on the actual impact of the effluent discharge on the receiving water body.

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